



BSI Standards Publication

Characterization of waste — Overall guidance document for characterization of waste from the extractive industries

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National foreword

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The UK participation in its preparation was entrusted by Technical Committee B/508, Waste Management, to Subcommittee B/508/3, Characterization of waste.

A list of organizations represented on this committee can be obtained on request to its secretary.

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Published by BSI Standards Limited 2013

ISBN 978 0 580 72733 7

ICS 13.030.01

Compliance with a British Standard cannot confer immunity from legal obligations.

This Published Document was published under the authority of the Standards Policy and Strategy Committee on 31 January 2013.

Amendments issued since publication

Amd. No.	Date	Text affected
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TECHNICAL REPORT
RAPPORT TECHNIQUE
TECHNISCHER BERICHT

CEN/TR 16376

October 2012

ICS 13.030.01

English Version

**Characterization of waste - Overall guidance document for
characterization of waste from the extractive industries**

Caractérisation des déchets - Document guide pour la
caractérisation des déchets issus des industries extractives

Charakterisierung von Abfällen - Leitfaden zur
Charakterisierung von Abfällen der mineralgewinnenden
Industrie

This Technical Report was approved by CEN on 24 June 2012. It has been drawn up by the Technical Committee CEN/TC 292.

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Ref. No. CEN/TR 16376:2012: E

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Foreword

This document (CEN/TR 16376:2012) has been prepared by Technical Committee CEN/TC 292 "Characterization of waste", the secretariat of which is held by NEN.

The preparation of this document by CEN is based on a mandate by the European Commission (Mandate M/395), which assigned the development of standards on the characterization of waste from extractive industries. The target audience of this guidance document includes all stakeholders concerned with the management of extractive waste including authorities, regulators, waste producers, consultants and testing laboratories.

The overall guidance document is one out of three guideline documents (TR, technical reports) and one technical specification (TS) on aspects related to the characterization of extractive wastes developed by CEN/TC 292. These four documents are:

- overall guidance document for characterization of waste from extractive industries (CEN/TR 16376);
- guidance on sampling of wastes from extractive industries (CEN/TR 16365);
- kinetic testing for sulfidic waste from extractive industries (CEN/TR 16363); and
- sampling and analysis of cyanides (WAD) discharged into tailings ponds (CEN/TS 16229).

In addition to these four documents, CEN/TC 292 developed a European Standard (EN 15875) for static determination of acid and neutralization potential of sulfidic waste (acid-base accounting).

The overall guidance document applies to waste from extractive industries according to the waste definition in Art. 3 para 1 of the Directive 2008/98/EC on Waste. Therefore, as far as residues from the extractive industries are mentioned in this document they are only covered if they fulfil the criteria of the above mentioned waste definition.

This document provides guidance and is not a required procedure. It gives recommendations on what to evaluate during characterization of waste from extractive industries. It provides a tool box with many different methods that may or may not be applicable in a specific case, and it is not a legally binding document.

Introduction

Waste from the extractive industries can only be managed properly if sufficient knowledge about its geochemical and physical properties and behaviour is available. Such knowledge may be obtained through characterization of the waste. Consequently, Directive 2006/21/EC of the European Parliament and of the Council of 15 March 2006 on the management of waste from extractive industries and the associated Commission Decisions on waste facility classification, inert waste definition and waste characterization include several requirements related to characterization of waste.

In one of its decisions the European Commission states that: “The purpose of the characterization of extractive waste is to obtain the relevant information on the waste to be managed in order to be able to assess and monitor its properties, behaviour and characteristics and thereby ensure that it is managed under environmentally safe conditions in the long term. Furthermore, the characterization of extractive waste should facilitate the determination of the options for managing such waste and the related mitigation measures in order to protect human health and the environment.”

A multitude of methods and tools are available for various waste characterization purposes – some are standardized and some are not. Often several methods that differ only slightly from each other are available for the same purpose. Tradition and geography often determine which method is used. In some cases, the use of specific methods is required by legislation. Within EU legislation, European (CEN) Standards and methods are generally preferred if they are available. The implementation of Directive 2006/21/EC and the COM decisions calls for appropriate waste characterization which may be achieved by the use of several characterization methods and standards. Some of these methods and standards have been applied in the extractive industry for many years, while others have been less commonly used in this context. In a few cases, it has been necessary to develop or initiate development of new CEN standards for the purpose.

This overall guidance document has been developed by CEN under mandate M/395 by the European Commission to support stakeholders in the EU Member States involved in the characterization and management of extractive waste in selecting the appropriate waste characterization tools (standards or methods) for a given purpose related to the management of extractive wastes and to the requirements of Directive 2006/21/EC and the associated COM decisions. Furthermore; it is meant to provide information on the possibilities and limitations of the methods and to provide some guidance on where to find further information on the interpretation and application of the waste characterization results. The overall guidance document is intended to cover all the different waste categories produced by the wide range of sectors within the extractive industry and to reflect state-of-the-art with respect to waste characterization methods. It is the purpose of the document to provide the stakeholders with an overall summary of the specific aspects of characterizing waste from the extractive industries, but it will not replace the in-depth expertise required in most cases. Stakeholders include authorities, regulators, operators/waste producers, consultants and test laboratories.

1 Scope

This Technical Report gives guidance and recommendations on the application of methods for the characterization of waste from extractive industries¹, i.e. wastes resulting from the prospecting, extraction, treatment and storage of mineral resources and the working of quarries. The document covers characterization methods for both physical and geochemical properties and also other significant aspects, from planning to interpretation and reporting.

The main purpose of the document is to aid the extractive industry and regulatory agencies in the member states in understanding how to perform waste characterization for planned, active and closed extractive operations.

The document includes a discussion on when and why characterization may be needed and on the contexts within which characterization data may need to be applied. However, it does not cover information on how to apply these characterization results, e.g. for dam design or closure planning. For guidance on how to use characterization results correctly for predictive modelling or design purposes references are made to other sources of information.

The extractive industry covers many different sectors with very different waste categories and characterization may be carried out with many different objectives. For this reason, a guidance document on characterization cannot be prescriptive or provide generally applicable instructions on how waste characterization should be performed in each and every case.

2 Principles and procedures

2.1 Definition and role of waste characterization

Waste characterization is generally understood as the determination of waste properties and behaviour in terms of geochemical characteristics (e.g. composition, reactivity, thermodynamic stability, mineralogy, leaching properties) and physical properties (e.g. particle size distribution, density, permeability, compactibility, physical stability) and the interdependence and changes of these properties under varying conditions.

Whereas the above more general definition of waste characterization is fairly straightforward, the Commission (COM) decision 2009/360/EC on waste characterization applies a broader definition which includes a substantial amount of additional information. The COM decision also addresses background information on the extractive operation in question, geological background of the deposit to be exploited and on the origin and amount of wastes occurring during prospecting, extraction and operation as well as information on the classification, transport and management of the wastes produced². These issues are discussed in Clause 4.

Waste characterization is primarily a management tool. In the extractive industry, waste characterization is often carried out to determine or estimate the present and future behaviour of a given type of waste under specified conditions to facilitate proper management of that waste. One cornerstone of the European legislation on extractive waste is the development of waste management plans, and one key component of a waste management plan is the waste characterization. The waste management plans will cover many aspects related to the waste management. Waste characterization may thus provide important information in many different contexts. For example, it may constitute an important part of an environmental impact or risk assessment, it may be used to assist in the definition of the most appropriate waste management solution in order to achieve physical and geochemical stability of the waste or it may be used to assess the suitability of an extractive waste for various construction purposes.

2.2 The waste characterization process at a glance

The starting point when designing a plan for waste characterization would normally be a definition of the general objective of the characterization exercise and the related questions that should be answered or may need to be answered at some time in the future.

¹ as defined in Article 2 of Directive 2006/21/EC

² Sections 1, 2 and 3 of COM decision 2009/360/EC

Waste characterization is related to the short and long-term physical and geochemical stability and environmental performance of the waste facility and is carried out to understand the relevant waste properties in order to predict the behaviour of a waste material in a specified scenario. The properties that are of interest will depend on the situation at hand and the decisions to be made. In many cases, the leaching behaviour of the waste will be a key concern. Short term and medium term leaching potential will be an important input in the decision process with regards to the location and design of dumps or tailings storage facilities and the need for collection and treatment of drainage. The long term leaching potential will be the critical factor in the development of closure plans.

Sulfidic wastes, primarily from some metal and coal mines, require special attention due to the potential weathering of sulfides that may lead to the production of acidic (or neutral) and metal laden drainage, commonly known as acid rock drainage (ARD) or acid/neutral rock drainage (A/NRD).

When the waste management plan includes the construction of waste dumps, or the use of waste for dams or other construction purposes, stability is an issue and physical properties of the waste become a key concern.

To obtain a permit for a new or existing operation it is necessary to characterize the waste. The complexity of this characterization depends on the type of material. For a geologically/mineralogically uncomplicated case, with access to existing information, a field inspection and comparison with other sites with the same type of material may provide sufficient information. For geologically/mineralogically complex sites there may be many samples run for different types of analysis. During operation, sampling and testing may be carried out to check that the initial characterization remains valid and in some cases to check compliance when there are certain criteria that need to be met.

When the general objectives of the waste characterization have been defined the next step will be to define the relevant site specific scenario.

It is only then that decisions can be made on relevant waste properties, which tests to carry out, which methods to use, how many samples are needed and so on.

The sequence of characterization is illustrated in Figure 1.

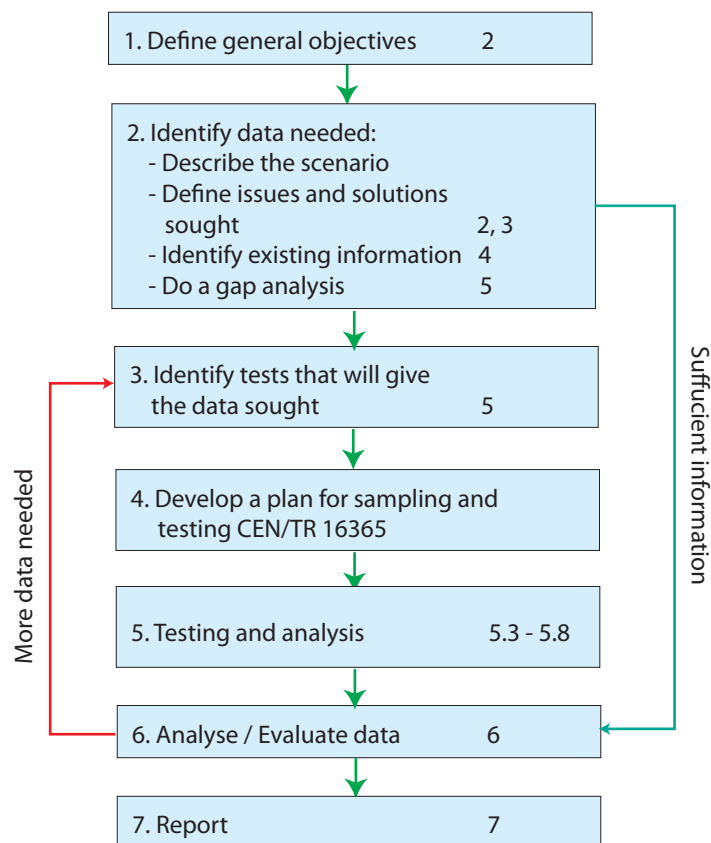


Figure 1 — Flow chart of the characterization process, with references to the clauses within this document

Below follows a simplified, stepwise description of the whole characterization process:

Step 1: Define general objective

As a first step it is important to define and understand the general objective of waste characterization in the specific case. Characterization should always be done with a purpose. Without keeping that purpose clearly in mind it is very easy to end up with an overly ambitious characterization program, or, with results that are too uncertain to allow any conclusions.

Examples of general objectives (most characterization programs will include multiple objectives) with references to current European legislation include:

- development of waste management plans (Dir 2006/21/EC, Art 5.3); including
 - design of waste facilities (Dir 2006/21/EC, Art 11);
 - assessment of leachate generation and design of treatment measures (Dir 2006/21/EC, Art 13);
 - development of closure plans (Dir 2006/21/EC, Art 12);
 - classification of waste facilities (COM decision 2009/337/EC).
- classification of inert waste (Dir 2006/21/EC, Art 3 and COM decision 2009/359/EC);
- calculation of financial guarantee (Dir 2006/21/EC, Art 14 and COM decision 2009/335/EC);

- classification of waste categories according to the European waste list (COM decision 2000/532/EC and subsequent amendments).

Step 2: Identification of data needed

The following four steps will have to be carried out in parallel.

- Describing the scenario

It is useful to document a general description of the scenario at hand (Clause 4) e.g.:

- a) the kind of operation, existing or planned (e.g. metal mining, lime stone quarry, salt mining, open-pit or underground, size of mineral deposit);
- b) the phase of operation during which the study is conducted (exploration/pre-mining, on-going operation, existing waste dump/disposal site);
- c) the character of the surroundings (e.g. urban, industrial, farmland, forest, distance to receiving waters, existence of protected areas, other industrial activities);
- d) the kind of waste management foreseen (e.g. disposal in dams, dumps, stockpiling, saturated/unsaturated, separation/mixing).

- Definition of the issues and the solutions sought

Based on the general objective defined in step 1, information about environmental aspects associated with different categories of extractive waste (Clause 3) and given the scenario at hand, specific questions that the operator (or the competent authority) wants to answer by characterizing the waste should be defined.

Examples of questions;

- Will there be a release of drainage from the waste facility? If so, how will the drainage quality develop over time? Will drainage water require collection and treatment to meet water quality standards? If so, what treatment would be appropriate?
- What kind of closure of the waste facility will be needed?
- Will the waste meet short and long-term specifications for construction purposes?
- Is there a potential to optimize the waste management by separation into different categories?

- Identifying existing information

It is not in anyone's interest to carry out characterization work to produce information that is already available. Given the questions that need to be answered, relevant existing information should be identified (Clause 4). This could include:

- mineralogical and geochemical information from exploration/mapping;
- data from previous waste characterization;
- relevant information from comparable operations;
- information on the disposal site, topography, hydrology, geological and geotechnical;
- other local conditions, e.g. climatic data.

- Gap analysis

Does existing data (e.g. available characterization data on the mineralization and on future extractive waste, background information) give sufficient information to answer the relevant questions and to support the management decisions that have to be taken? If that is the case, no further testing is needed at this stage. However, there may still be a need to verify these results over time.

If the conclusion is that more information is needed, these needs should be specified in as much detail as possible to guide the choice of test method and the development of a characterization plan. Part of this specification should be an evaluation of the data quality needed, i.e. what level of uncertainty is acceptable (6.2). This will be important when deciding on a sampling strategy and might influence the choice of test methods.

The gap analysis might also lead to the conclusion that there is a lack of information regarding local conditions or other background information.

Step 3: Identify tests that will give the data sought

There are a large number of test methods for determining different waste properties, but also different methods for determining the same property. Some methods are standardized, some are established industry practice and some are under development. Some methods are applicable to specific types of extractive waste, but not to other types. When considering the use of any test method, its applicability and limitations should be well understood.

Clause 5 gives guidance on what methods are available and may be relevant for the determination of specific properties of extractive waste. Additional information is given in Annexes B to F.

Based on the information needs specified in earlier steps and information on available methods the most appropriate test methods should be identified. In some cases, a visual inspection may be sufficient to confirm that the waste material at hand corresponds to existing information while in other cases a whole package of tests will be needed.

See also 2.3 for some further comments on the choice of test methods.

Step 4: Develop plan for sampling and testing

The development of sampling plans is briefly described in 5.2. EN 14899 describes how the sampling plan for waste characterization should be compiled. Additional information specific for the extractive sector is available in CEN/TR 16365.

It is not possible to give general guidance on the number of samples needed as this will depend, amongst other things, on the amount and quality of background information and on the acceptable level of uncertainty of the results. In general, a more heterogeneous geology will require more samples than a homogeneous rock mass. Typically, exploration data will be used to design a sampling plan that is representative of the whole ore body and potential waste. In the case of sampling of waste from the process, the required frequency of sampling will depend on the variability in the waste stream. A statistical approach is recommended to avoid a situation where the characterization results are inconclusive due to too few, or non-representative, samples (for more information on statistical approaches see CEN/TR 15310-1).

Getting representative samples of future tailings will in many cases require processing of the ore in a pilot plant.

It is important that plans for sampling and testing are coordinated as e.g. the size of samples needed and potential pre-treatment or conservation requirements will be given by the test method(s) chosen. A general recommendation is to always collect and store extra material during sampling to allow for additional tests without renewed sampling (when testing is done on stored samples potential ageing effects will have to be considered).

Step 5: Carry out sampling and testing

Guidance regarding field sampling is given in CEN/TR 16365. It should be noted that sampling of extractive waste may present some very specific health and safety risks that shall be taken into account and managed (2.4).

When a high accuracy of the test results is needed it is recommended to use laboratories accredited for the test methods in question (not applicable for methods or within jurisdictions that are lacking accreditation schemes). General quality assurance and quality control (QA/QC) procedures should always be applied.

Step 6: Analyse/evaluate

When test results are reported they will have to be analysed and evaluated by a suitably qualified person with experience and knowledge of the behaviour of mineral wastes (Clause 6). It should be assessed whether these results allow the questions defined in the beginning of the process to be answered with an acceptable level of certainty. If not, additional sampling and/or testing will be needed (i.e. back to step 3 or 4).

There may e.g. be a need to take more samples because the waste proves to be more heterogeneous than expected, or the testing program may need to be complemented with more sophisticated methods to allow conclusions to be drawn.

In some cases the evaluation will be quite simple and straight forward: e.g. a comparison of total content with given criteria.

In other cases, the evaluation will involve interpretation of results, sometimes in combination with sophisticated modelling. E.g. when making assessments of drainage quality based on leaching tests. The scope of this document is limited to the characterization as such. Further guidance on how to carry out modelling, other than the overview of available modelling tools in Annex H, will have to be found elsewhere.

Step 7: Report

The whole characterization procedure should be documented and reported (Clause 7). It is important that the report covers not only final results and conclusions, but also the previous steps in the procedure, i.e. what decisions were made and why. What was the objective of the characterization, what background information was used, what assumptions were made etc.

Additional reports may be considered for specific audiences.

2.3 Choice of test methods

This guidance document roughly groups test methods (and properties) into:

- mineralogical analysis (5.3);
- geotechnical methods (5.4);
- geochemical analysis (5.5);
- leaching tests (5.7).

In the case of waste containing sulfide minerals, methods to evaluate acid generation and buffering potential have been developed (5.6). They can be divided into static (Acid-base accounting) and kinetic tests.

Figure 2 and the following text give an overview of categories of test methods and how they relate to potential waste management issues.

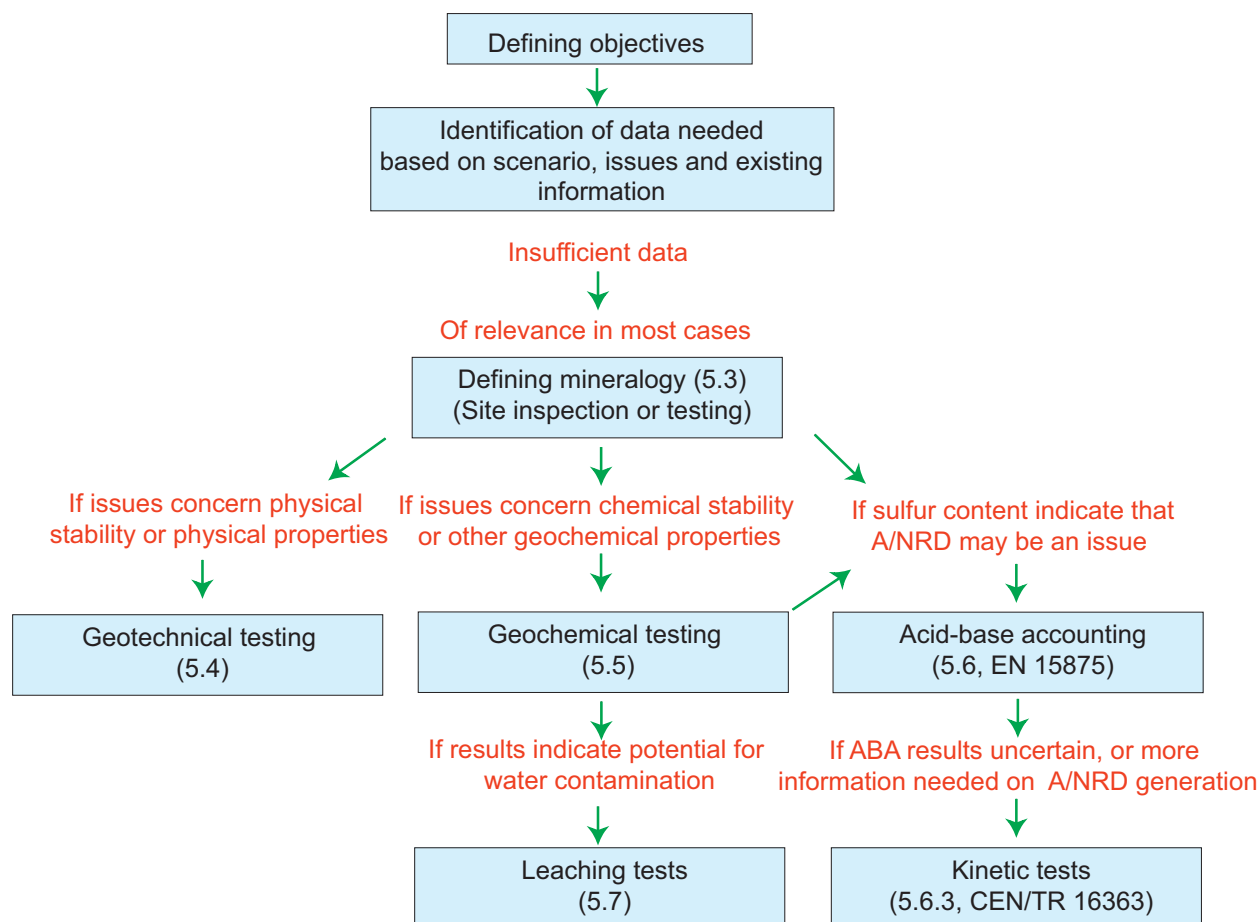


Figure 2 — Examples of sequences of testing in extractive waste characterization

For an assessment of the properties of extractive waste, a good knowledge of the mineralogy of the waste material is generally necessary. This information is essential for the evaluation of results from chemical analysis and leaching tests as well as for the assessment of A/NRD potential. Mineralogical information may be available from geological mapping and/or exploration efforts. An analysis of the mineralogy may take different forms. Depending on the quality of existing information and the complexity of the geology a visual inspection may be sufficient, while in other cases, advanced laboratory equipment such as electron microscopes or X-ray may be needed.

The physical properties of the waste relate, in particular, to two main aspects:

- Physical stability; e.g. slope stability of waste dumps or tailings used in dam construction, including changes of the stability due to physical or chemical weathering;
- Hydrology of the waste facility; e.g. infiltration rates, residence times, water saturation. Hydrology is a key factor in assessing the performance of any given waste facility design.

Chemical analysis to determine total concentrations of relevant substances will be part of most characterization programs. The substances of relevance are different for different types of waste from the extractive industry. Many test methods detect a whole range of substances, which may be useful for screening. However, characterization should focus on those substances that can potentially exceed critical levels in future discharges or, if the characterization is aimed at classification of the waste, those substances where relevant thresholds might be exceeded.

For an assessment of environmental impacts the total content is not representative of what may be released from the waste. There are different leaching tests available for this determination. Some tests will give total leachable amounts; others will be more relevant for an assessment of drainage quality.

Leaching tests should be carefully chosen depending on which data is needed to satisfy the defined objectives of the characterization exercise.

For waste containing sulfide minerals, the issue of potential A/NRD (acid/neutral rock drainage) has led to the development of a number of specially designed test methods for the assessment of whether or not a material will produce acidic drainage. Standard chemical or leaching methods are not sufficient to assess element release related to, or driven by, sulphide oxidation. For screening purposes, or as a first step, so called static testing, e.g. Acid-base accounting (ABA), is applied. The ABA test is a simple approach of comparing acid production potential based on sulfur (sulfide) content with readily available buffering capacity based on a standardized titration with acid. EN 15875 describes a European standard procedure for a 24 h ABA test. The ABA test results in a ratio of buffering capacity over acid production potential leading to one of three conclusions; "potentially ARD generating", "not ARD generating" or "uncertain". The ABA test is evaluating the potential of the waste to generate acidic drainage. It should be noted that if the waste contains sulphides that are oxidising, even if the drainage is well buffered, the drainage may still contain constituents of concern, i.e. what is often called Neutral Rock Drainage. If the ABA test does not give a clear answer, or if the waste is potentially A/NRD generating and there is a need for a deeper understanding of processes in the waste, there are a number of long term tests available, so called kinetic tests. These tests can be run in different scales, from lab columns to test dumps in the field. The set up will allow oxidation, weathering and drainage processes to take place in the waste, either under controlled lab conditions or under natural field conditions. Depending on the set-up the kinetic test results may form the basis for an evaluation of, among other things, A/NRD potential, reaction rates and drainage quality. Different kinetic tests are described in more detail in CEN/TR 16363.

2.4 Health and safety

The specific health and safety issues in the context of waste characterization are mainly related to field sampling. During sampling there are physical and chemical risks to be aware of. The physical risks may be related to:

- movement of large vehicles, e.g. trucks;
- collapse of waste rock heaps/slopes during sampling;
- active waste dumping;
- sink holes and cavities;
- inhalation of dust (e.g. silica, asbestos fibre);
- unstable wet tailings etc.

Chemical issues are mainly related to the use of potentially hazardous chemicals in the process (e.g. sodium cyanide) or off-gases resulting from processes in the waste (e.g. hydrogen sulfide or carbon monoxide).

The sampling plans should identify all relevant physical and chemical health and safety risks and safety measures should be specified. Health and safety issues should be streamlined with the health and safety procedures of the operator. Good practice when planning a characterization program would be to develop a project and site specific health and safety plan. It is recommended that, at an operating site, waste sampling should never be performed on your own and that at least one member of the sampling team should be a local employee. These issues are further discussed in the sampling standard EN 14899.

2.5 Applications

2.5.1 Development of waste management plans

For any operation producing and managing significant volumes of extractive waste the development of a waste management plan is good practice and is also required under current European legislation (Directive 2006/21/EC).

An appropriate description of waste properties will be a key input to many aspects covered by the waste management plan, including:

- design of waste facilities;
- development of closure plans;
- classification of waste facilities (e.g. according to COM decision 2009/337/EC), see 2.5.2.

Depending on the situation at hand, selected parts of what is presented in this overall guidance document are relevant in the development of waste management plans. It is recommended that a plan for the characterization work is developed based on the steps defined in 2.2.

The preamble to COM decision 2009/360/EC on technical requirements for waste characterization (point 3) specifically notes that characterization should be done primarily “on the basis of existing relevant and appropriate information or, if needed, by sampling and testing.” It further notes (point 4) that “the level of detail of information to be gathered and the related sampling or testing needs should be adapted to the type of waste, the potential environmental risks, and the intended waste facility.” The level of detail should also be correlated to whether or not the characterization results may change the waste management procedures.

2.5.2 Waste facility classification

EU legislation requires certain extractive waste facilities within the EU to be classified in one of two categories. The methodology and criteria for classification are described in more detail in COM Decision 2009/337/EC. One key factor to consider is the relevant waste characteristics.

The classification should be based on an assessment of:

- a) the consequences of a potential failure due to the loss of structural integrity or incorrect operation;
- b) the percentage of the waste that is either classified as hazardous waste or the content of substances or preparations classified as dangerous.

The COM Decision specifies a number of factors to consider when assessing potential consequences of a failure (Articles 5 and 6), one of them being the physical and chemical properties of the waste in the facility.

The most important physical properties for this assessment will be those related to the potential spread of the waste (see 5.4).

The chemical properties that will be of interest relate to both total content and mobility of constituents in the short and long term (see 5.5, 5.7). According to Article 4 of the COM decision, this information will be used as input to establish the source term in the context of a source-pathway-receptor chain.

Article 3 of the COM decision further requires an assessment of potential hazards related to reactive waste. Hence, it will be necessary to determine if the waste is “reactive”, i.e. if it is thermodynamically unstable under present or expected future conditions and therefore may react (for example oxidize) and cause the release of significant amounts of contaminants or heat. Potential self-ignition is one such property that indicates “reactivity”, A/NRD production capacity is another (see 5.6).

An analysis of total chemical composition (see 5.5), an assessment of self-ignition properties (see 5.5) and of the potential for A/NRD production (see 5.6) of the extractive waste may be required to establish whether or not the waste, or particular sub-categories of waste, is hazardous in accordance with Directive 91/689/EEC and subsequent amendments.

Finally, according to the COM decision the assessment of dangerous substances content is based on an inventory of substances and preparations used in the process and does not require any characterization of the waste. However, in the case of operating tailings storage facilities this inventory can be replaced by a chemical analysis of the water and solids contained in the facility.

2.5.3 Inert waste classification

All of the criteria given in COM decision 2009/359/EC on the definition of inert waste are dealt with in the characterization options and tools that are described within this document (see Clause 5). A couple of the criteria are judgemental, i.e. “sufficiently low” and “substantially free”. It is not a part of the mandate to CEN to make those judgements. In order to evaluate “sufficiently low” content the COM decision states that “the content of these substances [substances potentially harmful to the environment or human health] shall not exceed national threshold values for sites identified as not contaminated or relevant national natural background levels”. Methods described in this guidance may be used to evaluate the speciation of metal-bearing minerals in order to accurately determine the content of substances potentially harmful to the environment or human health. This information may be considered in the assessment of “sufficiently low content”.

In addition, Article 1(3) of COM decision 2009/359/EC states that the Member States may draw up lists of waste materials to be regarded as inert in accordance with the above criteria. In such cases, the characterization required by authorities may be limited to verifying that the waste at hand corresponds to the listed waste material.

2.5.4 Prediction of discharge water quality

The results of waste characterization play a key role in assessments of the potential impact of extractive waste on groundwater, surface water and surrounding soil due to leaching from the waste and subsequent attenuation and transport of released substances and in the design of measures to control such impacts. Leaching behaviour is a key property in this context. However, there are different test procedures for leachability that will be more or less suitable depending on the scenario at hand. Moreover, there is still a long way to go from characterization data on leachability to an assessment of what might in fact be the discharge from the waste facility. There are modelling tools (batch modelling or reactive transport modelling) available with the ability to simulate different chemical and physical reactions that will influence the drainage water quality on its way through the waste deposit (see Annex H).

A risk to the environment caused by leaching may be described as a chain of events (Figure 3). In order for a negative effect to occur at the receptor or target, the chain shall remain unbroken. An assessment of the resulting impact is made based on knowledge of the nature, size and behaviour of the source, the pathway and the interaction between the released substances and the pathway (soil, groundwater, surface water) and the nature and vulnerability of the receptor (or based on legal requirements at a point of compliance, e.g. expressed as a concentration at the point of discharge or as an environmental quality standard, EQS).

In a waste characterization context, however, only the source term in the impact assessment chain will be addressed. Guidance on impact assessment as such, including determination of the transport and effect of contaminants shall be sought elsewhere.

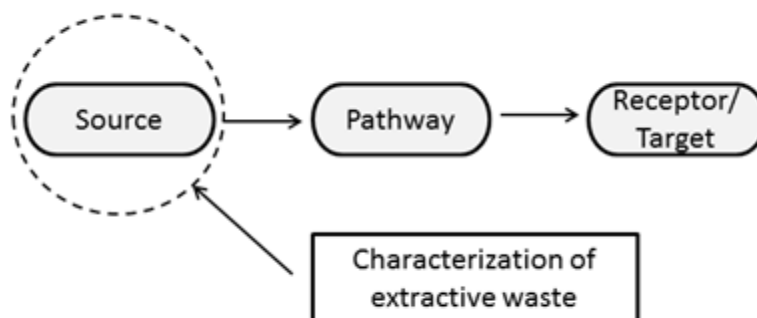


Figure 3 — The concept of impact illustrated as a chain of events.

NOTE For an impact to materialize, the chain remains unbroken. The figure also indicates that characterization of waste only applies directly to assessment of the source term

To define the source term information will be needed both on the leaching behaviour of the waste (including potential effects of weathering), the physical properties of the waste, the scenario (design) and the water balance, calculated or measured, for the system in question.

For this type of analysis the leaching behaviour may be described as a function of different parameters such as pH, redox, liquid-to-solid ratio (L/S) or time, water saturation, mineral reaction rates etc. This will generally require more than one test and careful interpretation of the results (e.g. by means of modelling).

The water balance will depend on external factors such as climate and rainfall, on design parameters such as surface area and slopes, covers etc. and on waste specific properties such as particle size distribution and hydraulic conductivity. It is only the waste specific properties that will be part of the waste characterization.

2.5.5 Assessment of closed waste facilities

Waste characterization is an essential part, but not the only one, of the assessment of a closed waste facility. Closed extractive waste facilities may in principle be evaluated in the same way as active waste dumps and tailings ponds. Ideally, there will be enough information available through records and from field inspections to evaluate the risks related to the physical and geochemical stability of the waste material. If available, monitoring borehole data (level and quality) may provide very useful information.

A field inspection will in many cases give a lot of valuable information on the properties and status of the waste. Things to look for include general design, signs of leakages, erosion and cracks. Further guidance on field inspections can be found e.g. in CEN/TR 16365.

If there is not enough data to evaluate the facility after reviewing existing information and the field inspection, further waste characterization may be performed by carrying out geotechnical and/or chemical/mineralogical analysis following the same structure as described in 2.2 and the flow chart in Figure 1.

In evaluating the chemical-mineralogical aspects of closed sites containing sulfidic tailings it is important to evaluate the oxidation stage and the oxidation front in the tailings. This can be done by field observations in combination with sampling and testing of waste material and pore water.

Most of the information on investigations of existing facilities given in 5.8 is relevant also for closed facilities.

2.5.6 Planning for monitoring

Monitoring of seepage water quality and/or groundwater quality is commonly performed during operation and after closure of facilities. The need for monitoring should be evaluated based on the result from the characterization, the type of facility and other local factors. If the waste characterization does not indicate any concerns regarding water quality, further monitoring may not be needed or justified.

Data from monitoring of seepage water quality and/or groundwater quality can be used for verification of predicted water quality and be considered as in-place field scale leach/kinetic tests. The level of monitoring (e.g. number of monitoring points, frequency and constituents analysed) should be proportionate to the potential for significant environmental impacts.

It may also be advisable to verify within the waste facility that predicted mineral reactions and weathering are in fact taking place. This type of information together with the water quality monitoring could give valuable input to the planning of progressive or final closure.

3 Waste categories, potential environmental impacts and related characterization methods

3.1 General

Within the extractive industry there are a number of greatly differing sectors. A distinction is often made between construction minerals (minerals mainly intended for the construction industry), industrial minerals (intended for the manufacture of products such as glass, ceramic and paper), metal ores (intended for the production of metals) and energy fuels (intended for energy production).

The environmental issues vary from sector to sector, within each sector, and even for different wastes at the same site, depending upon the mineralogy of the material and surrounding rock, the processing type (including chemicals added during processing), the size of operation and the location for deposition of the waste.

This means that the appropriate set of characterization methods to be applied will differ between sectors and for different waste types.

With respect to the types of wastes falling under the term “wastes from the extractive industry”, a substantial difference in potential impacts exists between acid producing waste, highly alkaline wastes, salty waste and fines from aggregate extraction. This ultimately translates in the required level of testing needed for the different types of waste.

More details on the different sectors, their processes and related waste categories can be found in the BAT document on mine waste management (Reference Document on BAT, 2004). However, it should be noted that, due to the limited risks associated with the sector, the BAT document does not include the extraction of construction materials/aggregates.

It should also be noted that, while this document is focusing on the characterization of solid wastes, the basic principles and many of the methods presented may be applied to other waste categories within the sector. E.g. the process water being discharged together with tailings is also a part of the waste stream and may contain, besides elements dissolved from the minerals, process chemicals and chemicals from blasting. An extractive operation may also produce wastes in the form of sludge from the treatment of water or gases. During drilling, especially for on-shore oil exploration there can be considerable amounts of drill mud that also need to be discarded in a managed way.

3.2 Characterization during the different phases of extractive operations

In general, the life of an extractive operation can be divided in three (or more) phases:

— exploration (including feasibility and design);

- operation (including transport and deposition);
- closure (including after-care).

While waste will mainly be produced during the operation phase, waste characterization will have to be considered in all phases of the mine life.

The exploration phase starts with the first evaluation of the potential for economic mineral deposits. This may be done by evaluating existing geological information such as geophysical and geological mapping. Drilling may follow if the first evaluations seem promising. When the exploration phase moves into feasibility study, the development of a permit application becomes a part of the project. It is normally in the permitting process that the waste characterization becomes more focused, even though the environmental issues should be a part of the project from the very beginning.

Most of the characterization will normally be done during the exploration phase. However, at this stage the amount of material available for sampling and characterization is limited. In the early stage of exploration, there may only be a limited amount of drilling or surface sampling performed to define the mineralization (pre-feasibility stage). In the later stage of exploration (feasibility stage) there is often a larger amount of drill cores or surface samples collected. There may also be test pits or shafts excavated in order to evaluate the quality of the material, test the processing methods or evaluate the ore grade. In this stage of exploration the amount of material available for characterizing the future waste would normally not be a limitation. It is commonly in this later stage that the characterization needed for the waste management plan and the permit application is carried out. When defining the objective of the characterization program the information needs for the permit application, for the waste management plan, for the design of waste facilities and for the closure plans, will be important to consider.

Exploration drilling will normally continue throughout the life of the operation.

For a new mine, the operation phase starts when the permits have been issued and excavation and construction works can commence. During the operation phase characterization is primarily performed in order to confirm the results of the earlier characterization, performed during the feasibility study and preparation of the permit application. Confirmation characterization will normally be performed primarily on the waste streams (conveyer belts, haul trucks, pipelines etc.) but may also be based on samples from drilling (exploration or production) or from the production front in the mine/quarry itself. However, if the verification does not agree with the previous characterization and the criterion set up for production, a renewed detailed characterization may be needed.

For mines that were already in operation when EU Directive 2006/21/EC came into force the requirement to develop a waste management plan may include the characterization of waste already deposited on waste rock dumps and tailings dams, if that information does not already exist.

Expansions or other changes of the operation may also lead to the need for a renewal of the permit, including requirements to carry out characterization of expected waste streams.

A conceptual closure plan will be required before start-up of a new mine or quarry. The plan will be based on the early waste characterization. During the operation, and particularly as part of the detailed closure planning towards the end of the mine life, there is a need to verify and update those early characterization results and, if needed, modify the closure plan. At this stage, valuable information (confirmation) can also be obtained by field investigations of deposited waste and of actual pore water and drainage water quality. However, towards the end of mine life the available management/closure options have usually become more limited.

Where possible, closure/reclamation is carried out as an integrated part of the ongoing operation.

Table 1 — Illustration of characterization efforts and closure options during phases of an extractive operation

Phases of an extractive operation	Characterization	Access information to	Management Options (incl. closure)
Exploration (incl. design and permitting)	Initial characterization followed by detailed studies.	Usually limited to drill cores. Representativeness a major issue.	Many options.
Operation (incl. construction)	Follow up characterization, testing for closure alternatives.	Easy access to samples, gradual build-up of data base including field data.	Reduced amount of options, but equipment available, can make adjustments and changes to the closure plans.
Closure and after closure	Verification of the models, waste management plans, long term mineral weathering etc. set up during operation. Verification of effectiveness/function of implemented closure measures.	Access to full scale, in situ, information.	Very limited. Location given, Only variations within the options chosen earlier.

EU member states are required to keep an inventory of closed waste facilities. The purpose of characterizing the wastes at closed and/or abandoned sites/facilities would commonly be to evaluate if they constitute a risk to human health and safety and to the environment and if they do, to determine what is needed to reduce this risk to acceptable levels. Aspects to be studied would normally include physical stability of dams and dumps and leaching potential/chemical stability of the waste.

3.3 Types of waste facilities

Within the extractive sector there are different types of waste facilities. The two main types are dumps/heaps and ponds/lagoons. The methods of deposition, the properties of the underlying soil/bedrock and the local topography are examples of other important factors that will differ from site to site. In combination with different waste properties this means that waste facilities will represent different engineering, environmental, economic or human risks or challenges and therefore the appropriate characterization approach will vary.

Overburden and waste rock are typically deposited on heaps (if not back-filled or used for construction purposes). This material is characterized by diverse grain size, from boulders to clay fraction, heterogeneous composition and varied water content. In some sectors tailings are dewatered and deposited on heaps. This is common practice e.g. in the potash industry.

Washing plants at quarries are designed to remove fines and generate a clean mineral product from crushed rock or sand and gravel using wet processes. Fines are removed from the water phase in settling lagoons or by thickener/ filter press systems. The settling lagoon becomes the final deposit for these fines while filtered fines may be dry-stacked. Water is typically recovered from these systems and recycled to the washing plant in order to minimize water consumption.

Tailings from flotation, or other processing, deposited in tailings ponds present different properties and risks. Tailings are normally composed of fine-grained material with relatively uniform grain size distribution. Tailings are commonly separated by hydrocyclone in fine-grained and coarser-grained fractions at the concentrator to produce back-fill material or dam construction material at the disposal site.

In this way, the coarser fraction may be utilized while the water-saturated, fine-grained material is deposited into the tailings pond. Even though tailings are normally more homogenous than waste rock and thus easier to characterize, tailings in general represent a higher risk of failure, and a higher risk to cause external harm in case of an accident. This is why tailings and tailings storage facilities are in the foci of geotechnical characterization of extractive wastes and waste deposits. A current trend in tailings management is the increased application of paste technology. Paste makes it possible to use un-separated tailings for backfill or to design a tailings storage facility with much less free water. In most cases this would increase the physical stability but introduces other challenges.

3.4 Associated environmental aspects

3.4.1 General

The environmental aspects of extractive wastes can in general be split in two categories: physical and geochemical. These aspects are briefly discussed in the following sub-clauses. Further information can be found in the BREF document (Reference Document on BAT, 2004), Chapter 1.6 “Key Environmental Issues”.

3.4.2 Risk of dam / slope failure

3.4.2.1 General

One of the primary risks is that of physical movement of the waste, either through failure of the deposited waste itself or of its confining structure. The risk of dam or slope failure is relevant for most mines and quarries. In the context of slope/dam stability the physical properties of the waste are relevant for dry-stacked tailings / waste rock dumps, for the use of residues (waste rock and/or coarse tailings) in dam construction and for the calculation of loadings on dams. The geochemical characteristics of the waste may also have an impact on stability as they might lead to a change over time of the physical properties.

In addition, both physical and geochemical properties of the waste will be relevant for the assessment of the potential consequences in case of a failure.

This guidance document does not deal with the design of dams or give guidance on the assessment of dam/slope stability or on the assessment of consequences of a dam/slope failure. However, waste characterization will provide essential input to such assessments and, therefore, a brief introduction to these issues is given here.

3.4.2.2 Waste dumps/tips/spoils

The placement of waste materials such as waste rock on dumps is generally done either by vehicle or conveyor at a natural angle of repose. Under some circumstances such waste materials can both fail and liquefy resulting in the footprint of the slide extending far beyond the toe of the waste slope. Though such occurrences are rare, and the risk usually confined within the operation site, they can and have happened and the risk needs to be recognized and appropriately addressed in the design of all waste dumps.

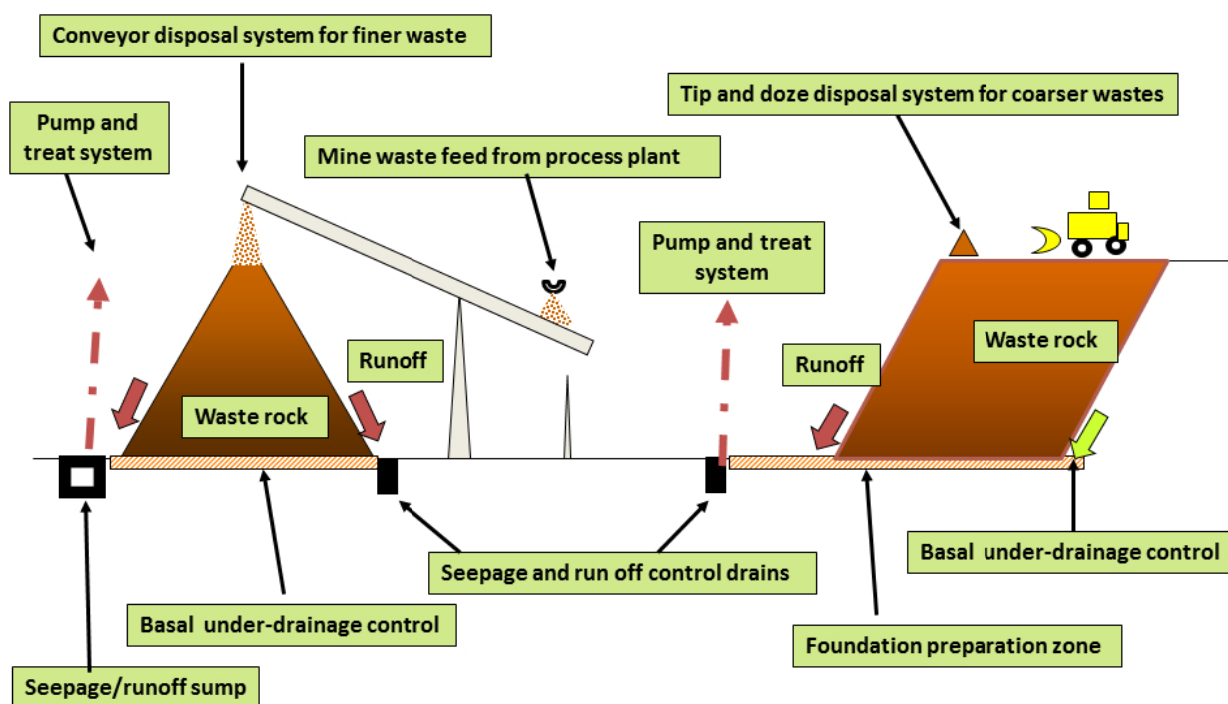


Figure 4 — Two typical sections of waste rock dumps (from Cambridge 2010)

The construction of the waste dump/tip should normally follow established geotechnical design procedures associated with slope stabilization, e.g. material selection, controlled placement/compaction and control of underlying ground. During its active lifetime the dump may receive a wide range of material types and sizes dependent on the geological setting of the ore body. The physical and geochemical properties of the different waste materials should be evaluated and characterized as appropriate to allow for a design and operation of the tip recognising the properties of the varying materials over time.

3.4.2.3 Tailings ponds/silt lagoons

Tailings are generally produced and discharged in a slurry form (as a mixture of particles and water) to a facility where sedimentation takes place. The aggregates and industrial minerals sectors tend to refer to these as silt lagoons and the metal mining industry as tailings management facilities (TMFs). The purpose of a TMF is the disposal of tailings from an extractive activity in a way that is designed to remain stable for an infinite amount of time (Bjelkevick 2005a). In many cases, these facilities are also designed to provide a cost effective and environmentally appropriate means of recycling process water.

A typical section through a tailings management facility is shown in Figure 5 including a number of key features of a complex facility. It should be noted that, depending on the setting, not all the features shown may be required or relevant. Depending on the water balance/water management there may be a need to discharge excess water. This water may need treatment before discharge.

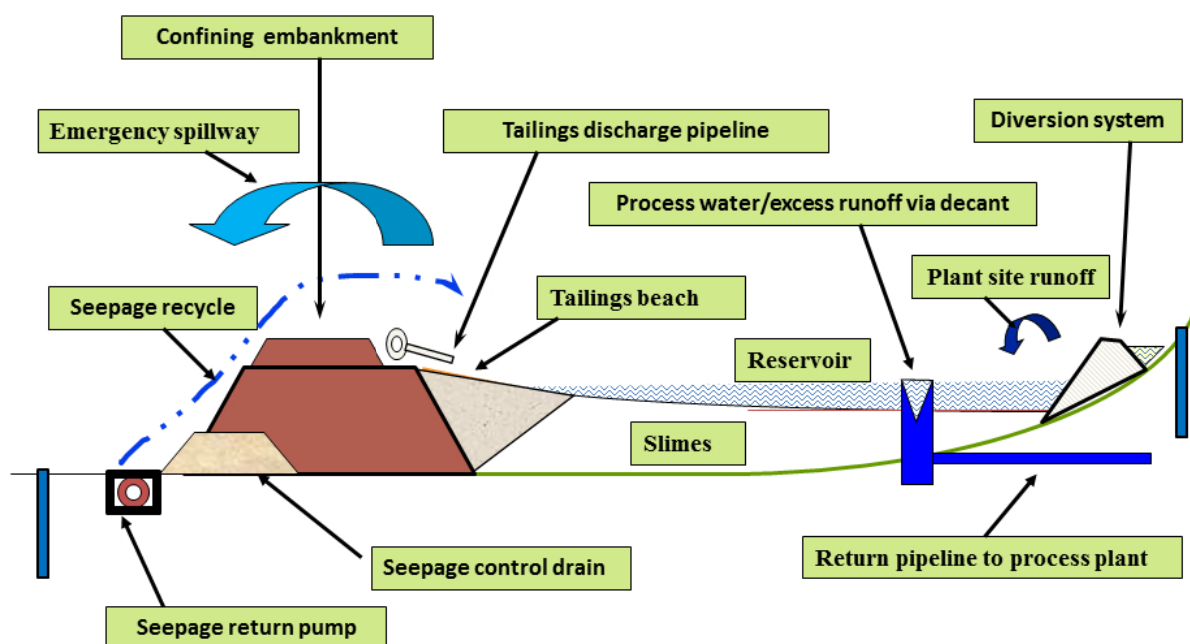


Figure 5 — Typical section through a tailings management facility, TMF (from Cambridge, 2010)

The embankment may be constructed using a wide range of construction techniques and materials, including locally won borrow materials, waste rock derived from the mineral extraction operation or the tailings themselves. A good understanding of the different properties of the materials available for construction and how those properties may change over the life of the facility is important. In each case the intrinsic physical and geochemical properties of the materials to be used shall be characterized and the design prepared accordingly using recognized good practice.

Dam failures (total or partial) and incidents related to the stability of the tailings dam may be caused by several factors related to the properties of the construction material, e.g.:

- internal erosion;
- external erosion;
- seepage;
- changes in physical properties of the dam over time, e.g. due to sulfide oxidation;
- overloading of the facility;
- frost heave and thaw weakening;

as well as by external factors, not related to material properties, e.g.:

- inadequate foundations;

- overtopping of dams;
- seismic events.

(Ref: e.g. ICOLD 2011, 2009, 2001)

The failure of a tailings facility could potentially lead to significant consequences due to the immediate impact of any spillage and the resulting short, medium and long-term effects (e.g., contamination of soil and water bodies, loss of animal life, etc.). Disregarding hazardous properties, any fine grained waste may cause an environmental impact due to the formation of high levels of suspended materials in the receiving waters. The potential long-term negative effects on the affected ecosystem will depend on the hazardous properties of the waste, but also on the remedial actions taken after an accident.

The risk to life and the environment downstream shall be assessed in order to classify the facility and to determine the appropriate factors of safety to be used in the design. An appropriate characterization of the waste will be essential for these assessments.

Some potentially useful tools for waste characterization to produce input data for the design and/or classification of waste facilities are discussed in the following clauses of this guidance, including:

5.3 Mineralogical analysis;

5.4 Physical and hydraulic properties;

5.5 Chemical Analysis (for solids and water);

5.6 A/NRD prediction tests (static tests and kinetic tests, laboratory and field scale); and

5.7 Leach tests (short term for materials that are not affected by reaction rate or are in a stable release setting).

3.4.3 Risk of dusting and siltation

The risk of significant erosion or dust emissions is relevant for most extractive waste facilities and most waste management techniques.

Run-off from waste rock dumps, quarry waste tips or quarry fines stockpiles can cause erosion and contaminate local watercourses. Suspended solids (siltation) may harm freshwater ecosystems and impact on other water users.

Dust can be picked up by the wind from the ground or a stockpile. Dry sections of tailings storage facilities as well as large quarry waste tips or quarry fines stockpiles can be a source of airborne dust, which can be exacerbated if the facilities are elevated above the original ground level. Generally, the impacts diminish greatly as distance from the source increases and the most acute impacts are likely to occur in close proximity to major sources.

Transportation of waste (or products) on conveyer belts and/or trucks is potentially another significant source of airborne dust.

Examples of key properties that would feed into an assessment of these risks are:

5.8 Particle size distribution, density;

5.5 Chemical composition.

3.4.4 Risk of contaminated drainage

3.4.4.1 Risk of acid/neutral rock drainage

The risk of environmental impacts related to acid/neutral rock drainage is related to the sulfide content of the extractive waste.

When sulfide minerals are exposed to oxygen, they are likely to oxidize and may have the potential to generate sulfuric acid. Due to the oxidation (mineral weathering), there is a potential for metal release from the same sulfide minerals. This process is called acid rock drainage (ARD) or acid mine drainage (AMD).

Not all sulfide minerals generate acidity during oxidation, but they may still release metal ions. If acidic conditions are generated, metals may also be released from the non-sulfide minerals.

There may be minerals present that have the potential to consume the acid and, thereby, raise the pH. The most efficient of these minerals are some of the carbonate minerals, particularly calcite, while dolomite and siderite have a lower reaction rate.

When the acid produced from sulfide oxidation is being neutralized, it is called Neutral Rock Drainage and the combined processes are referred to as acid/neutral rock drainage (A/NRD).

The transport and/or attenuation of released metals will among other things depend on site hydrology and on material properties.

This is a complex system and predictions of drainage water quality will in most cases require geochemical and transport modelling. While waste characterization alone will not predict actual drainage quality, it will provide essential input data to these models.

The A/NRD concepts are further discussed in Annex G, A/NRD processes and Mineralogy.

Some potentially useful tools for waste characterization for the purpose of A/NRD prediction and management are discussed in the following clauses of this guidance, including;

5.3 Mineralogical analysis;

5.4 Physical and hydraulic properties;

5.5 Chemical Analysis (for solids and water);

5.6 A/NRD prediction tests (static tests and kinetic tests, laboratory and field scale).

3.4.4.2 Other impacts on drainage quality

Other wastes from the extractive industries may provide other stresses to the environment than those caused by acid production.

Alkaline drainage in the extractive sector is commonly an effect of the processing agents used, e.g. soda ash and lime used in processing bauxite ore for Al production and sodium cyanide used in gold leaching.

Another potential impact is high salt loads in the discharge from salt (e.g. potash) extraction and waste facilities.

Most operations need to blast to excavate the material. This may result in contamination of water from undetonated explosives. Nitrogen compounds from undetonated explosives may be leached into groundwater from the production site or from the waste rock dump, or it may follow the ore to the processing plant and end up in the process water in the tailings pond.

During processing there are many different chemicals that may be needed as part of a mineral separation process, e.g. frothers or suppressing agents, and during settling of fine grained material. These chemicals are transported in the water phase or adsorbed to the solid material and end up in the tailings dam. The process may also result in saturation and precipitation of thiosalts (sulfate containing precipitates).

Some potentially useful tools for waste characterization for the purpose of drainage quality prediction and management are discussed in the following clauses of this guidance, including:

5.3 Mineralogical analysis;

5.4 Physical and hydraulic properties;

5.5 Chemical Analysis (for solids and water).

3.4.5 Risk of spontaneous combustion

The risk of spontaneous combustion is mostly relevant for stacked waste rock at coal and lignite mines.

Despite extensive research having been carried out on spontaneous combustion of coal wastes, the process is still not fully understood (Banerjee, 1985; Pone et al, 2007). Spontaneous combustion takes place when the rate of heat generated by the oxidation of organic matter exceeds the rate of heat dissipation. The main driver of the process is the oxidation of organic matter, but other factors could also favour or hinder spontaneous combustion. It is likely to occur when fresh coal waste is suddenly exposed to the air for a variety of reasons (side cutting of stream, landslides, rapid erosion, mining or dumping, among others). The waste can also start to burn from forest fires or lightning.

Susceptibility to self-heating depends on the rank of coal, surface area exposed (particle size), moisture content, oxygen content, mineral content (especially pyrite), organic matter type, storage time and climatic conditions, mainly the maximum temperature and prevailing wind directions (Chesnokov, Shscerbakova, 1991).

In the case of stockpiles and waste piles the structure or shape of the piles and the level of compaction also play an important role in self-heating (van Krevelen, 1993). The risk of spontaneous combustion can be reduced or prevented by a reduction of coal content in the waste and by reducing the permeability to air in the disposed material through improvements in the production process, dump shaping and compaction of the waste in thin layers (Szczepanska and Twardowska, 2004).

Some potentially useful tools for waste characterization for the purpose of predicting spontaneous combustion are discussed in the following clauses of this guidance, including;

5.3 Mineralogical analysis;

5.4 Physical and hydraulic properties (surface area, porosity, moisture content, conductivity);

5.5 Chemical Analysis (for solids and water);

3.4.6 Naturally occurring radioactive materials (NORM)

The directive 2006/21/EC on the management of extractive wastes states that “while covering the management of waste from the extractive industries which may be radioactive, this Directive should not cover such aspects as are specific to radioactivity, which are a matter dealt with under the Treaty establishing the European atomic energy community (Euratom)”.

Sources of ionizing radiation include natural radiation sources from terrestrial origin and may, therefore, be present in extractive wastes. Even if the directive and this guidance do not deal with specific aspects of radioactivity, other characterization aspects of these materials are covered. There may be a need for extra precautions during sampling, storage and sample transport of wastes that may have naturally elevated levels of radioactivity.

The risk of nuclear radiation is mostly related to uranium mines, but is also relevant for any waste with sufficient radionuclide content (e.g. radium, radon, thorium or uranium). The potential for radiation impacts can readily be determined from a basic elemental analysis of the waste.

4 Supporting information

4.1 General

In addition to waste properties there is other information that may give valuable input for the evaluation of waste characteristics and for an assessment of potential short and long term impacts on soil, surface water and groundwater. For example, the COM decision 2009/360/EC specifies five categories of information:

- background information;
- geological background of deposit to be exploited;
- the waste and its intended handling;
- geotechnical behaviour of waste; and
- geochemical characteristics and behaviour of waste.

The last two points cover what is generally considered as waste characterization and are discussed throughout this document. The first three categories cover supporting information that is discussed in this clause. In addition, information from the site of disposal is briefly discussed.

For new operations a lot of the information specified in the following sections will already be documented as part of the exploration activities. For ongoing operations, additional background data will be available from the continuous registration of operational data. Existing information may also include results from previously performed waste characterization.

Examples of useful information gathered during exploration and production may be:

- Geological mapping, commonly three dimensional and often combined with mineralogical and geochemical analysis, will normally be an essential part of the exploration results; and
- Groundwater and surface water information may be collected and evaluated before and during the operation, e.g. to evaluate access of process water or to assess the need of pumping capacity for open pits and underground operations.

Any use of existing information should normally be complemented with a field visit to verify and supplement the information gathered.

4.2 Background information

Information on general background and objectives of the extractive operation is helpful in order to put the waste and the waste characterization process into context. The background information would typically include general information about:

- ongoing or planned prospecting, extraction, or processing activity;
- type and description of method of extraction and process applied/planned;
- the intended product.

These points are rather straightforward and will normally be readily available in permit applications or other existing documents.

4.3 Geological background of deposit to be exploited

4.3.1 General

Information under this heading is aiming at the identification of waste units that will be exposed by extraction and processing by providing relevant information on:

- nature of surrounding rocks, their chemistry and mineralogy, including hydrothermal alteration of mineralized rocks and barren rocks;
- style of mineralization and morphology of mineral deposits including mineralized rocks or rock-bearing mineralization;
- mineralization typology, including physical properties such as density, porosity, particle size distribution, water content, covering worked minerals, gangue minerals, hydrothermal newly-formed minerals;
- size and geometry of deposit; and
- weathering and supergene alteration from a chemical and mineralogical point of view.

However, not all of this information is relevant for all types of operations or extractive industries. The level of detail of the information to be gathered should be adapted to the type of waste, the potential environmental risk, and the intended waste facility.

The information listed above is discussed in the following clauses.

4.3.2 Surrounding geology

Information about the surrounding geology (including hydrology) will often contribute to the understanding of the potential environmental impacts of the extractive waste and is commonly an integral part of both the exploration and production phases, but not for all sectors.

For the production planning, as well as for the waste management plan, it is important to establish the borders between the ore and the waste. In cases where the mineralization is defined by distinct rock types the borders are commonly easy to establish. In cases with a rock alteration type mineralization, like in disseminated deposits, the border is often defined as a cut-off grade based on production cost and product price. In these cases, the border may change over time.

Geological information may also be documented for the evaluation of the stability of mine tunnels and pit walls. This information is in some cases useful for the evaluation of the geotechnical stability of the waste.

Draw-down of the water table due to pumping during the operation may expose rocks and soils that were previously below the water table to air. If these rocks contain sulfides, the lowering of the water table may result in sulfide oxidation, acidic drainage and possible generation of secondary iron sulfate minerals. An understanding of these processes may provide valuable input to the waste characterization as the surrounding rock in many cases presents the same properties as the waste. In some cases, the surrounding rock is in fact the future waste.

Information regarding the surrounding geology may include:

- mineralogy and geochemical properties of the surrounding rocks;
- hydraulic properties;

— groundwater levels.

To carry out new investigations to obtain this type of information could be quite costly. However, for those operations where information about the surrounding geology will be important for the characterization and management of wastes this information will most likely already be documented.

4.3.3 Nature of deposit

The nature of the deposit together with the value of the product will to a large extent determine which extraction method is feasible (quarry, open pit, underground, block caving etc.). One key element of a description of the nature of the deposit would be the structure of the ore. i.e. if the deposit is a massive type, stock-work type, vein type or disseminated.

The nature of the deposit and the extraction method will have a significant impact on the types and volumes of waste produced. A quarry typically produces relatively small amounts of waste per tonne of product. Underground mining commonly means less waste rock produced per tonne of ore than an open pit. A massive deposit commonly means less tailings produced per tonne of product than a stock work or a disseminated deposit. However, in this context it should be mentioned that the economics of an open pit operation may mean a more efficient recovery of the resource overall through the inclusion of low grade material, i.e. a lower cut-off grade.

4.3.4 Mineral deposit

Knowing the nature of the mineral deposit is essential to the owner/operator in order to plan an efficient and profitable operation. The information about the mineral deposit may include:

- mineralization typology;
- textural descriptions; lithology, structural features, depth of oxidation;
- whole rock geochemistry and elements distribution in mineral phases;
- geochemical properties (e.g. reducing capacity, degradable organic matter content, thermodynamic stability, acid forming potential and acid neutralization potential);
- mineralogy (ore minerals, gangue minerals, hydrothermal newly-formed minerals etc.);
- physical properties such as density, porosity, particle size distribution, water content.

Relevant parts of the information described above may be obtained from existing plans and reports and be included as part of the waste characterization. The level of detail should be adapted to the mineralization in question and proportional to the size of the operation and risks to be managed.

4.3.5 Size and geometry

Information on the size and geometry of the ore deposit are important in the development of plans for the operation. The plan gives information on the estimated volume of ore and waste rock together with information on when different types of ore and waste rock will be extracted. This information is essential when developing the waste management plan.

The information about waste volumes over the planned lifetime of the operation needs to be combined with information about waste characteristics as discussed elsewhere in this document. This implies that during exploration not only the mineral resource should be analysed but also the volumes and behaviour of the future extractive waste.

In recent years, most resource calculations performed during exploration and in feasibility studies used a specialized computer package that deals with 3D data. The “block model” of the future operation can be considered as a 3D database of the potential mining units, based on which the definition of ore or waste

is made. The block model is based on all relevant and available test results. Assuming that the environmentally critical and relevant parameters (acid producing capacity, mineralogy, leachability etc.) of future waste blocks are defined with a certain probability during the detailed exploration phases, this information can be fed into the block model and serve as a base for the waste management plan (an example of a cross section, 2D, waste model is shown in Figure 6).

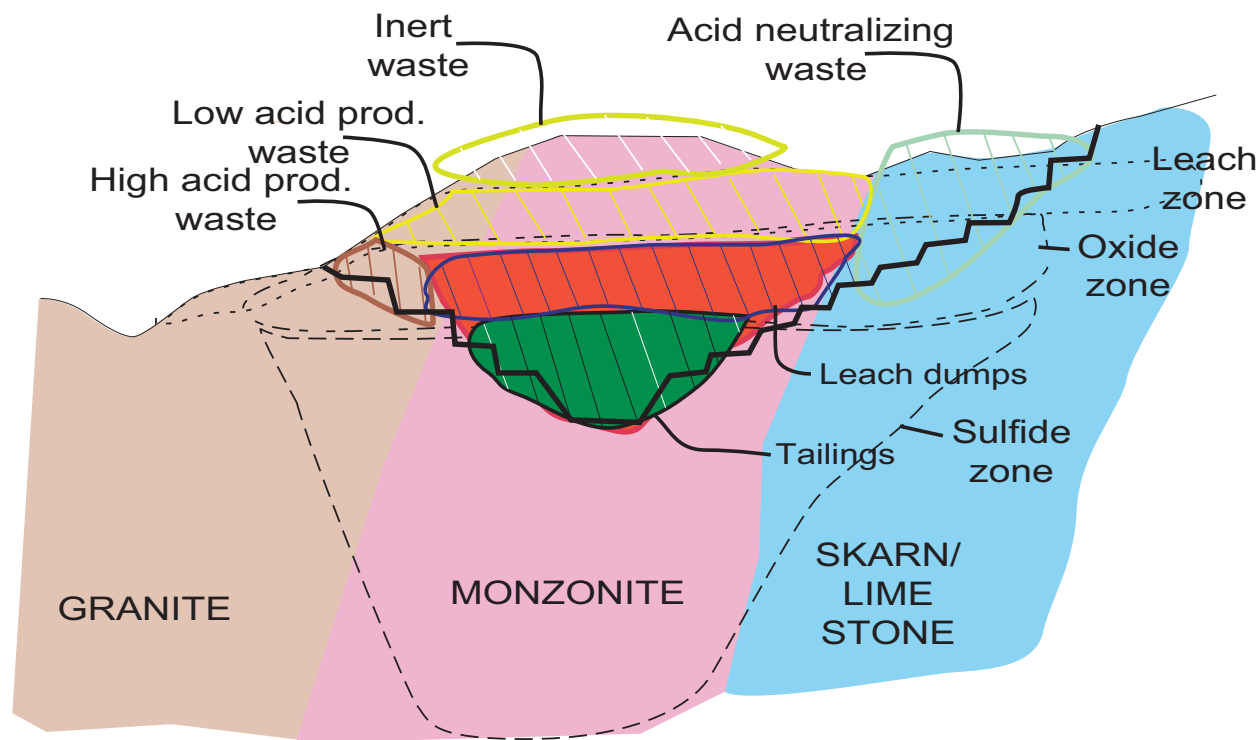


Figure 6 — Waste model linked to geology and production types are illustrated for a hypothetical porphyry copper deposit. The waste model illustrates different types of waste rocks in addition to ore that is producing tailings and ore that is producing copper leach rocks (Walder, 2001)

4.3.6 Weathering stage of deposit

The significance of weathering primarily relates to mineral deposits containing sulfide minerals with the potential to form A/NRD. Defining the weathering and alteration of a deposit is commonly a part of the information gathered during exploration and details about these processes can be found in text books (e.g. Robb, 2007; Barnes, 1989).

A sulfidic metal mineralization is commonly divided into:

- a hypogene mineralization, which relates to the original mineral assemblage, i.e. the mineral assemblage formed during the primary mineral forming processes.
- a supergene mineralization, which relates to mineral assemblage that has formed due to near surface processes (weathering processes).

The supergene processes do not only relate to metal ore deposits but to weathering in general.

In most of the case the supergene alteration can be enhanced by the hydrothermal alteration that develops a pervasive alteration increasing the porosity, changing the chemistry of the parental rock and leading to the deposition of newly formed minerals (e.g. pyrite, biotite), or the replacement of primary minerals by clay.

The supergene alteration (commonly associated with sulfide containing deposits) takes place when the mineralization is exposed to oxidizing conditions. This may occur if there is erosion of the overlying rocks and the water table is lowered within the sulphide mineralization. The sulfide minerals are then likely to oxidize with a transport of elements as shown in Figure 7. The processes illustrated here are natural ARD processes; however, due to limited access to oxygen, the processes may be relatively slow.

In some cases, the supergene alteration is crucial for developing an economic viable deposit where the supergene processes transport valuable metals downward and re-precipitate them on top of primary minerals with the same valuable metals. Understanding the processes of the ore deposit can often give an indication of how waste material from that deposit will react.

The hydrothermal alteration zones may also be found in deposits that do not contain sulfides. However, it is commonly less important to understand the hydrothermal alteration zones for those deposits. Sedimentary deposits such as limestone, sand and gravel will not have the hydrothermal alteration zones.

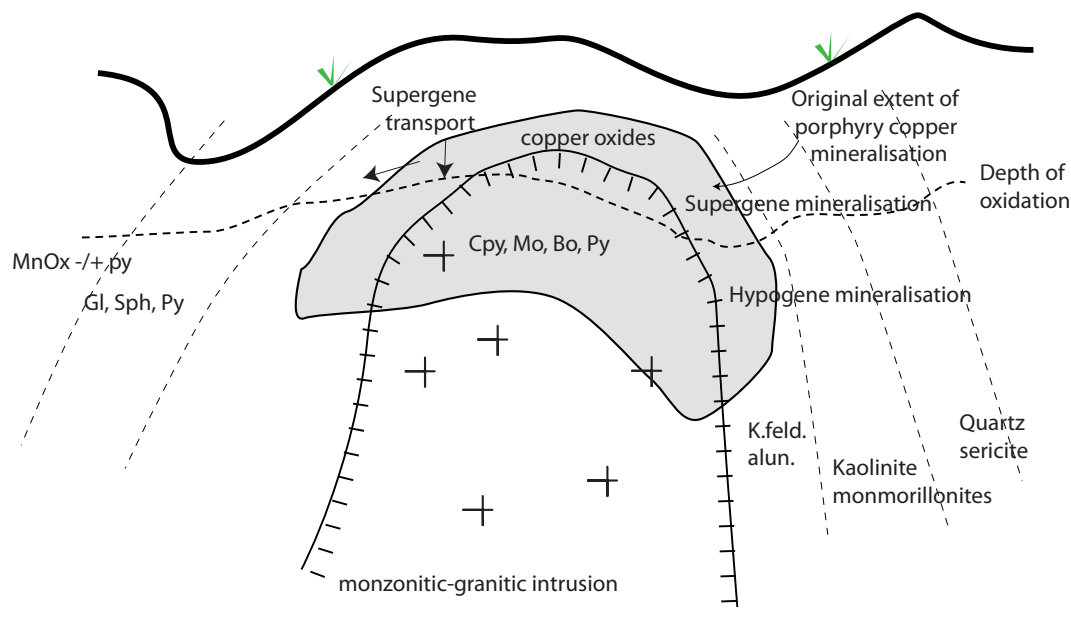


Figure 7 — Mineral distribution in and around a hypothetical porphyry copper deposit. The dotted semi-vertical lines represent hydrothermal alteration zonation, while the horizontal line represents the bottom of the supergene-oxidation processes. Cpy-chalcopyrite (FeCuS_2), Py-pyrite (FeS_2), Bornite (Cu_5FeS_4), Mo-molybdenite (MoS_2), Sph-sphalerite (ZnS), Gl-galena (PbS), MnOx-manganese oxides (Walder, 2003)

4.4 The waste and its intended handling

Information about the origin of the waste within the extraction site and the processes generating such waste could give valuable supporting information when evaluating waste characteristics.

A practical approach could be to document predicted quantities (annual and total) of site specific waste categories based on two factors: mineralogical characteristics relative to the mineralization and the geology of the extraction site and the type of process the waste has gone through before being deposited. For example:

— waste rock, type x, without processing;

- waste rock, type y, after crushing and sorting;
- tailings from ore type a, after froth flotation;
- tailings from ore type b, after gravity separation;
- tailings from ore type c, after leaching.

Waste handling includes transport, processing and disposal. It is recommended to document planned or existing waste transportation systems, e.g. transport by trucks, conveyer belts or pipe lines.

Mineral processing may involve the use of chemical substances, e.g. frothers, suppressing agents, flocculants and leaching agents. These substances may end up in the waste stream and it is therefore recommended that all process chemicals are listed.

In addition, under EU legislation, information should be provided on the classification of the waste according to the Commission Decision 2000/532/EC, including the hazardous properties (the so called European Waste Catalogue).

The COM decision also requires the waste characterization to include information on “type of waste facility, final form of exposure of the waste and method of deposition of the waste into the facility”. It should be noted that for new operations, even though preliminary plans and information may be available at an early stage, these are management decisions that should be made based on the result of the waste characterization.

4.5 Baseline data for the site of disposal

For future waste facilities or expansions, information regarding baseline properties of the intended disposal site (or alternative sites where relevant) may provide useful supporting information. The appropriate level of detail will depend on the type of waste and the disposal scenario envisioned. Both normal and exceptional site conditions which may influence the properties of the future waste facility and the behaviour of the deposited waste could be of interest.

Relevant information regarding potential disposal sites may include:

- Site topography, hydrology and geotechnical data, e.g.:
 - water balance and degree of water saturation;
 - dimensions of the planned waste facility;
 - physical properties of the foundation soils and bedrock.
- Geochemical conditions, e.g.:
 - geochemistry of foundation soils and bedrock;
 - groundwater chemistry.

5 Characterization tools

5.1 General

The most common methods used for mineralogical, geotechnical and geochemical analysis in extractive industries are presented in this clause, together with a discussion of their applicability.

The methods described should be seen as a set of tools. Which tools to use in a specific case will depend on characterization objectives, type of operation, available disposal scenarios and other site specific conditions.

5.2 Sampling

When available data is insufficient for meeting the characterization objectives, a plan for further sampling and testing may need to be developed. A field visit will normally be part of developing a sampling plan.

A specific sampling guideline for the characterization of waste from extractive industries has been developed (CEN/TR 16365). This guideline builds upon EN 14899, "Sampling of Waste Materials – Framework for the preparation and application of a Sampling Plan". The sampling guideline is focusing on the development of sampling plans but does also discuss some practical aspects such as sampling equipment, storage and transport. According to the sampling guideline a plan for characterization of extractive waste should normally cover the aspects listed in Table 2.

Table 2 — List of aspects to be covered in a sampling plan

Aspect	Explanation
Identification of stakeholders	List with contact information of all stakeholders
Identify general objectives	General objectives as described in Clause 2,
Background information	Information of the process type, waste types, known geology, mineralogy, previously performed characterization etc.
Specific objectives	Detailed objectives such as prediction of drainage quality, ARD potential, mineralogy
Determine generic level of testing	Sampling for screening, detailed characterization, confirmation etc.
Identify constituents and analytical methods	Elements/constituents of concern e.g. total metal content, pyrite content, and analytical methods to determine these constituents
Identify health and safety precautions	Health and safety issues for the sampler and the storage and transport of the samples
Select sampling approach	Judgmental, unbiased, etc.
Identify sampling techniques	Sampling from drill core, auger, shovel etc.
Sub-sampling	Splitting system of samples after collection for reduction of volume/mass
Sample preparation	Drying, splitting for different analysis, storage requirements
Transport sample	Transport system to the lab and transport documentation
Document sampling plan and produce instructions for the sampler	Details on sampling procedure for the sampler
Produce a field sample record	List of information to be included in the field sample record
Complete sample record and document changes	List deviations to the sampling plan and reasons for the deviation

5.3 Mineralogy

5.3.1 General

Knowledge of the mineral composition and mineral chemistry may be essential to interpret data on chemical composition or leach tests and to predict short and long-term drainage water quality from the waste material generated in the extractive industry. The mineralogy may further be of significance when interpreting acid production and buffering potential based on acid-base accounting.

Mineralogy in this context provides supporting information for the characterization of the waste material. Mineralogical information together with physico-chemical conditions may e.g. give indications about the occurrence of weathering processes such as:

- oxidation (sulfides);
- dissolution (carbonates, sulfates);
- hydrolysis (silicates);
- sorption;
- mineral stability/reaction rates.

This information in combination with geochemical data and leach test results can be used to evaluate leaching potential, metal transport, and attenuation.

Some key aspects of mineralogy and A/NRD processes are discussed in Annex G.

The following clauses discuss different approaches to obtaining relevant mineralogical information.

5.3.2 Analytical methods

There are many different mineralogical analyses that can be performed and their usefulness varies with the type of issues that need to be solved.

The mineral sciences, especially in the last few decades, have become very equipment-focused. The analytical methods are being developed towards high accuracy determination of small quantities. A pitfall to be avoided is to get too deep into details, losing sight of the integrated assessment that is usually what is sought.

Microscopic analysis is often the basic form of mineralogy analysis. The microscopy analysis can give information on type of minerals and if these minerals have undergone any alteration/weathering.

X-ray diffraction, XRD, methods are commonly used to identify minerals, but the method has detection limits of 2 wt % to 3 wt % (weight %, commonly used for mass fraction within the sector). This means that the method may not detect minerals that could be of concern even at lower concentrations. XRD methods are only semi quantitative and additional chemical analyses are necessary to quantitatively identify minerals using XRD (Rietveld method).

An electron probe micro-analyzer, EPMA, is a micro-beam instrument used primarily for the in situ chemical analysis of minute solid samples. EPMA is also informally called an electron microprobe, or just probe. The primary importance of an EPMA is the ability to acquire precise, quantitative elemental analyses at very small "spot" sizes (as little as 1 μm to 2 μm), primarily by wavelength-dispersive spectroscopy (WDS). The spatial scale of analysis, combined with the ability to create detailed images of the sample, makes it possible to analyze geological materials in situ and to resolve complex chemical variations within single mineral or amorphous phases.

The core concept of the Rietveld method as well as other full profile refinement methods is the comparison of the measured diffraction profile with a calculated profile. The latter one is based on calculated and refined crystal structures where certain elements can be substituted by others. Chemical information is therefore needed:

- to have the real composition of the mineral phases, which can be obtained by EPMA;
- to compare the measured whole rock composition with the calculated composition obtained from the quantitative XRD results.

In general the more additional information (microscopy, EPMA, whole rock chemistry) you have about the rock the better your refinement result will be.

The microscopic and XRD analysis give no information about trace element concentration (often substituting main elements in the mineral structures), which may be important for evaluating trace element sources and drainage chemistry. There are many different techniques that can be used to identify the mineral chemistry (e.g. scanning electron microprobe (SEM), X-ray photoelectron spectroscopy (XPS)).

Mineralogical analysis is a stepwise procedure. How far to go will depend on information needs, time available and costs. See Figure 8 below.

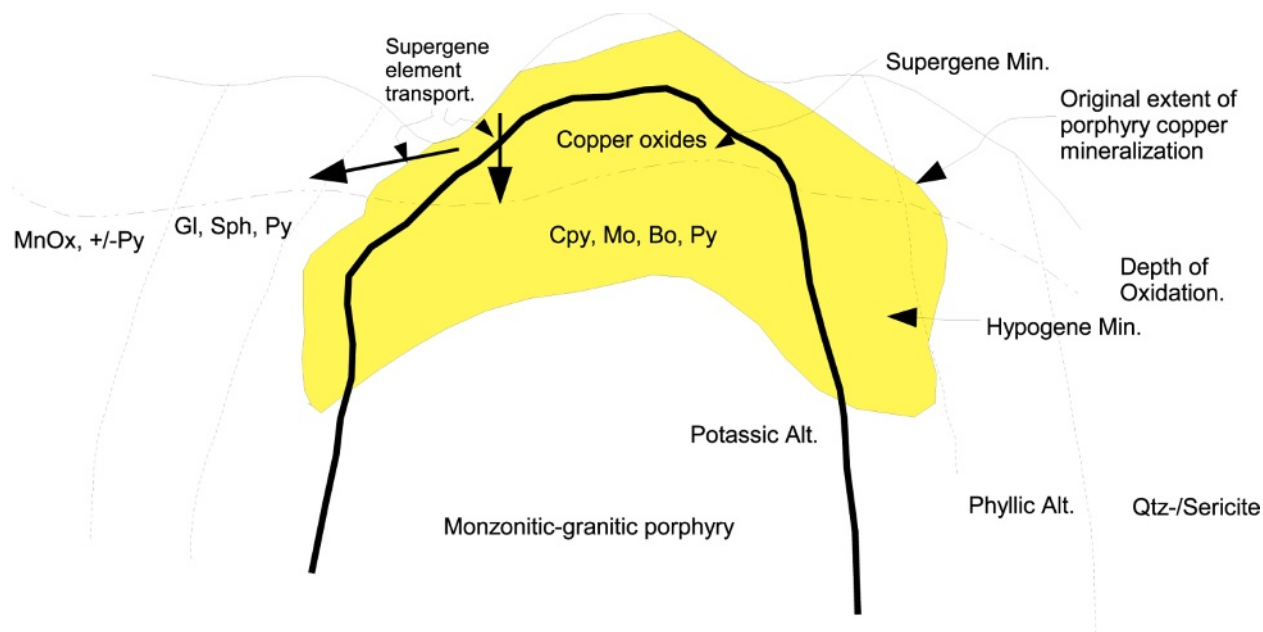


Figure 8 — Stepwise approach to mineralogical analysis

The most important analytical methods are discussed briefly in Annex E. These are methods which can provide reliable information on bulk mineralogical composition and especially on specific questions of minerals heterogeneity and alteration processes. The annex gives background information on capabilities and limitations of the analytical methods to facilitate dialogue with specialists.

5.3.3 Texture

The texture of the waste material may be important to assess when characterizing the waste material, because the texture of the rock gives information about the actual availability of the minerals to leaching and to generation and neutralization of acidity. If the reactive minerals are fine grained this will lead to a large surface area when crushed, i.e. high availability. If the reactive minerals occur only encapsulated within non-reactive minerals they may remain effectively immobilized.

It may also be relevant to assess the degree of liberation; i.e. if the surfaces of the mineral grains are available for surface reactions. This is relevant for neutralizing minerals, acid producing minerals, or leachable minerals.

Analysis of the texture of the waste material is commonly performed by classifying the texture of hand specimens and from microscopic analysis of polished thin sections (see Annex G).

5.4 Physical and hydraulic properties

5.4.1 General

Physical and hydraulic properties of extractive waste are important in the context of dam or slope stability assessment (as discussed in 3.3.1) and for the assessment of water balance and hydrology of a disposal site. Physical properties may impact the geochemical behaviour of the waste as well as being impacted by chemical reactions taking place.

Every mineral deposit is more or less unique with regard to waste properties as well as to its geological, geographical, hydrological, climatic etc. conditions. This in turn leads to site specific designs of waste disposal facilities. What information on physical properties is needed and relevant will have to be evaluated based on characterization objectives and site specific conditions. A complicating factor is that particle size and many other physical properties of the waste cannot be assessed in detail prior to extraction, which means that the initial characterization will have to be followed up during operation.

This clause gives an introduction to the general scope of geotechnical investigations and the reasons for their importance.

5.4.2 Overview of types of geotechnical investigations

Geotechnical investigations may be divided into laboratory and in situ investigations.

Laboratory characterization and testing of the waste materials may measure properties such as: compressibility, shear strength, angle of friction, grain size distribution, density (bulk density and specific weight), plasticity, fracturing (if appropriate), liquefaction potential, permeability and erosion potential.

While laboratory investigations in general make more accurate measurements possible, the average sample size is generally small. Therefore, an accurate sampling strategy to ensure representative samples is crucial. Up-scaling of the results should always be done with care.

In-situ tests may in many cases be less accurate, but they are of a more “integrating” character. This means that their results are generally valid for a larger volume. It should be noted that many in-situ tests will only give indirect information about the investigated material (e.g. in-situ measurements of the frictional forces or the peak resistance of the waste material may be used to get information on shear strength or angle of internal friction).

In-situ tests are in principle only applicable to waste already present in existing dumps and tailings storage facilities and their relevance for initial testing in the planning stage is limited.

Already this short introduction to field and laboratory investigations indicates that there is no perfect methodology for the characterization of physical properties of the waste material. There are different, more or less adequate, investigation strategies that all include some level of inaccuracy that can only be reduced using well educated and highly experienced professionals.

Geotechnical investigations of extractive wastes and waste facilities may include site specific information (e.g. hydrogeological, climate data, seismicity, topography, tailings and waste dump seepage) that are part of the general background information of the site, see Clause 4.

5.4.3 Test methods for physical and hydraulic properties

Different sets of testing may be considered for physical characterization of extractive wastes. These include:

- Physical characterization of the solid phase of tailings, which would normally include soil index properties such as grain size distribution; specific surface, specific weight; Atterberg limits; and permeability; as well as mechanical properties such as shear strength; and compressibility.

- Physical characterization of tailings used for dam construction, which would normally require additional physical characterization relevant for dam design. Additional tests that may be considered for this purpose include particle specific weight; natural water content; bulk density; Proctor compaction curves; variation of pore pressures; and swelling potential.
- Analysis of waste in existing dumps, which may also comprise estimation of the degree of aggregation; degree of compaction; amount of natural fines and amount of fines after compaction; weathering grade; initial and final moisture content due to drainage; effective cohesion; and angle of internal friction (see 5.4.4 below).

Compressibility and frictional behaviour are key parameters for the assessment of the behaviour of tailings and waste rock in impoundments and heaps. The internal friction is a key element of physical stability and is in turn strongly linked to the level of compaction and dependent on other processes taking place. Several factors are important to understand the compressibility and self-compaction properties of the waste materials, including: the overall compressibility; its dependence on moisture content; the possible migration velocity of moisture (seepage velocity); and the grain-size distribution.

It is important to consider the strong interdependence between physical and geochemical properties. While the physical properties of the waste may have a significant impact on the long term geochemical performance, chemical weathering of the waste will lead to changes of the physical properties.

Annex C briefly describes test methods for the categories of physical and hydraulic properties/parameters listed below (for each of the methods discussed in Annex C, existing international standards are listed).

- soil index properties including grain size distribution; moisture content; and plastic behaviour;
- density and compatibility;
- shear strength and bearing capacity;
- factors affecting permeability and subsurface flow (porosity, void ratio, saturation, hydraulic conductivity).

Some additional information on geotechnical test methods can be found e.g. in Annex 4 of the Mine waste BAT document (Reference Document on BAT, 2004).

5.4.4 In situ investigations of physical and hydraulic properties of deposited waste

Waste characterization at existing facilities may include an investigation of in situ physical and hydraulic properties of the waste and the resulting hydrogeological conditions in the waste facility. This may be important input e.g. to risk assessments of existing facilities or the development of closure plans.

Drilling is one way to get direct information. From boreholes disturbed samples can be collected or undisturbed samples can be taken using core samplers. The stratigraphy of the impoundment material may be described using the bore log. The disturbed samples are used to determine the Atterberg-limits, Proctor type, bulk density and compressibility. From these values bearing capacity, plastic and elastic soil parameter values can be estimated. Undisturbed samples can be used for triaxial or uniaxial tests to determine internal friction and cohesion of the materials. The mentioned properties of loose soils or of disturbed samples can also be investigated using shear tests. When using boring techniques the need to seal boreholes to avoid ingress of air and/or water should always be assessed. In specific cases it may be recommended to avoid boring.

Besides boring, Cone Penetrometer Testing and Standard Penetrometer Testing can also be used to characterize larger areas. Since they are quick and rather cheap testing methods they can be used to refine the information from the borehole investigations. Moreover, indirect information on bearing capacity, soil moisture distribution, etc. vs. depth can be recorded by special sensors.

To evaluate the hydrogeological conditions in operating tailings dams, monitoring wells can be established and the water levels regularly or continuously recorded. From the values the hydraulic gradient and the water flow direction can be determined. Wells or bore holes can be used to perform pumping tests (for highly permeable formations) or slug tests (for low permeability rocks) in order to determine the hydraulic conductivity (using steady state or transient data) and storage coefficient and specific yield (using transient data records).

5.5 Chemical composition

5.5.1 General

There is a variety of chemical methods that can be used to evaluate the chemical composition of water and solids. The solids can be analysed directly using e.g. atomic absorption with graphite furnace or subject to digestion followed by an analysis of the dissolved substances. There are different options for digestion and for the chemical analysis of the solutions. Which method to choose partly depends on the objective of the study, on analytical methods chosen in earlier studies (to produce comparable data) and on the laboratory resources available. There is a brief introduction to these methods in the following clauses. There are numerous publications on chemical analysis and Annex B lists applicability of CEN and ISO standardized tests methods for waste from extractive industries.

5.5.2 Digestion methods for inorganic substances

Before performing the analysis of elements by chemical analysis the solid waste material has to be digested resulting in an acidic aqueous solution. Generally, there are two approaches: either total digestion or a partial extraction. In environmental analysis often aqua regia is used, but (contrary to what is often attributed) this is a partial extraction and not a full digestion. Although aqua regia is a very strong acid, it is not able to fully digest silicates; therefore, all elements that are bound to that matrix are not digested and will consequently not be analysed. The digestion of silicates requires hydrofluoric acid which is used for total digestion. Alkaline fusion methods are applied to major components and to a selection of anions like chloride (Cl^-), sulfate (SO_4^{2-}) and fluoride (F^-), see Annex B.

5.5.3 Analysis of major, minor and trace elements

Following digestion, elements of interest are measured in the acidic aqueous solutions obtained using different detection methods. The choice of method depends on the specific element or elements and the range of concentrations of interest. When a large number of elements have to be determined, the first choice is inductively coupled plasma-atomic emission spectrometry (ICP-AES) or inductively coupled plasma-mass spectrometry (ICP-MS). These methods allow the simultaneous determination of: aluminium, antimony, arsenic, barium, beryllium, bismuth, boron, cadmium, calcium, chromium, cobalt, copper, iron, lead, lithium, magnesium, manganese, mercury, molybdenum, nickel, phosphorus, potassium, rubidium, selenium, silver, silicon, sodium, strontium, sulfur, tin, titanium, vanadium and zinc.

Direct analysis using flame atomic absorption spectrometry (F-AAS) or graphite furnace atomic absorption spectrometry (GF-AAS) is less frequently used nowadays. These methods are mostly used for single element determination rather than for multi-element analysis, however, new instruments can also perform multi-element analysis. AAS requires larger samples than ICP. Mercury is an element that requires special analytical techniques due to its usually low concentration. Applicable are cold-vapour atomic spectrometry (CV-AAS) or cold-vapour atomic fluorescence spectrometry (CV-AFS). Low concentrations of arsenic, antimony, and selenium are measured by hydride-generation atomic absorption spectrometry.

X-ray fluorescence (XRF) is an instrumental method for total composition without digestion. The sample is either fused with borate or mixed with wax to obtain a tablet for further analysis. This method will also give the total content of elements in the sample.

Field XRF instruments can give a rapid analysis and it requires no pre-treatment. The detection limit, however, is higher than for conventional XRF.

5.5.4 Chemical speciation

So far, element concentrations have been determined without regard to chemical speciation. Concentrations are given as pure elements while in fact they are almost always bound in chemical compounds with different states of oxidation. This may be significant from a toxicological point of view. For example, the element chromium is found as chromium (III) as well as chromium (VI). While chromium (III) is benign, the latter is toxic at low concentrations and requires a dedicated analytical technique.

Direct methods for quantifying an element in a specific chemical form in a mineral are available only for a few substances. However, knowing in which mineral a substance occurs will, in most cases, indicate its chemical form. Mineralogical speciation (i.e. in what minerals each element is located in a rock) can be performed as described in 5.3. This will usually give a good indication for elements in higher concentrations, while trace elements can be hidden as adsorbed, ion exchanged or substituted atoms, or occur in the form of small quantities of separate minerals. The combination of mineralogical data, water quality data and modelling would be the most commonly applied approach to assess speciation (Lichtner et al, 1996; Moritz et al, 2009).

5.5.5 Sulfur (total, sulfate, and sulfide)

For many wastes from the extractive industries the content of sulfur is of interest as it may lead to production of acid/neutral drainage. Sulfur can be found as sulfide or disulfide (e.g. pyrite), as sulfate (e.g. calcium sulfate = gypsum), or as organic sulfur. The latter would usually not be found in extractive wastes, the same holds for elementary sulfur. While most sulfides will contribute to acid production, sulfate and elementary sulfur will not.

Usually, the total content of sulfur is determined, which is sufficient for many applications. According to EN 15875, the preferred methods for sulfur determination are bomb combustion according to EN 14582 or high temperature combustion according to ISO 15178. When speciation is of interest, instead of total sulfur a more time and labour consuming analytical method has to be applied (see Annex F and EN 15875:2011, Annex C).

5.6 Determination of acid generation potential

5.6.1 General

Acid/neutral rock drainage (A/NRD) is the main long term environmental issue for the metal and coal mines sectors of the extractive industries. Different A/NRD prediction methods that are being used by the industry around the world include static testing and kinetic testing.

The static tests are designed for the single purpose of measuring the extractive waste's capacities for producing acidity and its acid neutralization capacity. Accordingly, static tests are commonly used for screening purposes and to provide an answer to whether the extractive waste material has a potential to be an acid producer or an acid neutralizer. The static tests focus on the intrinsic properties of the material. They do not provide any information on reaction rates or release rates of weathering products.

5.6.2 Paste pH

Paste pH is the most basic and simple static test. While it can be useful to indicate ongoing acidification of waste that has been exposed to air and water for a few years it does not give any useful information for fresh or un-weathered waste. The method is usually performed in the field, but laboratories will also perform the test. A pH result below neutral indicates that acid production has occurred.

5.6.3 Acid-base accounting

Acid-base accounting (ABA) is the most common type of static tests. They are all designed to quantify the total acid producing potential and acid neutralizing potential of the material tested. However, they do not give any information on the rate of acid production or neutralization.

ABA-tests quantitatively balance the sulfur or sulfide-sulfur content (acid potential, AP) with the neutralization potential (NP) of carbonates and other alkaline material.

The quantitative balance is commonly expressed as the neutralization potential ratio (NPR),

$$\text{NPR} = \frac{\text{NP}}{\text{AP}} \quad (1)$$

or as a difference between the acid potential (AP) and the neutralization potential of the host rock (NP), the net neutralization potential (NNP)

$$\text{NNP} = \text{NP} - \text{AP} \quad (2)$$

The static test described in EN 15875 has been developed as part of the implementation of the Directive on waste from extractive industries and is the recommended static test procedure within Europe.

There are several other static tests that are used internationally. E.g.:

- acid-base accounting (ABA) the Sobek method (Sobek et al, 1978);
- modified Sobek (Lawrence and Wang, 1996).

In most methods (including EN 15875) the acid potential is calculated based on sulfur, or sulfide, content (see 5.5.5).

The net acid generation (NAG) test (Miller et al, 1997) determines resulting acid generation directly and is often used as a complement to ABA to resolve unclear cases.

Although the static tests share some common features the different protocols may produce different results for the same sample. Different mineralogy will manifest itself in different sensitivity to the choice of protocol parameters as described in EN 15875.

The protocol for EN 15875 specifies acid addition on the basis of the carbonate content (EN 13137) (Kartinen and Wahlström, 2009) which is an upgrade of the most used ABA methods. In the standard ABA (Sobek et al, 1978), the modified ABA (Lawrence and Wang, 1996) and with peroxide siderite correction (Skousen, 1997) a fizz test is used for determination of the amount and molarity of hydrochloric acid added to the sample. Some concern has been raised regarding the rationale and appropriateness of this procedure (see for example Jambor et al, 2007).

As part of the standardization work, an evaluation of the different test methods for sulfur determination used for evaluating acid producing potential has been performed (see 5.5.5 and Annex F).

5.6.4 Kinetic testing

Kinetic tests are tests set up to allow for naturally occurring reactions to take place. These reactions will commonly change the behaviour of the tested material over time. The concept of kinetic tests could include any test that allows for, and measures, changes over time. Commonly kinetic testing refers specifically to tests run to evaluate acid generation behaviour of sulfidic wastes, i.e. to quantify reaction rates for acid producing and buffering reactions and to evaluate if the material actually will go acidic or not. The latter is the definition applied in this document. The more standardized kinetic test methods (ASTM 2001; USEPA 1978, Morin and Hutt, 2002) are designed to evaluate/calculate the maximum sulfide oxidation rate relative to neutralizing reactions and not to simulate waste behaviour under field conditions. They are not set up to provide information needed to evaluate leaching rates (Lapakko, 2004). Adjustments to the standardized methods are being used to evaluate leaching rates (Price, 2009), adjustments that take into account more site specific conditions such as airflow, grain size and climate. Information on leaching rates and drainage chemistry is also achieved from scaled up experiments and field tests.