



BSI Standards Publication

Earthworks

Part 7: Hydraulic placement of extractive waste

National foreword

This British Standard is the UK implementation of EN 16907-7:2021.

The UK participation in its preparation was entrusted to Technical Committee B/526/-/1, Earthworks.

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

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EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

CEN-CENELEC Management Centre: Rue de la Science 23, B-1040 Brussels

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European foreword

This document (EN 16907-7:2021) has been prepared by Technical Committee CEN/TC 396 “Earthworks”, the secretariat of which is held by AFNOR.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by January 2022, and conflicting national standards shall be withdrawn at the latest by January 2022.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN shall not be held responsible for identifying any or all such patent rights.

This document is one of the European Standards within the framework series of EN 16907 on *Earthworks*. The set of standards prepared by CEN/TC 396 is divided into several parts, which correspond to different steps of the planning, execution and control of earthworks and should be considered collectively as a group of standards for executing earthworks. The full set of Parts is as follows:

- EN 16907-1, Earthworks — Part 1: Principles and general rules;
- EN 16907-2, Earthworks — Part 2: Classification of materials;
- EN 16907-3, Earthworks — Part 3: Construction procedures;
- EN 16907-4, Earthworks — Part 4: Soil treatment with lime and/or hydraulic binders;
- EN 16907-5, Earthworks — Part 5: Quality control;
- EN 16907-6, Earthworks — Part 6: Land reclamation earthworks using dredged hydraulic fill;
- EN 16907-7, Earthworks — Part 7: Hydraulic placement of extractive waste (this document).

Within this document, references to specific parts of the standard are written by reference to the full reference (e.g. “EN 16907-2”).

These “Earthworks standards” do not apply to the environmental planning and geotechnical design that determines the required form and properties of the earth-structure that is to be constructed. They apply to the design of the earthworks materials, execution, monitoring and checking of earthworks construction processes to ensure that the completed earth-structure satisfies the geotechnical design.

Any feedback and questions on this document should be directed to the users’ national standards body. A complete listing of these bodies can be found on the CEN website.

According to the CEN-CENELEC Internal Regulations, the national standards organisations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Republic of North Macedonia, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

Introduction

European Directive 2006/21/EC of the European Parliament and of the Council of 15 March 2006 on the management of waste from the extractive industries states that the preparation of a waste management plan is required for certain mine waste facilities (MWFs). One of the objectives of the waste management plan is to ensure both short- and long-term safe disposal of the extractive waste by choosing a design which achieves geotechnical and geochemical stability of any hydraulic fill placed above a pre-existing ground surface. By inference this requires that suitable features are incorporated into the design, construction, operation and maintenance, closure and after-closure of a MWF to prevent major accidents and to limit any adverse consequences for human health and/or the environment. This document addresses all technical stages of the development of a hydraulic fill project in the context of the Extractive Waste Directive (EWD), with an emphasis on waste and facility characterization and on earthworks procedures.

All sectors of the extractive industry are likely to produce a residue which, during mineral processing, will have been physically, and sometimes chemically, altered due to both the comminution and concentration processes employed. These residues (extractive waste/tailings) comprise fine particulate materials which are generally discharged from the process plant in slurry form as a hydraulic fill, noting that coarse particles are generally neither transported nor deposited by hydraulic means. Such extractive wastes, regardless of their consistency and general characteristics, need to be placed in a secure containment facility unless they are to be immediately recycled. The metal mining industry tends to refer to these facilities as “tailings management facilities” (Figure 1), the aggregates and industrial minerals sectors as “silt lagoons” (Figure 2), and the energy sector as “ash lagoons”. Within this standard, all three are referred to as mine waste facilities (MWFs).

NOTE Definitions of some of the less familiar terms used in this document can be found in Clause 3.

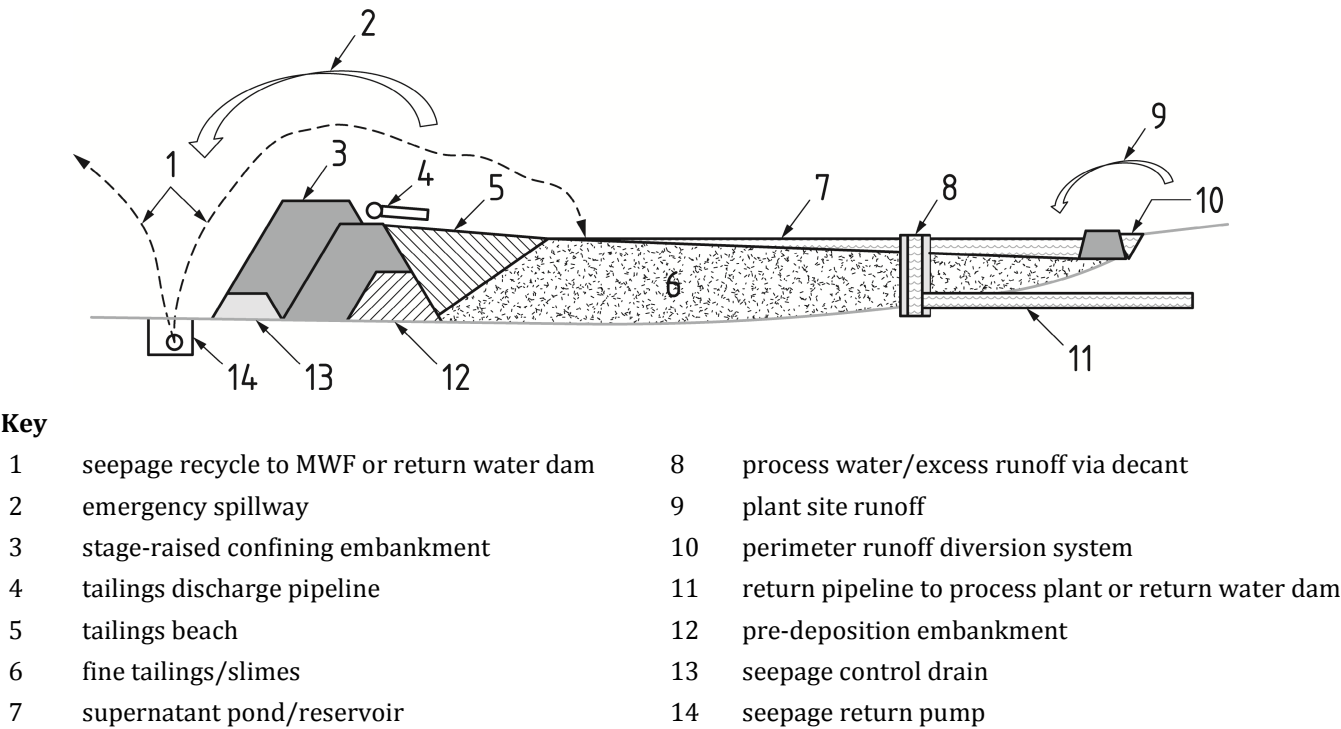
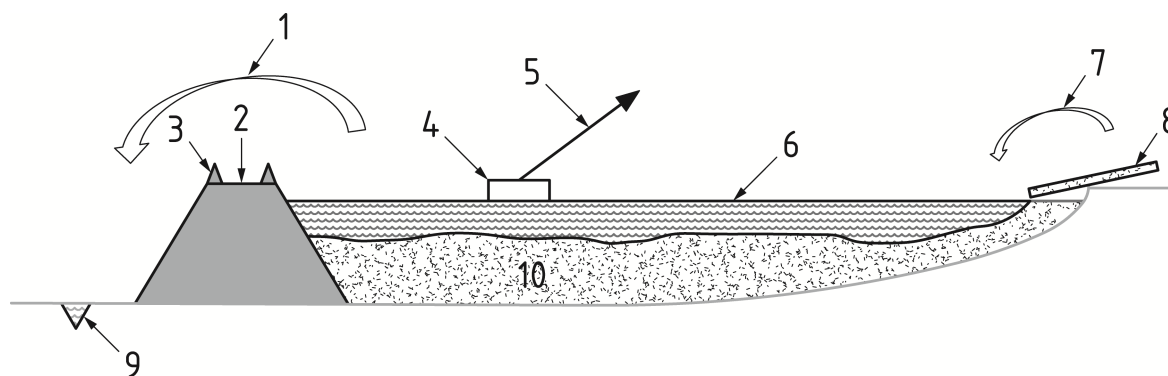


Figure 1 — Typical section — tailings management facility

**Key**

1	emergency overflow/spillway	6	lagoon
2	earthfill confining embankment	7	site runoff
3	edge protection	8	silt discharge pipeline
4	floating lagoon level pump control system	9	drainage control channel
5	return to clean water lagoon	10	unconsolidated silt deposit

Figure 2 — Typical section — silt lagoon

When deposited using hydraulic filling techniques, the MWF for such fine particulate wastes comprises an engineered facility impounding or containing both the extractive waste and a proportion of free water derived from processing operations, from other site waters and from rainfall. This process requires the design and construction of a dam, confining embankment or other structure serving to contain, retain, confine or otherwise support such wastes on surface in a terrestrial environment, together with the appurtenant infrastructure.

Numerous techniques are available for the execution, operation and rehabilitation of a MWF, some of which are standardized and have a long history of application to the extractive industry. It is therefore recognized that no standard can prescribe or recommend specific engineering or environmental elements of the design of a complex hydraulic fill structure such as a MWF, which is site-specific and determined by the climate, geology, topography, hydrology, seismology and environmental setting. However, of importance is that hydraulic placement of extractive waste can only be managed properly if sufficient knowledge of its geochemical, physical and geotechnical properties and behaviour is available. Such knowledge may be obtained through detailed characterization of the waste and of the waste facility and its subsequent consequence classification. The different regional situations in geology and climate result in national differences in the earthwork procedures, and therefore this standard identifies the general principles and systems for the execution, operation and rehabilitation of a MWF as they relate to earthworks.

This document is part of a European Standard on Earthworks, it having been decided by CEN/TC 396 to establish a stand-alone document on the hydraulic placement of extractive wastes relating to earthworks. This document provides the geotechnical and geochemical standards necessary to meet the requirements of Directive 2006/21/EC and presents a unified approach for all stakeholders involved in the development of hydraulic fill projects and in the extension of existing mine waste facilities, together with a framework for project initiation and implementation.

This document is generic in content, and much of the text is synoptic as it is recognized that the range of extractive operations is broad and that the precise characteristics of each waste and its depositional properties will be dependent on the geology, the extraction and mineral processing techniques adopted, and on the type and location of the MWF. For more detail, reference is made to textbooks and other documents included in the Bibliography, particularly *“The hydraulic transport and storage of extractive waste, Guidelines to European Practice”*.

1 Scope

This document gives recommendations for the hydraulic placement of extractive wastes and may be applicable to the following:

- all stakeholders engaged in the deposition of extractive wastes using hydraulic placement techniques with respect to geotechnical and geochemical aspects of the investigation, engineering design, construction and operation of a mine waste facility and all associated monitoring activities;
- those extractive industries involving the production of fine particulate wastes which, in the course of industrial processing, require to be stored in a safe, stable and environmentally acceptable location;
- practitioners in non-extractive industries in fields where similar techniques may be applicable and for which no other European guidance exists.

The scope of this document includes all aspects of a dam, confining embankment or other structure serving to contain, retain, confine or otherwise support such wastes on surface in a terrestrial environment. The overall framework for the standard and for each stage of a hydraulic fill project is shown in Figure 3.

This document addresses the characterization of the extractive waste for the purposes of hydraulic placement in the MWF, both as part of the confining embankment and for safe storage. In addition the standard recommends:

- minimum requirements for the data to be acquired before the design and execution stage of a hydraulic fill project;
- guidelines for the selection of the type of confining embankment appropriate for the selected site;
- guidelines for the selection and characterization of the construction materials;
- general principles on the design and execution of the hydraulic fill project from pre-deposition through operation to closure and rehabilitation;
- guidelines for monitoring and quality control of all stages of the hydraulic fill project to ensure long-term safety and stability.

This document considers how to store safely a given material resulting from a preceding process. It does not define, establish or specify detailed elements of the design of a hydraulic fill project but provides overall recommendations in order to comply with good regulatory and engineering practice. The document recognizes that similar techniques may be applicable to the hydraulic placement of materials in the non-extractive industries where no other European guidance exists.

This document does not consider the design of earth-structures in terms of safety and serviceability. These are ruled by EN 1997 (series) (Eurocode) and other relevant standards. This document assumes that the earth-structures have been properly designed.

This document is not applicable to landfill, dredging or the hydraulic filling aspects related to grouting.

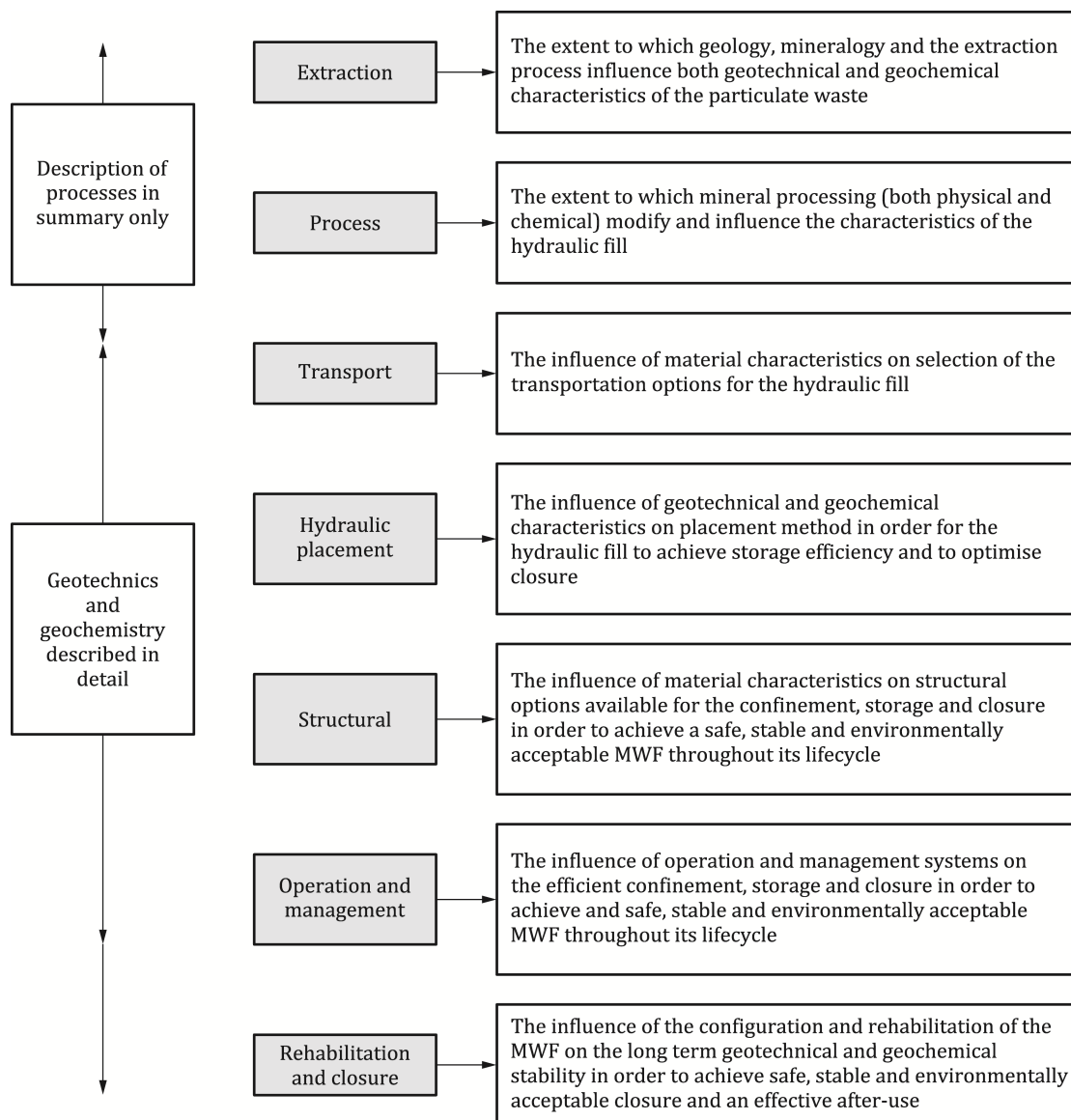


Figure 3 — Stages of hydraulic placement covered by this document

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 1990, *Eurocode - Basis of structural design*

EN 1997 (series), *Eurocode 7: Geotechnical design*

EN 1998 (series), *Eurocode 8: Design of structures for earthquake resistance*

EN 14899, *Characterization of waste - Sampling of waste materials - Framework for the preparation and application of a Sampling Plan*

EN 15875, *Characterization of waste - Static test for determination of acid potential and neutralisation potential of sulfidic waste*

EN 16907 (series), *Earthworks*

EN ISO 14688 (series), *Geotechnical investigation and testing – Identification and classification of soil (ISO 14688 (series))*

EN ISO 14689, *Geotechnical investigation and testing - Identification, description and classification of rock (ISO 14689)*

EN ISO 17892 (series), *Geotechnical investigation and testing – Laboratory testing of soil (ISO 17892 (series))*

EN ISO 18674 (series), *Geotechnical investigation and testing – Geotechnical monitoring by field instrumentation (ISO 18674 (series))*

EN ISO 22282 (series), *Geotechnical investigation and testing – Geohydraulic testing (ISO 22282 (series))*

EN ISO 22475-1, *Geotechnical investigation and testing - Sampling methods and groundwater measurements - Part 1: Technical principles for execution (ISO 22475-1)*

EN ISO 22476 (series), *Geotechnical investigation and testing – Field testing (ISO 22476 (series))*

CEN/TR 15310 (series), *Characterization of waste – Sampling of waste materials*

CEN/TS 16229, *Characterization of waste - Sampling and analysis of weak acid dissociable cyanide discharged into tailings ponds*

CEN/TR 16363, *Characterization of waste - Kinetic testing for assessing acid generation potential of sulfidic waste from extractive industries*

CEN/TR 16365, *Characterization of waste - Sampling of waste from extractive industries*

CEN/TR 16376, *Characterization of waste - Overall guidance document for characterization of waste from the extractive industries*

3 Terms and definitions

For the purposes of this document the following terms and definitions apply

Note 1 to entry: For additional information, see Directive 2006/21/EC.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at <https://www.electropedia.org/>
- ISO Online browsing platform: available at <https://www.iso.org/obp>

3.1

comminution

act of crushing, milling and grinding geomaterials in order to reduce their grain size in advance of mineral processing

3.2

confining embankment

engineered dam constructed from both natural and processed geotechnical materials to retain in safety the fine-grained hydraulic fills (extractive waste) and process water derived from a mineral-processing plant, together with any residual natural runoff

3.3

construction material

geomaterials comprising soil, rock or suitably-sized extractive waste placed and compacted by conventional earthmoving equipment to form the confining embankment

3.4

crest of confining embankment

top level of the dam structure or the lowest part of the top of the embankment if, or in cases where, the upper surface undulates

3.5

critical value

value of a particular parameter, such as pore pressure or surface movement, defined in the design or by the operating rules and which should not be exceeded

3.6

decant

engineered structure designed to facilitate recycling of process water and, as appropriate, to discharge natural runoff

Note 1 to entry: This structure may comprise a tower, a floating/static pump or a gravity overflow system.

3.7

design criteria

parameters for the mine waste facility which define the structure and its subsequent operation

3.8

design flood

flood inflow to the reservoir which produces the maximum stillwater level the dam is required to accept under normal conditions with no damage and with a safety margin provided by the freeboard

3.9

emergency spillway

engineered structure designed to operate only during extreme events and to pass in safety flood surcharge water without endangering the stability of the confining embankment

3.10

extractive waste

see tailings

3.11

flood surcharge

maximum rise of stillwater level above reservoir top water level (or retention water level) during a flood event

3.12

freeboard

vertical height from the top of the dam to top water level (or retention water level)

3.13**hydraulic fill**

material placed in a liquid form in a deliberate manner as a mixture of soil particles and water so that the particles accumulate as a deposit, and densify as further fill is placed above to create a body of fill

3.14**hydraulic fill system**

reticulation and deposition pipework and infrastructure necessary to transport and to deposit the hydraulic fill

3.15**independent**

free from any personal interest and, in particular, from family and financial interests in the outcome of a related inspection

Note 1 to entry: Payment for inspection services is not to be considered an impairment to independence.

3.16**inspection**

act of checking and monitoring performance and compliance with criteria to indicate that identified objectives have been met and that critical values have not been exceeded

3.17**intrinsic parameters**

parameters that do not change in the course of earthworks, such as particle size distribution or plasticity

3.18**Long-term**

design or operating time scale generally measured in years

3.19**maximum reservoir level**

maximum safe level of the supernatant pond defined in the design and operating rules for the MWF

3.20**Mine Waste Facility****MWF**

engineered structure which, together with all necessary appurtenant works, is designed to retain or confine extractive waste in safety and to temporarily store and recycle, where necessary, process and flood waters

Note 1 to entry: These facilities are often known by the quarries/industrial minerals sector as “silt lagoons”, by the energy sector as “ash lagoons” and by the metal mining industry as “tailings management facilities”

3.21**mineral processing**

mechanical, physical, biological, thermal or chemical processes carried out on a mineral resource for the purpose of extracting the economic mineral, together with the re-processing of previously discarded waste but excluding smelting, thermal manufacturing processes (other than the burning of limestone) and metallurgical processes

3.22

monitoring

systematic surveillance of the mine waste facility, including all associated operations such as geochemical and geotechnical characterisation, physical measurements and instrumentation readings, together with their processing, analysis and interpretation

3.23

paste

highly-thickened hydraulic fill with solids content which exhibits high viscosity and minimal solids/water separation during placement

3.24

polymetallic

mineral source/ore which is the source of more than one metal suitable for recovery

3.25

Probable Maximum Flood

PMF

flood hydrograph resulting from the PMP and, where applicable, snow-melt, coupled with the worst flood-producing catchment conditions which can be realistically expected in the prevailing meteorological conditions

3.26

Probable Maximum Precipitation

PMP

theoretical greatest depth of precipitation meteorologically possible for a given duration

3.27

regulatory inspection

act of checking and promoting compliance with relevant legislation (e.g. local, national or international regulations or permit conditions) and/or monitoring impacts to determine whether further action is required to secure such compliance (e.g. with safety, stability or environmental provisions)

Note 1 to entry: Regulatory inspections may be carried out by any public authority which is designated responsible, or may be delegated under its authority and supervision to independent experts acting on its behalf.

3.28

reservoir flood routing

passage of a flood volume through a reservoir

3.29

return period

average expected probability of occurrence of floods equal to or greater than a stated magnitude

3.30

return water dam

optional additional water storage facility designed to facilitate recirculation or discharge of excess process and meteoric waters from the MWF

3.31

reservoir

see supernatant pond

3.32**risk assessment**

overall process of risk identification, risk analysis and risk evaluation, including the identification of all potential hazards and the risk of their occurrence

3.33**risk management**

engineering design, operation and closure to achieve the agreed level of risk mitigation

3.34**risk mitigation**

process of reducing risk and consequence through risk management procedures in order to reduce the probability of occurrence and/or negative outcomes to an acceptable rate of death, injury or damage

3.35**safety check flood**

flood inflow to the reservoir which produces the maximum stillwater level which the dam is required to accept and beyond which the safety of the dam cannot be assured

Note 1 to entry: Key components may exhibit only marginally safe performance for this flood condition.

3.36**short-term**

design or operating time scale generally measured in months

3.37**silt lagoon**

see Mine Waste Facility

3.38**solids concentration/content**

weight of solid material per unit weight of extractive waste in slurry form

3.39**spillway**

see emergency spillway

3.40**state parameter**

parameters that change during earthworks, such as density, water content or strength

3.41**stillwater level**

supernatant pond level in the absence of any wave effects

3.42**sub-aerial deposition**

deposition of hydraulic fill which takes place above water level to form a 'beach'

3.43**sub-aqueous deposition**

deposition of hydraulic fill which takes place below water level

3.44

supernatant pond

residual water volume retained on the surface of the MWF, comprising a combination of process and meteoric waters

3.45

tailings

extractive waste which remains after mineral processing by separation (e.g. crushing, grinding, size-sorting, flotation and other physico-chemical techniques) to remove the economic minerals from the less valuable rock

3.46

tailings dam

see confining embankment

3.47

Tailings Management Facility

TMF

see Mine Waste Facility

3.48

Tailings Storage Facility

TSF

see Mine Waste Facility

3.49

technical inspection

act of checking and promoting compliance with design criteria and critical values (e.g. geotechnical, corporate, managerial, safety, or environmental) and/or monitoring performance to determine whether further action is required to secure such compliance

Note 1 to entry: Technical inspections may be carried out by any suitably qualified “competent expert” who is designated responsible, or may be delegated under their authority and supervision to a suitably qualified person acting on their behalf.

3.50

top water level

lowest crest level of the emergency spillway

3.51

wave dam break

surge wave of water and solids released down valley by a dam which fails

3.52

wave overtopping

intermittent passage of water over the crest of the dam created by waves not contained by the available freeboard

4 Abbreviations

ABA	Acid Base Accounting
ARD	Acid Rock Drainage
CMP	Construction Management Plan
CQA	Construction Quality Assurance
EWD	Extractive Waste Directive (see also MWD)
ICOLD	International Commission on Large Dams
LOM	Life of Mine
MWD	Mine Waste Directive
MWF	Mine Waste Facility (see also TMF)
MWP	Mine Waste Plan
OMS	Operation, Maintenance and Surveillance
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
QMP	Quality Management Plan
TMF	Tailings Management Facility (see also MWF)
TSF	Tailings Storage Facility (see also MWF)
WMP	Waste Management Plan

5 Development of hydraulic placement projects

This Clause describes the derivation and sources of the hydraulic fill and the subsequent placement of such extractive wastes in surface MWFs as exemplified in the flow sheet Figure 4.

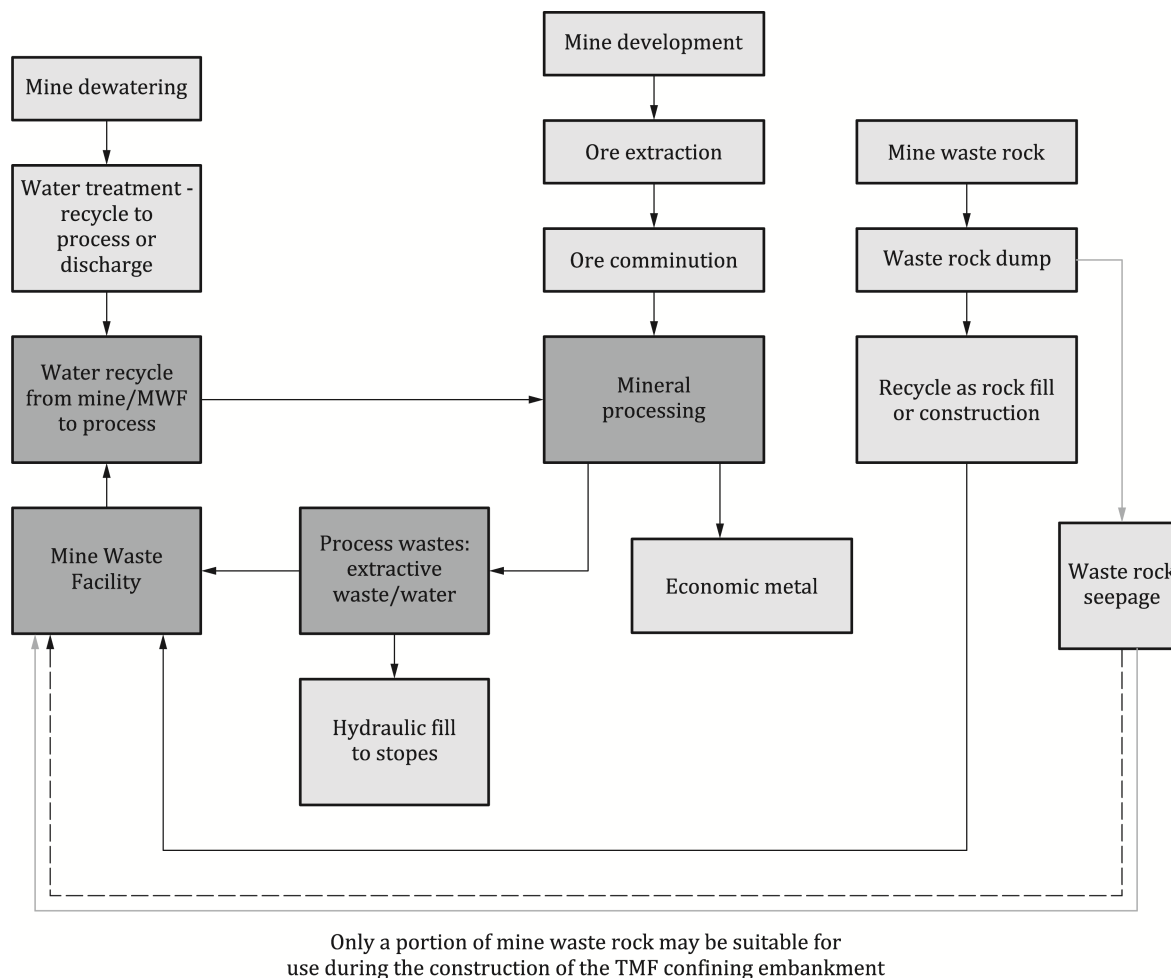


Figure 4 — Typical hydraulic fill flow sheet for a mining project

All sectors of the extractive industry are likely to produce a residue which, during mineral processing, will have been physically, and sometimes chemically, altered due to both the comminution and concentration processes employed. These residues (also designated as tailings) comprise fine grade extractive wastes which are generally discharged from the process plant in slurry form as a hydraulic fill. Such extractive wastes, regardless of their consistency and general characteristics, shall be placed in a secure containment facility unless they are to be immediately recycled. In most cases the resulting waste product would not be stable unless confined within an engineered impoundment area, i.e. a reservoir or lagoon developed behind a confining embankment. Mineral processing, transportation and placement of the fine-grained extractive waste generally involves significant volumes of water. This water, by virtue of its contact with the waste, constitutes an integral part of the hydraulic filling process. The efficiency and economics of the industrial process, environmental requirements and the site water balance will normally require that water, used to transport the fine-grained extractive waste, be recycled and reused in subsequent mineral processing. As a result, the MWF normally includes provision not only for containment of the hydraulically-transported fill but also for the effective sedimentation of the fine-graded waste and for the sedimentation (supernatant) water, which will be recirculated or recycled for the process.

The effective storage of the hydraulic fill, and the efficient recycling of the resulting water, requires the appropriate design, operation and management of the mineral processing and extractive waste storage system to achieve long-term (in perpetuity) safe and sustainable storage and geotechnical and geochemical stability. The options for transport from the mineral processing plant and for placement and deposition in a stable MWF are numerous, but the principal drivers are the long-term goal of safe, stable and efficient storage referred to above.

The MWF may vary in area from less than 10 000 m² to several square kilometres and in height from a few metres for an aggregate silt lagoon to over 100 m for a tailings management facility for a large and complex, e.g. polymetallic, mining operation. Typical sections through a tailings management facility and a silt lagoon are shown in Figures 1 and 2 and provide an indication of the key features of such MWFs. It is noted that, depending on the setting, not all of the features shown may be required.

The fine-grained extractive waste resulting from mineral processing is usually pumped or fed under gravity in slurry form from the mineral processing plant to the MWF. The consistency of the slurry will vary from project to project dependent on the geological origin of the ore, its geotechnical characteristics, the industrial processing, the configuration of the storage basin and the geographical setting. The slurry may take the form of a thin pulp with solids concentrations as low as 5 %, as for many silt lagoons, or be thickened to 70 % or 80 % solids and be deposited as a paste or thickened tailings hydraulic fill.

6 Mine Waste Facility Characterization

Under current European legislation (Directive 2006/21/EC), the Competent Authority classifies a MWF under Category A if:

- 1 failure or incorrect operation, e.g. the collapse of a heap or the bursting of a dam, could give rise to a major accident, on the basis of a risk assessment taking into account factors such as the present or future size, the location and the environmental impact of the waste facility; or
- 2 it contains waste classified as hazardous under Directive 91/689/EEC above a certain threshold; or
- 3 it contains substances or preparations classified as dangerous under Directives 67/548/EEC or 1999/45/EC above a certain threshold. 2006L0021 —EN —07.08.2009 — 001.001— 28

A MWF is classified as non-Category A if none of the above criteria are met.

The characterization of the extractive waste shall consider the parameters referred in 2 and 3, above.

7 Site and material characterization

7.1 General

Geotechnical and geochemical characterization of foundation materials, construction materials and extractive waste shall be carried out for all mine waste facilities. This Clause describes geotechnical and geochemical characterization, with an emphasis on the former, as geochemical characterization is covered in detail in other standards.

A geotechnical investigation shall be carried out for all new mine waste facilities, and prior to the expansion and modification of existing mine waste facilities. The geotechnical investigation shall collect, record, and interpret geotechnical information, including geology, geomorphology, seismicity, hydrology and history of the site.

The scope of the geotechnical investigation shall be such that adequate and sufficient information on ground conditions and availability of construction materials is obtained for design and construction. The scope shall take into account the nature and classification of the mine waste facility.

Geotechnical investigations shall meet the requirements outlined in EN 1997 (series) and EN 16907 (series).

NOTE 1 Mine waste facilities classified under Category A in accordance with Directive 2006/21/EC can be classified as Geotechnical Category 3, in accordance with EN 1997-1, when defining minimum requirements for the extent and content of a geotechnical investigation. Mine waste facilities not classified under Category A can also be classified as Geotechnical Category 3 unless there is sufficient evidence to indicate that the structure does not pose exceptional risk and there are no difficult ground or loading conditions.

Given the unacceptable risk of undermining the mine waste facility, the selected site should be investigated by condemnation drilling or by other means in order to assess the presence of a deposit of economic merit.

The extractive waste to be deposited in a mine waste facility shall be characterized in such a way as to allow the long-term physical and chemical stability of the structure to be assessed. Waste characterization shall cover all the following categories of information:

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

NOTE 2 This information is specified in Commission Decision 2009/360/EC.

The above information shall be included in a waste management plan for the mine waste facility.

In Directive 2006/21/EC, waste characterization for mine waste facilities classified under Category A shall be carried out at different stages of the project, starting at initial design and ending at closure (both active and passive). Waste characterization shall also be required whenever there is a change in the characteristics of the material deposited in a mine waste facility and the results shall be included in a revised waste management plan.

When characterizing waste, reference should be made to documents produced by CEN/TC 292, in particular EN 14899, EN 15875, CEN/TS 16229, CEN/TR 16363, CEN/TR 16365, CEN/TR 16376. Reference should also be made to available specialized literature, as indicated in the Bibliography.

7.2 Stages of the characterization process

The planning, design, construction, operation and closure of a mine waste facility shall be based on a detailed knowledge of the geotechnical and geochemical characteristics of the extractive waste to be deposited, of any construction materials used to build the confining structure, and of all foundation materials under the facility.

NOTE Although many mine waste facilities incorporate geosynthetics into their design, these materials are not considered in this document.

The physical and chemical characteristics of any geological materials incorporated into a mine waste facility influence their behaviour during operation and closure (both active and passive). The design choices in terms of disposal strategy and confinement technique shall be based on an appropriate assessment of the short- and long-term behaviour of these materials.

As a minimum, any characterization programme shall cover the following elements:

- foundation materials beneath the confining embankment and in the deposition area;
- construction materials, including any extractive waste to be incorporated into the confining embankment and associated structures;
- extractive waste to be deposited, confined, or stored.

The geotechnical and geochemical characterization process shall be undertaken during all stages of development of a mine waste facility. Stages of development of a mine waste facility are outlined in Annex B, Table B.1. Geotechnical characterization shall meet the requirements outlined in EN 1997 (series) and EN16907 (series).

The geotechnical and geochemical characterization process shall commence during the preliminary stages of the development of the project and should continue throughout the feasibility design, final (detailed) design, operation and closure (both active and passive). Characterization shall also be carried out during the post-closure stage in order to verify that the closure objectives of long-term geotechnical and geochemical stability have been met.

Materials shall be characterized as part of:

- the development of a new project;
- a regular programme of quality assurance for construction and deposition;
- active operation with the objective of addressing a specific problem;
- life of mine testing;
- the development or updating of a closure plan.

As a minimum, the following characterization campaigns shall be part of the development of any mine waste facility (reference should be made to the stages of development of a mine waste facility outlined in Annex B, Table B.1):

- Feasibility:
 - sampling and testing of geological materials in order to determine baseline parameters for both foundation and embankment design;
 - sampling and testing of extractive waste, if available from a pilot plant, in order to obtain initial design parameters;
- Pre-deposition (construction and commissioning):
 - sampling and testing of the foundation and confining embankment materials to confirm design assumptions;
 - sampling and testing for both the confining embankment and for the deposited extractive waste during the commissioning stage in order to confirm design assumptions;

- Operation:
 - ongoing sampling and testing of construction materials incorporated into the confining structure as part of the quality assurance programme;
 - sampling and testing of the deposited extractive waste in order to confirm design parameters and obtain parameters for the design of future embankment raises;
- Closure:
 - sampling and testing of cover and confining structure in order to confirm long-term stability;
 - sampling and testing of extractive waste in order to provide information on its future behaviour;
- Postclosure:
 - sampling and testing of all geomaterials included in the MWF for compliance purposes.

7.3 Geotechnical characterization

7.3.1 General

Geotechnical investigations shall be planned and conducted in such a way that the relevant physical, mechanical and hydraulic parameters of the foundation materials, construction materials and extractive waste are obtained and can be used as the basis for the design of a mine waste facility.

Geotechnical characterization should be carried out through a combination of sampling, laboratory testing and *in situ* testing, and should be undertaken in accordance with the requirements outlined in EN 1997 (series) and National Annexes, EN ISO 22475-1, EN 16907 (series), EN ISO 22476 (series), EN ISO 22282 (series), EN ISO 17892 (series), EN ISO 14688 (series), EN ISO 14689, and EN ISO 18674 (series).

7.3.2 Characterization of foundation and construction materials

A detailed geotechnical characterization shall be conducted once the final site of a mine waste facility has been selected from the evaluation of all potential sites. The geotechnical investigation shall be adequate to define the ground conditions and identify potential borrow areas for the construction of the confining embankment.

During the geotechnical investigation, samples should be collected for geotechnical and geochemical testing to an agreed plan. All investigation works should be undertaken by appropriately qualified personnel.

NOTE 1 Properly qualified personnel include a competent contractor supervised by a suitably qualified engineering geologist, geological engineer or geotechnical engineer familiar with ground investigation work.

NOTE 2 A minimum of two geotechnical investigation campaigns are generally undertaken during the development of a new mine waste facility: initially at the feasibility study stage and thereafter during the final (detailed) design stage, as shown in Annex B, Table B.1. Additional ground investigation campaigns may be required during operation for future embankment raises as well as during the closure works.

7.3.3 Characterization of extractive waste

As a minimum, detailed characterization of extractive waste shall be undertaken during the following phases:

- pre-operational - by means of laboratory testing of pilot and pre-operational (commissioning) samples;
- deposition - by means of *in situ* testing within the facility, fully supported by further laboratory testing of field samples.

Both the intrinsic and state parameters of the extractive waste should be determined as part of the geotechnical characterization process. Laboratory and field tests available for ground investigation work will yield the majority of properties of the extractive waste. Additional laboratory tests used to characterize extractive waste are described in Annex A.

7.3.4 Sampling and *in situ* testing

7.3.4.1 Foundation and construction materials

Sampling and *in situ* testing of foundation and construction materials for geotechnical characterization shall be carried out as part of a geotechnical investigation and shall be in accordance with EN 1997 (series), EN ISO 22475-1 and EN 16907 (series).

7.3.4.2 Extractive waste

Sampling, laboratory testing, and *in situ* testing of extractive waste shall be an ongoing process throughout the life of a mine waste facility.

Adequate laboratory testing of representative samples and *in situ* testing of deposited material shall be carried out during each design and construction stage in order to define the following:

- physical characteristics of the extractive waste prior to deposition, including settling and rheological properties;
- engineering characteristics of the deposited solids with regard to storage volume and stability;
- potential for the extractive waste to interact with the local environment.

Extractive waste from comminution and metallurgical pilot plants should be tested during the initial (pre-deposition) stage of the project, noting that the physical characteristics of this material may differ significantly from those derived from the full-scale operation of the process plant. Results from samples obtained from a pre-deposition pilot plant should therefore be considered as a guide and treated with caution.

Geotechnical characterization of deposited extractive waste should be carried out on the basis of laboratory and *in situ* tests. During the deposition phase, sampling and *in situ* testing should be used to confirm initial design parameters, in particular *in situ* density, state (void ratio, stress conditions, fabric) and consolidation characteristics, as well as effective stress and permeability. The extractive waste should be tested as a slurry at the outlet from the process plant and as a consolidated solid from the deposit.

NOTE 1 As an alternative to sampling, *in situ* density can be estimated on the basis of laboratory testing, together with a record of mass and volume of material deposited.

The assessment of the potential for brittle response during monotonic undrained loading (static liquefaction) as well as during dynamic loading (cyclic stress-induced liquefaction) should be based on laboratory and *in situ* tests.

The assessment of liquefaction resistance, the potential for flow liquefaction and post-liquefaction strength is highly complex and should only be carried out by relevant experts.

NOTE 2 Although several investigation methods are currently in use, the cone penetration test in conjunction with pore pressure probes (CPTU) is a widely-used *in situ* testing method for the characterization of the state of deposited extractive waste and the potential for liquefaction.

When sampling from the process plant outlet (end-of-pipe sampling) a strict protocol should be followed in order to ensure that the material collected is truly representative of the ore being processed and of the process system. Sampling during start-up, end of shift, or during changes in extraction operation should be avoided, as such material can yield misleading laboratory test results.

When sampling extractive waste from the deposit for laboratory testing the material may be obtained from both sub-aerial and sub-aqueous deposits. Given the depositional characteristics of the extractive waste, sampling within a deposit can be challenging, particularly as a result of density variations, high void ratios, high sensitivity, material segregation and anisotropy. In some circumstances it might be possible to employ conventional sampling techniques but in most instances the use of specialized methods will be required to minimize the effect of sample disturbance.

The sampling programme for the deposited material should recognize that the geotechnical properties of the waste will be influenced by the processes applied to the slurry as well as by the hydraulic transport and placement system and by the environment. All phases of the extractive waste should therefore be considered. Sampling of the process water for use in subsequent laboratory test work is recommended.

The hydraulic deposition of waste within a deposit can result in significant horizontal and vertical variation in grain size distribution, with the associated changes in physical and mechanical properties. Care should be exercised when planning the siting of sampling points in order to obtain representative materials, noting that reliance on random distribution or on a perimeter location for samples should be avoided.

Consideration should be given to the proper retrieval, packaging, storage and transport of all extractive waste samples in order to avoid deterioration prior to testing.

When it is not possible to obtain undisturbed samples from a depository, material will need to be tested in a reconstituted state in the laboratory. The testing protocol should recognize the influence of fabric in material behaviour.

7.3.5 Laboratory testing

Laboratory testing of representative samples shall be employed to gain a detailed understanding of the properties of the extractive waste to be stored, the foundation materials and the construction materials to be incorporated into the mine waste facility.

Tests presented in EN ISO 17892 (series) shall be used in conjunction with tests listed in EN 16907-2 to characterize foundation and fill materials.

Laboratory tests should be used to determine the following properties of extractive waste:

- Particle size distribution;
- Water content;
- Degree of saturation;
- Mineralogy;
- Plasticity;
- Particle specific gravity;

- Void ratio and porosity;
- Compaction characteristics;
- Permeability (horizontal and vertical);
- Compressibility;
- Consolidation;
- Shear strength;
- Potential for liquefaction: brittle response during monotonic undrained loading (static liquefaction) as well as during dynamic loading (cyclic stress-induced liquefaction);
- Rheology.

Not all properties will need to be determined for all mine waste facilities. Selection of appropriate parameters should be made according to project requirements.

NOTE Some of the geotechnical properties of the extractive waste which determine the design criteria and performance of a mine waste facility cannot be measured using standard test methods. Annex A includes detailed descriptions of, and procedural methods for, a number of tests not included in EN ISO 17892 (series) or mentioned in EN 16907-2:

- Percentage solids content test;
- Particle settling velocity test;
- Undrained settling test;
- Drained settling test;
- Air-drying test;
- Slurry (minimum density) consolidation test.

7.4 Geochemical characterization

7.4.1 General

The expected short- and long-term chemical characteristics of the extractive waste and construction materials shall be described, with particular emphasis on stability under atmospheric/meteorological conditions.

A geochemical characterization campaign for extractive waste shall provide information on whether:

- the waste contains material classified as hazardous;
- the waste contains any dangerous substances;
- the waste has potential for acid generation and, if so, how it would be realized;
- there are any significant metal leachability issues.

The potential for acid generation and issues related to metal leachability shall also be assessed for all construction materials.

Reference shall be made to existing documents on waste characterization produced by CEN/TC 292 when assessing all of the above, including EN 14899, EN 15875, CEN/TS 16229, CEN/TR 16363, CEN/TR 16365, CEN/TR 16376. Reference should also be made to available specialized literature, as indicated in the Bibliography.

The methodology to be followed when characterizing extractive waste is shown in Figure 5. The process should start with an initial review of background data and of relevant literature in order to define the general characteristics of the waste and determine the number of samples required. If the project has developed a block model for the deposit, this should be used for sample selection. This should be followed by a detailed geochemical characterization programme, which should include an assessment of whether the waste is inert. If the material is inert, there will be no impact on the environment; therefore only physical considerations are important for disposal. For non-inert materials, the programme should continue with screening and static testing, followed by mineralogical characterization, chemical analysis, short-term leachability and kinetic testing, as required.

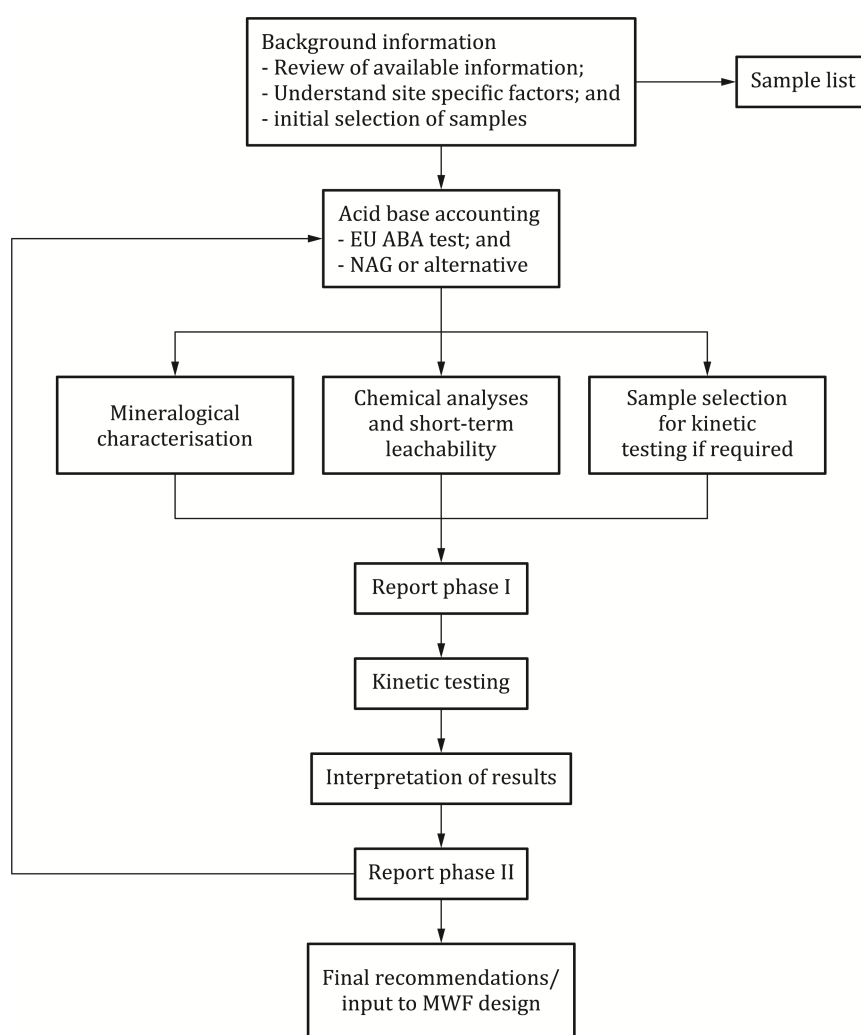


Figure 5 — Methodology for the geochemical characterization of extractive waste

7.4.2 Acid Rock Drainage

A key issue associated with the storage of extractive waste is that of Acid Rock Drainage (ARD), which is developed when reactive sulfide minerals present in the waste oxidize and where there is insufficient neutralizing capacity, leading to acidic drainage derived from both runoff and infiltration/subsurface flow. The presence of ARD in a mine waste facility may result in important structural changes in the confining embankment and in the long term release of potential pollutants. The problem should therefore be addressed at source and its effect mitigated during design and operation stages.

Any geochemical characterization for ARD shall have the following objectives:

- prevention or reduction of harm associated with waste production by considering changes due to increases in the surface area of potentially oxidising minerals and exposure to conditions above ground;
- description of expected short- and long-term physical and chemical characteristics of the waste, with emphasis on stability under surface atmospheric and meteorological conditions;
- prevention of deterioration of water quality by the evaluation of drainage potential and characteristics.

To be effective, a characterization programme should consider the properties of the extractive waste as well as any possible future physical and chemical changes which might affect its behaviour during the operational and post-closure stages of a mine waste facility. The programme should be iterative and consider all information available, including variability of ore deposits and variations in drainage rates associated with the origin and composition of constituent minerals. It should also consider potential future changes in ore processing.

7.4.3 Sampling

7.4.3.1 General

Sampling for geochemical characterization shall follow the guidance provided in EN 14899, CEN/TR 15310 (series) and CEN/TR 16365.

Guidance included in the Global Acid Rock Drainage (GARD) guide, developed by the International Network for Acid Prevention (INAP), as well as in other documents prepared by various organizations and programmes, should also be taken into consideration. A list of geochemical organizations and programmes is presented in the Bibliography.

7.4.3.2 Sampling during pre-deposition phase

On new projects, samples of extractive waste for geochemical characterization should be obtained from a pilot plant and should include both the solution phase of the slurry as well as any water used during processing. The number of samples to be tested should be dependent on the expected variability of the material and be representative of the material to be deposited in the mine waste facility.

It should be recognized that extractive waste generated in a pilot plant may not be fully representative of that to be generated during full-scale plant operation. Therefore test data derived during the early stages of a project should be treated with caution in the design.

It is also noted that hydraulic transport, deposition and sedimentation may result in particle sorting and therefore samples may need to be divided into coarse and fine fractions to ensure that their behaviour is fully characterized.

Both the foundation geology of the mine waste facility, together with all materials to be used for construction, should be subject to geochemical assessment in the laboratory in order to determine suitability for incorporation into the confining embankment or appurtenant structures.

7.4.3.3 Sampling during the operational phase

During the operational phase of a mine waste facility, further testing for geochemical characterization of extractive waste and construction materials should be undertaken both for confirmation of the design parameters as well as for compliance purposes. Sampling during this phase should be undertaken in accordance with an appropriate protocol. Sampling should also take account of the properties of the deposited extractive waste and any spatial variation within the depository. The sampling plan should make suitable provision for safe access and be subject to regular review by relevant experts.

7.4.3.4 Sampling during the closure phase

The sampling strategy for this phase should consider the following:

- initial design of the facility;
- variability of the deposit over the life of the project;
- climate;
- operational development of the facility;
- closure strategy.

7.4.4 Laboratory testing

7.4.4.1 General

The laboratory testing programme for all extractive waste, construction materials and foundation materials shall be properly planned and documented.

The preparation of testing schedules should include a review of all geological information and of the process flow sheet, together with an assessment to ensure that representative samples are selected for the testing programme.

Key testing phases shall include:

- static testing;
- mineralogical characterization;
- chemical composition and short-term leaching;
- kinetic testing.

7.4.4.2 Static testing

Static testing has been developed to determine the acid generation potential and assesses the sulfide content of a sample and its neutralization potential. Material is classified as potentially acid-generating, as lying in a zone of uncertainty or as being unlikely to generate ARD. When material is classified as potentially acid-generating or uncertain, kinetic testing should be undertaken in order to confirm whether the material will generate ARD and, if so, with what intensity.

The most common static testing procedures include the following:

- EN 15875;
- Sobek Acid Base Accounting (ABA);
- Modified Acid Base Accounting (ABA);
- Net Acid Generation (NAG).

ABA tests should be accompanied by parallel short-term leaching tests and chemical analyses in order to complement the mineralogical data.

7.4.4.3 Mineralogical characterization

Mineralogical assessment enables identification of the type of minerals present, their degree of liberation and whether they are capable of maintaining a neutral pH. Mineralogical characterization is essential in interpreting results from screening (static tests) and kinetic tests. The two main methods available are the Reitveld quantitative X-ray diffraction and QUEMSCAN. The limitations of each test should be understood when interpreting results.

7.4.4.4 Chemical composition and short-term leaching

Short-term leachability tests, combined with evaluation of chemical composition, should be used to determine the mobility of the constituent metals when the extractive waste is exposed to leaching agents capable of simulating acid or alkaline environments, as well as to assess whether there could be a release of certain elements of environmental concern in concentrations above safe limits. These test methods may also be used to classify material as either hazardous or non-hazardous.

Evaluation of metals, oxyanions and salt leachability over time should be carried out by means of one or more of the following methods:

- pH-dependence leaching test;
- percolation test;
- time-dependent release test;
- other suitable tests.

Recommended tests to determine short-term leachability are presented in CEN/TR 16376. However, additional methods are included in CEN/TS 14429, CEN/TS 14997, and EN 12457 (series) (see Bibliography for full reference).

The chemical composition of extractive waste should be determined in order to provide context to the results obtained from short-term leaching tests. The two most popular testing methods are the whole rock analysis using X-ray Fluorescence (XRF) and the instrumental methods using a type of digestion and Inductively Coupled Plasma (ICP) and Mass Spectrometry (MS).

The solubility of the different elements present in the extractive waste should be interpreted following the recommendations included in CEN/TR 16376.

7.4.4.5 Kinetic testing

Kinetic testing should be used to determine whether material will generate net acidity at any point in time. This type of test provides primary rates of acid generation, neutralization and metal release, which are used to determine whether acid-generating sulfides or alkalinity-generating minerals are likely to be exhausted first, in addition to determining whether the alkalinity-generating minerals are capable of sustaining a neutral pH.

Kinetic testing can be carried out in the field and in the laboratory, although laboratory testing is generally preferred due to the difficulties associated with field testing. In the laboratory, two main types of apparatus are used to perform the test, namely humidity cells and columns. Kinetic tests are expensive and should be carefully designed and performed as they generally need to be undertaken for more than a year. In addition, only experienced professionals should interpret results.

The execution and interpretation of kinetic testing should follow the recommendations included in CEN/TR 16376 and CEN/TR 16363.

8 Extractive Waste Management Plan

A Waste Management Plan (WMP) shall be prepared for all MWFs. This shall demonstrate the minimization, treatment, recovery and disposal of extractive waste, taking into account the principle of sustainable development.

The WMP shall include:

- the design and construction of any confining embankment;
- the extractive waste deposition plan;
- the planned rate of rise of the depository and associated confining embankments;
- the optimum transport and disposal arrangements;
- the operation and management system;
- safe operating criteria.

Directive 2006/21/EC contains the requirements for a WMP.

Any amendments to the WMP should be notified to the Competent Authority.

9 Mine Waste Facility design, construction, operation and closure

9.1 Design objectives

The primary design objective shall be to ensure both short- and long-term safe disposal of the extractive waste. The purpose of a MWF shall therefore be twofold:

- to provide a cost-effective and environmentally appropriate means of storing the waste and of recycling the process water;
- to provide safe and stable storage of the waste such that at closure the mine facility achieves long-term geotechnical and geochemical stability.

The objectives shall apply throughout the design, operation and closure of the MWF (see Annex C, Table C.1) and shall ultimately ensure the following:

- minimal post-closure intervention;
- prevention or minimization of any long-term negative effects arising from the migration of airborne or aquatic pollutants;
- long-term geotechnical and geochemical stability of the MWF.

A MWF shall therefore include the following provisions:

- safety – design and construction to meet both short- and long-term geotechnical and geochemical stability requirements;
- economy and sustainability – use of extractive waste, where appropriate, for confining embankment construction;
- water management – maximization of water recycle and re-use whilst managing flood events in safety;
- mine facility management – operation, technical inspection and monitoring in accordance with good practice and with statutory requirements;
- environmental management – control and monitoring of all potential emissions against compliance targets;
- closure – design of the MWF at end of mine life, as currently foreseen, to achieve a sustainable landform which minimizes long-term liabilities and impacts.

9.2 Site selection

9.2.1 General

The MWF shall be suitably located, taking particular account of the following factors:

- community or national obligations relating to protected areas;
- climate;
- geology;
- hydrology;
- hydrogeology;
- seismicity.