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Mine closure and reclamation planning —

Part 2: **Guidance**

Planification de la fermeture et de la restauration des mines — Partie 2: Recommandations

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents shall be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2(see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 82, *Mining*, Subcommittee SC 7, *Mine closure and reclamation management*.

A list of all parts in the ISO 21785 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

This document provides guidance for mine closure and reclamation planning applicable to both new and operating mines. The overarching objective is to promote consistency and quality in planning for mine closure and reclamation internationally. ISO 21795-1 provides requirements for the same material.

The intended audience are those with responsibility for, or an interest in, planning for mine closure and reclamation. This includes mine planners and designers, mine operators, regulators, environmental assessors, communities, indigenous peoples, and financial stakeholders, amongst others.

Mine planning, design and operations must be fully integrated with the closure and reclamation process. Early, continual and comprehensive mine closure and reclamation planning is essential for all new and operating mines because it:

— leads to the highest degree of environmental and social success, usually at a lower cost than if mine closure and reclamation planning is not done from the beginning of the mining project;

— reduces risks and liabilities throughout the mine's operational life and on closure;

— allows for stakeholder involvement throughout, so that relevant knowledge and understanding are brought into the planning process;

— allows for devoting more attention to sustainable development activities identifying socio-economic opportunities for the various closure phases;

— helps build trust with governments, stakeholders and international communities;

— provides additional planning time to understand the complexity of the biophysical characteristics and socio-economic context of each mine site;

— provides for continual improvement and updating of closure and reclamation plans;

— allows companies to better integrate closure and reclamation activities with operations;

— provides time to identify, research and develop new technologies for mine closure strategies and mine closure treatments that increase robustness and resilience of mine closure and reclamation; and

— allows companies to better provision for and schedule closure and reclamation funding.

There are many leading practices and guidance documents related to mine closure and reclamation planning available in various jurisdictions and used by many mining companies and stakeholders. This document captures the intent of such guidance documents so that it can be applied globally.

Mine closure and reclamation planning —

Part 2:
Guidance

1 Scope

This document provides guidance related to the necessary mine closure and reclamation planning activities for new and operating mines. Recommendations are provided on:

— closure and reclamation of a mine site;

— land reclamation and water management;

— stakeholder engagement;

— decision and analysis tools.

The following aspects of closure and reclamation are not addressed in this document:

— infrastructure such as rail lines, ports, off-site ore loaders, power stations, etc. that are associated with the mine operation, but which are not located at the mine site;

— detailed survey, testing or monitoring methods, detailed engineering procedures, detailed product requirements, or detailed construction and operational procedures; occupational health and safety management related to closure and reclamation, construction and exploration activities;

— relinquishment of a closed and reclaimed mine site, or portions thereof, to a party (governmental or private entity) not related to the mine operator;

— specific requirements for dealing with the radiological aspects of mine closure and reclamation, such as those that occur at uranium mining and processing facilities and other mines at which naturally occurring radioactive materials are present; however, the other aspects associated with closure and reclamation of these mines are included in this document; and

— closure and reclamation of abandoned mines.

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.

ISO 20305, *Mine closure and reclamation — Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 20305 apply.

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

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

4 Closure and reclamation of a mine site

4.1 General

During the mine closure and reclamation planning and design process, a significant amount of knowledge from a range of internal and external sources, including government agencies, consultants, indigenous peoples and other landowners/users, downstream water users, as well as from field investigations, laboratory testing and field trials and research, is collected. This data collection process should be initiated early in the mine life cycle in order to produce a more comprehensive and precise database. The collected data should be summarized in reports, maps and electronic information in a form that can be used in geographical information systems (GIS) and, if necessary, be provided to stakeholders. Digitizing and geo-referencing old maps found in various archives should be avoided or undertaken with care, since their quality can be quite poor.

4.2 Tailings storage facilities

4.2.1 General

Tailings storage facilities (TSFs) are frequently amongst the largest and most complex facilities to close and reclaim. Since they also frequently involve the long-term storage of millions of tonnes of potentially liquefiable finely ground materials and large water volumes, they can represent the highest risks at a closed mine site; a catastrophic failure of the containment dam can lead to loss of human life and extensive, irreversible environmental damage. The structures retaining the tailings are typically engineered dams that rely on sound foundations and internal drainage systems to remain stable; they therefore require sophisticated long-term care programs, including professional engineering oversight monitoring, inspections, and maintenance.

The design criteria, such as the geotechnical criteria for confirming dam stability (e.g. the design earthquake) and the hydrological criteria (e.g. inflow design flood volumes and peaks flows) at a TSF can require to be augmented at closure. This is because the closure period is much longer than the operating period, and more stringent design criteria with lower frequencies of occurrence are needed to reduce the annual probabilities of failure to a reasonable value for the long-term closure period. This can require the installation of additional engineering measures, such as dam support buttresses and larger spillways.

Tailings can also be filtered to remove excess moisture, and the resultant tailings waste can be stored in a compacted pile, referred to as a dry stack. Dry stack tailings are typically unsaturated and have sufficient strength to be placed in compacted layers without a containment dam. In some cases, they can contain enough moisture to render them liquefiable, which requires some form of containment. Dry stacks typically require less intensive post-closure and reclamation care and professional oversight, monitoring and inspections than tailings dams. Since dry stacks are susceptible to water and wind erosion, they can require long-term maintenance.

In some regulatory jurisdictions, TSFs that contain water or liquefiable tailings are classified as dams and require sophisticated long-term care programs, including professional engineering oversight monitoring, inspections and maintenance as discussed above. Dry stacks on the other hand, can be classified as waste piles, and similar to waste rock dumps discussed in 4.4, require less care and maintenance than a TSF.

Subclauses 4.2.2 to 4.2.7 apply to TSFs. Generally, these are also applicable to dry stacks. Were these requirements differ from those for dry stacks, these differences are noted. Furthermore, many of the approaches described in 4.5, for heap leach facilities, also apply to dry stacks.

4.2.2 Objectives

Specific long-term objectives for the closure and reclamation of a TSF include:

— the closed TSF should be non-polluting;

— tailings disposal structures should remain physically stable with regards to both overall stability of the major structures and erosion resistance;

— long-term maintenance requirements should be minimized; and

— suitable design criteria should provide for an acceptably low risk over the long-term.

4.2.3 Approach

Subclauses 4.2.4 to 4.2.7 describe the following actions that should be undertaken for the preparation of closure and reclamation plans and designs for a TSF:

— assessment of the status and condition of the TSF (4.2.4);

— risk assessment of the TSF (4.2.5);

— closure and reclamation alternatives analyses (4.2.6); and

— closure and reclamation plan (4.2.7).

4.2.4 Status and condition assessment

The status and condition of the TSF should be known in order to complete an effective closure and reclamation design. During the mine planning phases, the TSF may not exist, in which case its design can serve as a basis for closure and reclamation planning and design. During operations and prior to the implementation of closure and reclamation, the condition and status of the TSF should be determined.

Information required to determine the TSF status and condition includes the following:

— TSF site climate, geology, hydrology and hydrogeology;

— design drawings and specifications or "as-built" details, drawings and construction quality assurance/quality control (QA/QC) results;

— predicted and actual physical and geochemical characteristics of the tailings, where:

  — physical characteristics include the particle shape (e.g. granular or fibrous), particle size distribution and the moisture content, and

  — chemical characteristics include the mineral types, the presence of minerals that react with air and water to release soluble contaminants, and residual reagents, amongst potentially others factors;

— predicted and actual water balance of the TSF; and

— for existing TSFs:

  — reports on the geotechnical inspections and dam safety reviews,

  — reports by the engineer of record (EOR) and any other peer reviewers,

  — surface water and groundwater monitoring data to assess the extent, if any, of leakage that occurred from the facility, and

  — information on any progressive reclamation performed.

If the TSF contains tailings with sulphide or other reactive minerals that have the potential to cause water quality impacts other than suspended sediment issues, then the following additional information should also be assembled:

— predictions and measurement of pore water, pond water and seepage quality from the active TSF;

— acid base accounting, based on laboratory testing; and

— humidity cell and/or field scale barrel testing.

This testing and information should provide data on both the quality and quantity of water that infiltrates through the waste, and the quality of runoff that passes over the waste.

As part of the status assessment, the long-term performance of the embankment construction materials and the performance of any internal drains should also be assessed. Embankment construction materials subject to accelerated weathering and degradation can result in reduced strength over the long-term, potentially requiring reinforcement of the embankment, such as a downstream buttress fill. Oxidation of iron or chemical reactions by other constituents in embankment seepage can cause blockages of key drain systems in the embankment, which are intended to prevent the build-up of water pressures that can cause embankment failures. While this is not expected during the operations phase, these issues should be addressed during closure and reclamation, by installing additional drains and/or constructing a buttress below the toe of the embankment to increase its stability under higher water pressures in the downstream shell.

In some instances, e.g. where the groundwater table rises due to seepage from the TSF, the foundation materials have the potential to impart dissolved salts or metals to groundwater under the embankment. Where this occurs (e.g. TSFs constructed on desert salt flats), the water quality impacts of these formations should be assessed using testing of foundation samples during mine planning, as well as by groundwater and seepage monitoring during operations.

These requirements are generally applicable to a dry stack. In the case of a dry stack, the requirements stated above for the tailings generally apply to the stack. Furthermore, dry stacks are closed as piles and not as water retaining structures.

4.2.5 Risk assessment

A formal risk assessment of the mine closure and reclamation plan (or completed closure and reclamation) for the TSF should be completed when the closure and reclamation is first prepared and, as necessary, each time it is updated, and for the completed mine closure and reclamation. This assessment should identify potential failure modes and consequences. Examples of where an updated risk assessment is required include where the embankment height exceeds the original design, where habitations have moved closer to the embankment and where the tailings properties are different to those originally anticipated, among others.

A closure and reclamation dam breach assessment should be considered both to determine the closure consequence classification and as input to the emergency response plan for the TSF. Dam breach assessments, including flood extent (inundation) maps, should be conducted for all TSFs that will store water or contain liquefiable tailings in the long-term. Appropriate international guidelines are available for conducting dam breach assessments. Based on the results of these assessments, an appropriate emergency and preparedness and response plan should be prepared and implemented.

4.2.6 Closure and reclamation alternatives analyses

During the initial mine closure and reclamation planning process, a wide range of closure alternatives should be considered and screened down to a shortlist of more viable alternatives. These alternatives should then be subjected to a more detailed comparative analysis, followed by the selection of a preferred alternative.

The initial closure alternatives that should be considered include:

— in-place closure options, such as:

  — a drained-down facility with a cover and surface water diversions around the TSF; different cover types can be considered including soil, vegetated soil, rock and gravel, store and release to reduce infiltration, and layered impermeable to eliminate infiltration, and

    — a "wet" facility containing a water cover over the tailings and spillway, often considered for reactive tailings;

— relocation options, such as:

    — relocation of some or all tailings into a mined-out pit or pits, and

    — relocation of all or some of the tailings into a new facility; this is usually not a viable candidate during initial planning but should be considered where an operating TSF fails and is not readily repairable;

— filtered and slurry tailings options, which are typically considered during the initial planning stages, in accordance with the principle of early and integrated mine closure and reclamation planning closure.

Later updates of the mine closure and reclamation plan usually should not require the identification and analysis of alternatives, unless the previously selected plan is determined to be no longer feasible. This can include, for example, where physical or chemical characteristics of the tailings are significantly different from those originally predicted, or where mine plan changes require a significantly smaller or larger TSF. If a previously selected plan is determined to be no longer feasible, a limited number of alternatives should be considered in conjunction with updating the mine closure and reclamation plan.

For dry stacks the list of closure alternatives is shorter and typically includes:

— in-place closure options, such as:

    — closure based on the as-place topography,

    — regarding to flatten slopes, and

    — different cover types;

— relocation options, such as:

    — relocation of some or all the tailings into a mined-out pit or pits, and

    — re-use of some or all of the tailings.

4.2.7 Closure and reclamation plan

The TSF closure and reclamation plan should generally include the following:

— general description of the TSF, deposition plans and history (where available), construction techniques used and operational processes;

— description of the general status of the structure and its contained tailings;

— current landform and its relationship to the final storage geometry, as well as to the closure and reclamation design;

— current survey plan of the facility (showing past and future staged earthworks);

— condition of embankment used to contain the tailings, including an assessment of the impacts on stability of long-term weathering of the fill materials, as well as the performance of any drains needed to limit water pressures in the embankment;

— overall long-term water balance of the facility;

— considerations of climate change and the necessary design adjustments;

— general water management plans including, as necessary, seepage collection and management, surface water management, the design of treatments to manage seepage and to dispose of any water treatment residuals;

- long-term flood management strategies, as well as the strategy for containment or deposition of rainfall from the design flood event;
- sources and properties of materials that should be used as part of the decommissioning, closure and reclamation cover, and rehabilitation process;
- proposed surface drainage works, including civil engineering design, construction and ongoing maintenance needs;
- consideration and risk management of extreme events (e.g. drought, flood, fire, earthquake) during post-closure and reclamation;
- overall closure and reclamation strategy for the TSF landform, addressing factors such as retention or drainage of incident rainfall, cover types required, and revegetation of covered or uncovered tailings;
- surface treatment to minimize erosion (via rock cover and/or vegetation), sustain vegetation and support proposed rehabilitation design and stabilization works; and monitoring and audit requirements for closure and post-closure.

4.3 Water storage facilities

4.3.1 General

Water storage facilities (WSFs) can either be decommissioned on closure or retained over the long-term to provide for future water supplies, water treatment systems, recreation or aquatic ecosystems – or a combination of these. The structures retaining water are typically engineered dams that rely on sound foundations and internal drainage systems to remain stable. If retained, these structures require a sophisticated long-term care program including professional engineering oversight, monitoring, inspections, and maintenance programs. They also can represent risks at a closed mine site and a catastrophic failure of the containment dam can lead to loss of human life and environmental damage.

The design criteria, such as the geotechnical criteria for confirming dam stability (e.g. the design earthquake) and the hydrological criteria (e.g. inflow design flood volumes and peaks flows) at a water storage embankment can require to be augmented at closure. This is because the closure period is typically much longer than the operating period, and more stringent design criteria with lower frequencies of occurrence are needed to reduce the annual probabilities of failure to a reasonable value for the long-term closure period. This can require the installation of additional engineering measures, such as dam support buttresses and larger spillways.

4.3.2 Objectives

Specific long-term objectives for WSFs are determined by the mine closure and reclamation objectives, and include:

- the water retaining structure should remain stable in the long-term;
- the long-term water quality regime should be consistent with the mine closure and reclamation objectives and relevant regulations;
- sediment accumulation over the long-term should not impair the future intended use or safety and security of the facility;
- appropriate flood design criteria and adequate provision for water storage during drought conditions should be considered if appropriate;
- long-term maintenance requirements should be minimized; and
- suitable design criteria should be selected to provide for an acceptably low risk over the long-term.

4.3.3 Approach

Subclauses 4.3.4 to 4.3.7 list and describe the following actions that should be undertaken for the preparation of mine closure and reclamation plans and designs for a water storage facility:

— assessment of the status and condition of the storage facility (4.3.4);

— risk assessment of the facility (4.3.5);

— closure and reclamation alternatives analyses (4.3.6); and

— closure and reclamation plan (4.3.7).

4.3.4 Status and condition assessment

The status and condition of the water storage facility should be known in order to complete an effective closure and reclamation design. During the mine planning phases, the storage facility may not exist, in which case its initial design can serve as a basis for the closure and reclamation planning and design. During operations and prior to the implementation of closure and reclamation, the condition and status of the storage facility should be determined.

Information required to determine the facility condition and status includes, but is not limited to, the following:

— facility site climate, geology, hydrology and hydrogeology;

— design drawings and specifications, or “as-built” details, drawings and construction QA/QC results;

— predicted or measured water quality in the facility;

— predicted or actual water balance of the facility;

— for existing storage facility embankments:

  — reports on the geotechnical inspections and dam safety reviews,

  — reports by the EOR and any other peer reviewers, and

  — surface water (including seepage) and groundwater monitoring data to assess the extent, if any, of leakage that occurred from the facility.

If the water storage facility is predicted to experience, or has already experienced, significant sediment accumulation, the following additional information should be collected to determine facility condition and status:

— catchment conditions and projected long-term sediment yields, and

— estimates of the facility’s sediment trap efficiency and projections of long-term sediment accumulation, in addition to the corresponding reduction in effective water storage.

The long-term performance of the embankment construction materials and the performance of any internal drains should be assessed. Embankment construction materials subjected to premature weathering and degradation can result in a reduced strength over the long-term, and can require reinforcement of the embankment (e.g. downstream buttress fill).

4.3.5 Risk assessment

A formal risk assessment of the mine closure and reclamation plan (or completed closure and reclamation) for the water storage facility should be completed when the mine closure and reclamation is first prepared and, as necessary, each time it is updated. This assessment should identify potential failure modes and consequences. Examples of where an updated risk assessment is required include where the embankment height exceeds the original design or where habitations have moved closer to the embankment, among others.

Closure and reclamation dam breach assessments should be considered both to determine the closed embankment's risk classification and as an input to the emergency response plan for the facility. As part of this, a dam breach analyses should also be conducted. Appropriate international guidelines are available for conducting dam breach assessments. Based on results of these assessments, an appropriate emergency and preparedness and response plans is prepared and implemented.

4.3.6 Closure and reclamation alternatives analyses

During the initial mine closure and reclamation planning process, consideration should be given to a range of alternatives that include:

- decommissioning and removal by:
  - complete removal of the embankment, or
  - removal of the central portion of the embankment so water storage is no longer possible, and regrading and reclamation of the remaining embankment segments;
- re-engineering to provide a smaller and/or shallower storage facility; and
- retaining as-is and upgrading the engineering design to comply with the long-term design criteria.

Later updates of the mine closure and reclamation plan do not usually require the identification and analysis of alternatives, unless the previously selected plan is determined to no longer meet mine closure and reclamation objectives, which may have been changed. In this instance, some of the alternatives listed above should be considered.

4.3.7 Closure and reclamation plan

The WSF closure and reclamation plan should generally include the following:

- general description of the complete facility, deposition plans and history (where available), construction techniques used, and operational processes;
- description of the general status of the structure;
- current landform and its relationship to the final storage geometry, as well as to the closure and reclamation plan;
- current survey plan of the facility (showing past and future staged earthworks);
- for facilities that will continue to be used:
  - condition of the embankment used to contain the water, including an assessment of the impacts on stability of long-term weathering of the fill materials and the performance of any drains needed to limit water pressures in the embankment,
  - overall long-term water balance of the facility,
  - long-term flood management strategies, as well as the strategy for containment or deposition of rainfall from the design flood event,
  - proposed surface drainage works, including civil engineering design, construction and in consideration of risk, storm events, and ongoing maintenance needs,
  - consideration and risk management of extreme events (e.g. drought, flood, fire, earthquake) post-closure and reclamation, and

  - monitoring and audit requirements for the implementation, post-closure and reclamation phases;
- when removal of the storage dam is proposed:
  - demolition plans including removed materials disposal plans,
  - plans for the removal and disposal of mechanical facilities, pipelines, sediment accumulation, any liners,
  - design of restored flow channel, and
  - reclamation of the previous water storage area and dam footprint.

4.4 Waste rock dumps

4.4.1 General

Waste rock dumps (WRD) are frequently the largest mine facility to close and reclaim. Since they can involve the long-term storage of millions of tonnes of potentially acid generating rock, they can also represent a high risk at a closed mine site, where chronic acid and/or metal containing leachate can result in significant aquatic and/or surface soil/vegetation impacts in humid and wet climates. In arid areas, limited leachate will likely be formed, resulting in much lower risks to the environment. In some instances, the facility's internal drainage systems can require continued operation in order to maintain the stability of the facility; this can require long-term care, including monitoring, inspections, and maintenance programs.

It is also important to note that the design criteria, such as the geotechnical criteria for maintaining overall stability (e.g. the design earthquake) and the hydrologic criteria (e.g. design flood peak flows) for surface water diversion systems at a WRD can require to be augmented at closure. This is because the closure period is much longer than the operating period; more stringent design criteria with lower frequencies of occurrence are needed to reduce the annual probabilities of failure to a reasonable value for the long-term closure period. This can require additional engineering measures, such as slope flattening.

Other structures are often associated with a WRD and include leachate collection ponds and sumps, as well as runoff sediment control ponds and dams. Some of these facilities can be retained for a period after closure and reclamation. Closure of these facilities are similar to that for water storage facilities, discussed in 4.3.

4.4.2 Objectives

Specific long-term objectives for the closure and reclamation of a WRD include:

- the closed facility should be non-polluting;
- the waste rock pile should remain physically stable with regards to both overall stability and erosion resistance;
- long-term maintenance requirements should be minimized;
- the design criteria should include at least the 1 000-year return period earthquake; and
- post-closure and reclamation hydraulic structures, such as diversion facilities, should be sized to minimize requirements for long-term maintenance.

4.4.3 Approach

From the start of closure and reclamation planning, which begins during the initial mine planning phase and continues through to the end of mining, WRD closure and reclamation plans should be prepared to at least a pre-feasibility level (see 7.1). For the purposes of mine closure and reclamation implementation, construction designs should also be prepared.

Subclauses 4.4.4 to 4.4.7 describe the following actions that should be undertaken for the preparation of mine closure and reclamation plans and designs for a WRD:

— assessment of the status and condition of the WRD (4.4.4);

— risk assessment of the WRD (4.4.5);

— closure and reclamation alternatives analyses (4.4.6); and

— closure and reclamation plan (4.4.7).

4.4.4 Status and condition assessment

The status and condition of the WRD should be known in order to complete an effective mine closure and reclamation design. During the mine planning phases, the facility may not exist, in which case its design can serve as a basis for the mine closure and reclamation design. During operations and prior to the implementation of closure and reclamation, the condition and status of the WRD should be determined.

Information required to determine the WRD condition and status includes the following:

— the WRD site climate, geology, hydrology and hydrogeology;

— design drawings and specifications, or "as-built" details and drawings – particularly on the locations of specific types of rock and the extent that any low permeability cells may have been incorporated into the facility to limit water and oxygen infiltration;

— monitoring data of any seepage quantity and quality, over time;

— predicted or actual physical and geochemical characteristics of the waste rock;

— for existing waste rock dumps: surface water (including seepage) and groundwater monitoring data to assess the extent, if any, of seepage that occurred from the facility; and

— information on any progressive reclamation completed.

If the WRD contains tailings with sulphide or other reactive minerals that have the potential to cause water quality impacts or other leachable materials, other than suspended sediment issues, then the following additional information should also be assembled to determine WRD condition and status:

— static tests, e.g. acid base accounting based on laboratory test results;

— humidity cell and/or field scale barrel test results;

— kinetic tests, e.g. humidity cells, leach columns and/or field scale barrel test results; and

— field measurements and geochemical modelling to assess the long-term acid generation and metal leaching potential.

This testing and information can provide data on both the quality of water that infiltrates through the waste, as well as the quality of runoff that passes over the waste. Assessing the long-term geochemical behaviour is critical because the timing of the start of acid generation and when it reaches its peak rate are important to closure design, operations and monitoring. It is not unusual for acid generation to start after mine closure and increase over several years —even decades— following mine closure and reclamation. The projected future geochemical characteristics largely determine whether the WRD should be covered and what type of cover should be used, or whether other engineering measures are needed to limit the amount of infiltration through the WRD.

The long-term performance of the drain construction materials should be assessed where these drains continue collecting leachate during the post-closure phase. Oxidation of iron or chemical reactions by other constituents in embankment seepage can cause blockages of key drain systems in the rock pile; this can result in stability issues and/or leachate flows exiting at other locations on the face of the pile and not flowing to the sumps constructed to collect it. While this is not expected during the operations phase, these issues should be addressed during post-closure and reclamation, by installing additional drains.

4.4.5 Risk assessment

A formal risk assessment of the mine closure and reclamation plan (or completed closure and reclamation) for the WRD should be completed when the closure and reclamation is first prepared and, as necessary, each time it is updated. This assessment should identify potential failure modes and consequences. Examples of where an updated risk assessment is required include, but are not limited to, where the pile height exceeds the original design, where habitations have moved closer to the pile, and where the WRD properties are different to those originally anticipated.

4.4.6 Closure and reclamation alternatives analyses

During the initial mine closure and reclamation planning process, a range of closure alternatives should be considered and screened down to a shortlist of more viable alternatives. These alternatives should then be subjected to a more detailed comparative analysis, followed by selection of a preferred alternative.

The initial closure alternatives that should be considered typically include (all of these include closure in-place and/or reutilization as construction material):

- grading alternatives:
  - initial placement at an overall slope angle required for closure, and
  - slope flattening during progressive and final closure and reclamation;
- cover extent:
  - direct revegetation of WRD,
  - cover over flat surfaces or partial cover; with uncovered angle of repose slopes, and
  - complete cover;
- cover types:
  - soil or gravel,
  - store and release,
  - geomembrane and soil, and
  - combinations of the above;
- reuse of all or a portion of the material.

Later updates of the mine closure and reclamation plan usually should not require the identification and analysis of alternatives, unless the previously selected plan is determined to no longer be feasible. This can, for example, be due to physical or chemical characteristics of the WRD differing significantly from those originally predicted, or to mine plan changes requiring a significantly smaller or larger WRD. If a previously selected plan is determined to be no longer feasible, a limited number of alternatives should be considered in conjunction with updating the mine closure and reclamation plan.

4.4.7 Closure and reclamation plan

The mine closure and reclamation plan should generally include the following:

- general description of the complete facility, deposition plans and history (where available), construction techniques used, and operational processes;
- description of the general status of the WRD, including the material's physical and geochemical characteristics;
- current landform and its relationship to the final storage geometry, as well as to the mine closure and reclamation design;
- current survey plan of the facility (showing past and future staged earthworks);
- condition of waste rock fill, including an assessment of the impacts on stability of long-term weathering of the fill materials and the performance of any drains needed to limit water pressures in the WRD;
- consideration of climate change and the necessary design adjustments;
- general water management plans including, as necessary, leachate collection and management, surface water management, the design of the systems to manage leachate and to dispose of any water treatment residuals;
- long-term flood management for the design flood event;
- sources and properties of materials to be used as part of the decommissioning process, as well as the mine closure and reclamation cover and rehabilitation process;
- proposed surface drainage works, including civil engineering design, construction and ongoing maintenance needs;
- consideration and risk management of extreme events (e.g. drought, flood, fire, earthquake) during post-closure and reclamation;
- overall mine closure and reclamation strategy for the WRD landform, addressing factors such as cover types required, as well as revegetation of covered or uncovered WRD; and
- surface treatment to minimize erosion (via rock cover and/or vegetation), sustain vegetation and support proposed rehabilitation design and stabilization works; monitoring and audit requirements for the implementation, post-mine closure and reclamation phases.

4.5 Heap leach facilities

4.5.1 General

Heap leach facilities (HLFs) are large facilities that can require detoxification or rinsing before mine closure and reclamation – or long-term collection and treatment of effluent. Since they are often used for the long-term storage of large amounts of potentially acid-generating rock, which in humid/wet climates chronic acid and/or metal-containing leachate can result in significant environmental impacts, they represent a risk at a closed mine site. In arid areas only, limited leachate will likely form resulting in much lower risks to the environment. In some instances, the facility's internal drainage systems can require continued operation to maintain the stability of the pile; this can involve long-term care including monitoring, inspection, and maintenance programs.

The design criteria, such as the geotechnical criteria for maintaining pile stability (e.g. the design earthquake) and the hydrologic criteria (e.g. design flood peak flows) for surface water diversion systems at an HLF, may need to be augmented at the time of closure. This is because the closure period is much longer than the operating period and more stringent design criteria with lower frequencies of occurrence are needed to reduce the annual probabilities of failure to a reasonable value for the long-term closure period. This can require additional engineering measures, such as slope flattening or buttressing.

There are other structures associated with a spent ore HLF, including solution collection ditches and ponds. Some of these facilities may be retained for a period after closure and reclamation.

4.5.2 Objectives

Specific long-term objectives for the mine closure and reclamation of HLFs include:

— the closed facility should be non-polluting;

— the HLF should remain physically stable with regards to both overall stability and erosion resistance;

— long-term maintenance requirements should be minimized; and

— post-closure and reclamation hydraulic structures, such as diversion facilities, should be sized to minimize requirements for long-term maintenance.

4.5.3 Approach

From the start of mine closure and reclamation planning (which starts during the initial mine planning phase and continues through to the end of operations), HLF closure and reclamation plans should be prepared to at least a pre-feasibility level. For the purposes of mine closure and reclamation implementation, construction designs should also be prepared.

The following list and 4.5.4 to 4.5.7 identify what actions should be undertaken for the preparation of mine closure and reclamation plans and designs for a HLF:

— assessment of the status and condition of the HLF;

— risk assessment of the HLF;

— closure and reclamation alternatives analyses; and

— closure and reclamation plan.

4.5.4 Status and condition assessment

The status and condition of the HLF should be known, in order to complete an effective mine closure and reclamation design. During the mine planning phases, the HLF may not exist, and in that event its design can serve as a basis for the mine closure and reclamation design. During operations and prior to the implementation of closure and reclamation, the condition and status of the HLF should be determined using the following information:

— site climate, geology, hydrology and hydrogeology;

— "as-built" details, drawings and construction QA/QC results with emphasis on the liner systems under the stacked ore;

— surface water and groundwater monitoring data to assess the extent, if any, of leakage that occurred from the facility;

— information on any progressive reclamation completed; and

— any laboratory or field testing of the type of detoxification and rinsing required to generate a more benign leachate.

The physical and geochemical characteristics of the leached ore should be used as input to the mine closure and reclamation design planning and design. It is good practice to retain records of the ore types placed on each HLF during operations. If such information has not been collected and recorded during operations, then a waste characterisation study should be completed as part of the mine closure and reclamation design.

Information about the characteristics of the residue (i.e. leached ore) materials should include:

— particle size distributions;

— shear strength; and

— mineralogical information.

If the residue contains sulphides or other reactive minerals that have the potential to cause environmental impacts other than suspended sediment issues, then the following additional information should be collected:

— measurement of solution quality from the active leach pile, if available;

— static tests, e.g. acid base accounting based on laboratory test results; and

— humidity cell and/or field scale barrel testing.

This testing and information should provide data both on the quality and quantity of water that infiltrates through the waste, and on the quality of runoff that passes over the residue.

4.5.5 Risk assessment

A formal risk assessment of the mine closure and reclamation plan (or completed closure and reclamation) for the HLF should be completed when the mine closure and reclamation design is first prepared and, as necessary, each time it is updated. This assessment should identify potential failure modes and consequences. Examples of where an updated risk assessment is required include, but are not limited to, where the pile height exceeds the original design, where habitations have moved closer to the pile, and where the HLF properties are different to those originally anticipated.

4.5.6 Closure and reclamation alternatives analyses

During the initial mine closure and reclamation planning process, a range of closure alternatives should be considered and screened down to a shortlist of more viable alternatives. These alternatives should then be subjected to more detailed comparative analyses, followed by selection of a preferred alternative.

The initial closure alternatives that should be considered typically include, but are not limited to, the following options (all of which include closure in-place and/or reutilization as construction material):

— grading alternatives:

  — initial placement at an overall slope angle required for closure, and

  — slope flattening during progressive and final closure and reclamation;

— cover extent:

  — direct revegetation of the rinsed ore, and

  — complete cover;

— cover types:

  — soil or gravel,

  — store and release,

  — geomembrane and soil, and

  - — combinations of the above;
- — reuse of all or a portion of the material.

Later updates of the mine closure and reclamation plan usually should not require the identification and analyses of alternatives, unless the previously selected plan is determined to no longer be feasible. This can, for example, be due to physical or chemical characteristics of the ore that are significantly different from those originally predicted, or to mine plan changes that require a significantly smaller or larger HLF. If a previously selected plan is determined to no longer be feasible, a limited number of alternatives should be considered in conjunction with updating the mine closure and reclamation plan.

4.5.7 Closure and reclamation plan

The initial stage in mine closure and reclamation planning should be the establishment of a plan to stabilize the quantity and chemistry of the leachate from the facility and to manage the residual leachate in the long-term.

Alternatives that can be considered in establishing this plan include, but are not limited to:

- — rinsing with “clean” or treated water;
- — addition of chemicals to the rinse solutions to treat for process reagents and metals;
- — recirculation and evaporation on the heap and/or in ponds to reduce the volume of solution contained in the heap;
- — drain down and pond evaporation or treatment of the solution; and
- — land application, evaporation or treatment of any long-term leachate generated by precipitation infiltration.

The mine closure and reclamation plan should generally include, but not be limited to, provisions for:

- — chemical stability of the HLF: the water quality of any seepage generated should not pose a threat to the receiving water quality (both surface water and groundwater). Measures that may be needed include (but are not limited to) low infiltration covers, segregation and clay encapsulation of the more geochemically active wastes, and water collection and treatment;
- — physical stability: surface and larger-scale slides and slumps, as well as erosional material losses, should be prevented. Measures that may be needed include (but are not limited to) slope flattening (best completed during the operations phase), buttress construction, surface grading to direct flows to erosion protected swales, and placement of erosion-resistant covers;
- — landform design approaches that can be implemented: successful application of landforming for visual reasons, erosion control, stability, and reclamation/revegetation; requires that the process be started during the design and operations phase of the project;
- — consideration of climate change and the necessary design adjustments;
- — surface water controls (including water collection and conveyance structures) that provide for transfer of surface water from one location to another. Natural erosion-resistant materials should be used in these structures to minimize long-term maintenance. Consideration can be given to using cementation products or components to stabilize channels;
- — leakage collection and/or groundwater capture and management plans, if necessary. The design of the systems to manage seepage and for the disposal of any water treatment residuals should also be provided as necessary. The existing solution ponds can be used to create bioreactors for leachate treatment;
- — covers (as needed) for dust control, vegetation establishment, reducing infiltration of precipitation moisture or multiples of these; refer to 5.6;

— establishment of vegetation as applicable; and

— monitoring plan, data analysis and reporting.

4.6 Open pits

4.6.1 General

During closure and reclamation, mine pits remain dry, or filled or partially filled with waste rock and/or surface water and groundwater, process or treated wastewater and may seep or overflow into the surrounding environment. Closure and reclamation requirements generally include providing for human safety and, for pits that fill as lakes, providing for surface water and groundwater quality protection.

4.6.2 Objectives

Closure and reclamation objectives that should be considered include, but are not limited to:

— protection of human safety;

— protection of receiving water quality;

— provision of suitable habitat; and

— pit stability.

4.6.3 Approach

The following list and 4.6.4 to 4.6.7 describe what actions should be undertaken for the preparation of mine closure and reclamation plans and designs for open pits:

— assessment of the status and condition of the pits by observing benching and wall stability (4.6.4);

— risk assessment of the pits (4.6.5);

— closure and reclamation alternatives analyses (4.6.6); and

— closure and reclamation plan (4.6.7).

4.6.4 Status and condition assessment

The general approach to developing a mine closure and reclamation plan of open pits involves the following steps:

— site climate, geology, hydrology and hydrogeology;

— determining to what extent the pit will flood with groundwater and surface water, and whether an "internal" or an "overflow" pit lake will be established in the long-term;

— assessing the pit wall stability to determine whether catastrophic failures are likely to occur;

— assessing what type of pit will result at closure and reclamation, either:

  — a dry pit,

  — a backfilled or partially backfilled pit,

  — an internal pit lake, or

  — an overflow pit lake; and

— evaluating the characteristics for the type of pit that is projected to occur.

When selecting the most appropriate mine closure and reclamation option, the following factors should be taken into consideration, but not be limited to:

— dimensions of the pit;

— characteristics of the pit walls and benches;

— access to the crest of the pit;

— nature of the rock, both physical and geochemical;

— faulting;

— rock slope stability;

— surrounding topography;

— availability of suitable backfill materials, including possible use of waste rock;

— surrounding land use;

— proximity to residential or recreational areas;

— disposition of waste rock extracted from the pit;

— surface water runoff into the pit; and

— water elevations and groundwater characteristics.

The following factors should be considered when designing for pit lake closure and reclamation:

— availability of open pits in the mining sequence;

— geochemical properties of the tailings and waste rock (if deposited in a pit) and pit walls (e.g. flooding of sulphide-bearing tailings at mine closure and reclamation can also flush and mobilize metals from the tailings);

— geotechnical properties of the tailings or waste rock (if deposited in a pit) and the pit walls (e.g. potential for seepage pathways through faults or fracture zones in the walls);

— predicted pore water, pit water, and surface water and groundwater quality;

— hydrology of the open pit (e.g. runoff may mobilize secondary reaction products such as acidity, sulphate and metals from the permanently exposed pit walls); and

— hydrogeology of the open pit (e.g. does the pit act as a regional groundwater discharge zone? Where does the regional groundwater flow?).

4.6.5 Risk assessment

A formal risk assessment of the mine closure and reclamation plan (or completed closure and reclamation) for the open pits should be completed when the mine closure and reclamation is first prepared and, as necessary, each time it is updated. This assessment should identify potential failure modes and consequences. Examples of where an updated risk assessment is required include, but are not limited to, where the pit size exceeds the original design and where the physical or geochemical properties of the rock walls are different to those originally anticipated.

4.6.6 Closure and reclamation alternatives analyses

During the initial mine closure and reclamation planning process, a range of closure alternatives should be considered and screened down to a shortlist of more viable alternatives. These alternatives should then be subjected to more detailed comparative analyses, followed by selection of a preferred alternative.

Alternatives include (but are not limited to):

- no further action after completion of mining;
- backfill with either waste rock or tailings or both;
- stabilize the pit walls and or remove highwall;
- manage the water quality;
- perform partial backfill with excavation of the pit rim to allow surface drainage;
- complete pit backfill and mine closure and reclamation as a dry surface;
- accelerate pit water filling to improve the pit lake water quality;
- manage chemoclines in pit lakes to prevent overturning;
- provide for the collection and discharge of un-impacted shallow water above the chemocline; and
- repurposing either a dry pit, or a pit lake for other uses.

Pit lakes can also be used to dispose of tailings and/or waste rock that are then submerged in water to prevent acid and metalliferous drainage and metal leaching. The required data, evaluations, and relevant pit closure and reclamation alternatives are discussed in 4.6.7 for each type of closed pit.

4.6.7 Closure and reclamation plan

4.6.7.1 General

General closure and reclamation designs for two types of pits are described in 4.6.7.2 and 4.6.7.3. Common to each of these closure and reclamation types is the removal of all mining equipment, infrastructure (pumps, pipes, etc.), fuels and lubricants from the pit. Any chemical or oil-related spill in the pit that can impact the water quality of a pit lake should also be removed or remediated. Climate change considerations should be included in the pit closure plans.

4.6.7.2 Dry pits

The overall approach for dealing with dry pits should include at a minimum the following actions:

- determine to what extent, if any, pit slopes should be reduced, or partial pit backfill should be placed, in order to:
  - enhance long-term stability to limit the likelihood of a catastrophic failure that poses health and safety risks,
  - limit the increased likelihood of a human health and safety risk posed by pit slopes that are steeper than the natural slopes in the general area surrounding the pit, and
  - determine means to make human and large-animal access to the pit crest as difficult as practicable in the long-term.

Alternatives for closure and reclamation include:

- pit slope stabilization by slope reduction, terracing or buttressing; and
- access restrictions by construction of a perimeter berm of coarse rock fill. Other measures such as earthen berms or fences can be considered but are not as durable and/or effective.

4.6.7.3 Pit lakes

The overall approach for dealing with pit lakes should include at a minimum the following actions:

- determine the overall water and chemical balance and assess the long-term equilibrium pit lake level;
- determine to what extent, if any, pit slopes should be reduced, or partial pit backfill should be placed, in order to enhance long-term stability;
- assess the long-term water quality of the pit lake considering the following:
  - for closed pit lakes, the major outflow of water from the pit lake is by evaporation and the constituent concentrations are expected to continue to increase and can reach saturation and chemical equilibrium values,
  - for overflow lakes, concentration increases will be limited and will depend upon the relative volumes of surface water and groundwater inflows versus water lost by evaporation,
  - in some instances, pits can naturally drain and act as a hydrogeologic sink, and
  - in many instances, pit lakes can stratify either permanently or seasonally; in cold climates, the lakes may overturn seasonally; limnologic studies should therefore be considered to assess the quality of the water that will be discharged;
- determine the impact of the pit lake water on local surface water and groundwater, in order to assess whether any pit lake seepage barriers (e.g. grout curtains) are required and the impact on surface waters from overflow pit lakes; and
- determine means to make human and large animal access to the pit crest, and avian access to the pit lake surface, as difficult as practicable.

Alternatives for closure and reclamation include, but are not limited to:

- pit slope stabilization by slope reduction, terracing or buttressing;
- access restriction by construction of a perimeter berm of coarse rock fill; other measures such as earthen berms and fences can be considered but are not as durable and/or effective;
- installation of seepage barriers or seepage collection systems;
- installation of devices to discourage avian access, in the event that water quality deteriorates significantly over time; and
- stratification enhancement by, for example, introducing sea water or water treatment reject brine.

Monitoring programs should be used to validate success of the implemented closure and reclamation alternative and should address (as necessary):

- slope stability (e.g. visual inspections, surveying and/or instrumenting);
- water filling rate (e.g. observed water levels);
- pit lake water quality sampling, vertical chemistry and temperature profiling, as necessary; and
- surface water and groundwater monitoring.

Monitoring should continue until both the pit walls have been demonstrated to be reasonably stable and the water quality has stabilized. In the case of pit lake closure and reclamation, the filling of the pit can take many decades. As a result, monitoring programs should extend beyond the period of filling, although the frequency of water quality monitoring during these extended periods can be reduced significantly.

4.7 Underground workings

4.7.1 General

During mine closure and reclamation, underground workings typically fill or partially fill with groundwater, which, in turn, flows out through existing mine adits. In some cases, the working can drain completely and act as a hydrogeologic sink. Closure and reclamation activities should focus on managing the exiting water quality, preventing future human or animal access to the workings, and dealing with any subsidence that can occur on the surface above the mine workings.

In some instances, the mine workings are partially backfilled with waste rock and/or paste tailings to support the mine openings during the operations. The presence of, and potential impacts from, these materials should be considered in mine closure and reclamation planning.

4.7.2 Objectives

Closure and reclamation objectives that should be considered include, but are not limited to:

— protection of human safety; and

— protection of receiving surface water and groundwater quality.

4.7.3 Approach

The following list and 4.7.4 to 4.7.7 describe what actions should be undertaken for the preparation of mine closure and reclamation plans and designs for underground workings:

— assessment of the status and condition of the underground workings (4.7.4);

— risk assessment of the underground workings (4.7.5);

— closure and reclamation alternatives analyses (4.7.6); and

— closure and reclamation plan (4.7.7).

4.7.4 Status and condition assessment

The following information should be obtained from the designs of the underground mines (during the initial mine planning phase) and from actual as-mined information (during operations):

— site climate, geology, hydrology and hydrogeology;

— the extent of the existing (or proposed) mine cavities from:

  — design information,

  — mining records,

  — archives analysis,

  — in-mine surveys, and

  — field investigations, including geophysical methods and exploratory drilling, amongst others;

— details of the mine workings, including:

  — depth of cavities,

  — size of cavities (height of opening, length and width of galleries, pillars and panels),

  — thickness and characteristics of the overburden,

— rock mass properties, including the type of rock, floor strength, pillars and main roof layers, minerology and sensitivity to water,

— geological and hydrological parameters, such as flat sedimentary layers or vertical vein deposits, long-term water table level after the dewatering process, and

— evidence of instability, such as pre-existing cave-in on surface subsidence or potential issues with rock stability noticed during underground visits.

4.7.5 Risk assessment

A formal risk assessment of the mine closure and reclamation plan (or completed closure and reclamation) for the underground mine should be completed when the mine closure and reclamation is first prepared and, as necessary, each time it is updated. This assessment should identify potential failure modes and consequences. Examples of where an updated risk assessment is required include, but are not limited to, where the extent of the underground workings exceeds the original design, and where the physical and geochemical properties of the rock are different to those originally anticipated.

4.7.6 Closure and reclamation alternatives analyses

During the initial mine closure and reclamation planning process, a range of closure alternatives should be considered and screened down to a shortlist of more viable alternatives. These alternatives should then be subjected to more detailed comparative analyses, followed by selection of a preferred alternative.

Alternatives include (but are not limited to):

— no further action after completion of mining;

— backfill openings to reduce subsidence concerns;

— plug the mine openings to prevent access and/or seepage from the underground workings;

— manage the water quality of the seepage by either in-situ treatment in the underground workings or ex-situ treatment in a chemical-physical plant or bioreactor;

— accelerate water filling to improve the underground water quality;

— manage chemoclines in the underground workings to prevent overturning; and

— provide for the collection and discharge of un-impacted shallow water above the chemocline.

Underground workings can also be used to dispose of tailings and/or waste rock, which can be submerged in water to prevent acid and metalliferous drainage and metal leaching. The required data, evaluations, and relevant pit mine closure and reclamation alternatives are discussed below for each type of closed underground workings.

4.7.7 Closure and reclamation plan

4.7.7.1 General

General mine closure and reclamation designs for underground mines are described in 4.7.7.2 to 4.7.7.5. These plans should include the initial removal of all mining equipment, infrastructure (pumps, pipes, etc.), fuels and lubricants from the underground workings. Any chemical or oil-related spill in the workings that can impact the adjacent surface water or groundwater quality should also be removed or remediated. Closure plans and designs should also consider the effects of climate change as necessary.

4.7.7.2 Physical stability

Depending on the context, the voids and surrounding rock mass stability can deteriorate notably over the long term. It is thus essential to define if subsidence effects can develop towards surface. If so, the magnitude and kinetics of the potential movements should be identified and the areas that can be affected should be precisely delineated.

One of the key objectives of an underground workings hazard assessment process (in the mine closure and reclamation context) should be to identify the potential nature of geo-mechanical hazards that can develop on the mine surface over both short and long terms. The analysis should be performed by an experienced mining expert who is capable of analysing the mining data collected.

Analyses should be conducted by an experienced mining and/or rock mechanics expert to identify the subsidence effects that can develop up to the surface. This should be done considering scenarios comparing various geological, physical and mining contexts. The most classical subsidence effects can be classified as follows:

— continuous subsidence or heave, characterised by slow, smooth and flexible readjustments of surface with the classical form of a “dish-shaped” feature;

— discontinuous subsidence that can take the form of sinkholes, characterised by the sudden appearance of a crater at surface (with a diameter ranging from a few metres to several tens of metres) or, in some specific contexts, can take the form of collapses of large areas of underground workings via discontinuous failure on surface in time and space; and

— some more specific phenomena, like induced seismicity, can also be considered in rock burst prone mines.

Continuous subsidence is a common and, often, harmless phenomenon at long-wall mine, for example. Sinkholes can also occur where residual mining voids persist. Major collapses are quite unusual in a mine closure and reclamation context because they require some very specific, unfavourable configurations. The types of subsidence, as well as the potential for sinkhole occurrences, should be evaluated.

The potential hazard areas should be mapped, in order to highlight areas most sensitive to the development of potential surface issues. The related maps can also be valuable tools for communicating with stakeholders and local land-use planning actors.

Based on the potential risks associated with the above mechanisms, and considering the overall mine closure and reclamation objectives, remedial measures should be established, if necessary. Alternative mine closure and reclamation measures for the physical stability of underground workings include:

— mine stabilization measures, including backfilling (from surface or underground, hydraulic or mechanised, with or without grouting), rock reinforcement (rock-bolting, shotcrete, masonry) or geosynthetics. Because of the high costs associated with these methods, they are normally reserved for high-risk areas and under densely populated areas;

— land-use management of surface, to avoid exposure of humans to surface subsidence and sinkhole risks. This can include avoiding/limiting new buildings and development or defining specific construction rules to reduce structure vulnerability. Land-use management measures should be largely shared with stakeholders and integrated with the local community’s development plans; and

— preventative evacuation and compensation in some very specific contexts, where existing structures are located above hazardous workings and the triggering of hazardous phenomenon is feared.

4.7.7.3 Chemical control

The overall approach for dealing with underground workings should include (at a minimum) the following actions:

— determine the overall water and chemical balance and assess the long-term equilibrium mine pool level and outflows, considering plugging of various adits if appropriate;

— assess the long-term water quality of mine pools, considering sources of constituents from the natural formations, mine waste deposited in the mine workings and the reactions of the water with the minerals in the mine void walls. Evaluate the extent to which the water that collects in the underground workings is stratified; and

— determine the impact of mine water pool on local surface water or groundwater, in order to assess whether any seepage barriers are required.

Alternative mine closure and reclamation measures for the chemical stability of underground workings include, but are not limited to:

— removal of any materials that are hazardous – or that can cause water quality impacts – from the underground workings;

— direct discharge of adit flow if it meets receiving water standards;

— active or passive treatment of the mine water followed by controlled discharge;

— in-situ mine water treatment followed by controlled discharge;

— plugging of adits to raise the mine water level to minimize outflow sufficiently for discharge or, in some cases, convert it to diffuse flow through fractures and fissures in the rock mass; and

— installation of internal plugs within the underground workings to prevent migration of poor-quality waters to surface.

Any plugs installed for water management should be designed for the associated hydraulic pressure behind them. Typically, concrete plugs should be considered, grouting should be performed around the plug to provide water tightness and, as necessary, valves and pipes can be provided through the plugs to provide for collections of water for treatment, pressure monitoring, water quality sampling, etc.

4.7.7.4 Access controls

Mine openings to surface that pose a risk to humans and large animals should be identified. These typically include, but are not limited to:

— open shafts;

— adit portals; and

— collapsed ground above shallow mine workings.

Consideration should be given to plugging these openings. Examples of plugging methods include (but are not limited to):

— concrete plugs or shelves (over shafts);

— gates or doors;

— walls constructed with concrete or durable materials; and

— backfill with soil or rock fill.

Timing the sealing of portals and shafts should be planned, so as not entomb animals (e.g. bats).

4.7.7.5 Monitoring

Monitoring programs should be used to validate the success of the implemented mine closure and reclamation alternatives and should address (as necessary):

— ground monitoring, to confirm a progressive evolution of surface displacement (continuous subsidence development) or to provide early warning signals of unexpected failure or collapse. Both direct measure techniques (e.g. extensometers, GPS levelling) and indirect measure techniques (e.g. aerial photogrammetry, InSAR techniques) should be considered. Micro seismic monitoring offers promising perspectives for large-scale, early warning signals detection. Definition of “alert thresholds” and “monitoring duration” require some careful analysis;

— water filling rate (e.g. observed water levels);

— mine pool water quality sampling and vertical chemistry and temperature profiling as necessary; and

— surface water monitoring and groundwater monitoring around the mined area.

4.8 Mine infrastructure

4.8.1 General

All surface mine infrastructure can be removed at closure and reclamation. The overall goal can be to remove visible signs of infrastructure unless it is required by another user. Contaminated areas should be cleaned and rehabilitated. All infrastructure areas should be reclaimed unless they are planned for an alternate use, according to the closure and reclamation plan.

4.8.2 Objectives

The objectives for the long-term closure and reclamation of site infrastructure include:

— remove or minimize any remaining human health and environmental risks;

— create a non-polluting landform that is consistent with the proposed land uses; and

— maximize repurposing of facilities that are considered assets, such as roads, buildings, industrial structures, power lines to the grid, etc.

4.8.3 Approach

The following list and 4.8.4 to 4.8.7 describe what actions should be undertaken for the preparation of a mine closure and reclamation plan:

— assess the status of the existing surface water, groundwater, soils and remaining infrastructure;

— perform a risk assessment to determine what can pose future long-term risks and assess what opportunities are available for repurposing the mine’s facilities for long-term economic benefit for and use by others;

— identify and analyse alternatives to closure and reclamation; and

— establish a long-term mine closure and reclamation plan.

4.8.4 Status and condition assessment

The status and condition of the site and the remaining infrastructure should be known, in order to complete an effective mine closure and reclamation design. During the mine planning phases, plans for the proposed infrastructure are available. During operations and prior to implementation of closure and reclamation, the condition and status of the infrastructure should be re-assessed. The soils, surface water and groundwater should also be investigated for potential impacts from reagent as well as chemical and fuel spills, in addition to other potential operations activities that can have impacted the site – such as tailings spills, reactive waste rock placement, etc.

Information required to complete the status assessment includes the following, but is not limited to:

— site climate, geology, hydrology and hydrogeology;

— design drawings of the site infrastructure;

— inventories of the buildings, plants, fuel and chemical storage facilities, mobile and fixed equipment and plant, etc.;

— information on potential contamination (from mineral processing and other industrial activities) within the industrial structures;

— soil, surface water and groundwater investigation data to assess the extent, if any, of contamination;

— identification of the remaining, non-mining wastes that require management at closure, including inert waste, waste that has the potential to impact water quality and hazardous wastes that require special handling; and

— any assessments of/insights into the condition of the infrastructure (such and roads and buildings) that are considered for repurposing.

4.8.5 Risk and opportunity assessment

Human health and environmental risk assessments can be performed to assess what risks are associated with contaminated soil, surface water, groundwater and any structures that are to be repurposed. Any remediation of contamination should be based on the results of the risk assessment and can also need to consider the requirements of local regulations. Management of remaining non-mining wastes can also be based on the assessed risks and can also need to consider local regulations.

An assessment of the potential opportunities associated with repurposing the mine facilities should also be performed. This should involve engagement to determine stakeholder interests, developing an inventory of the site facilities that can be developed/retained as future assets, and conducting socio-economic and marketing studies to identify likely future opportunities (e.g. industrial, commercial, agricultural, tourism, recreational, etc.).

4.8.6 Closure and reclamation alternatives analyses

During the initial mine closure and reclamation planning process, a range of closure alternatives should be considered and screened-down to a shortlist of more viable alternatives. These alternatives should then be subjected to more detailed comparative analyses, followed by the selection of a preferred alternative. Considerations should also be given to renewable energy generation opportunities at the site.

Alternatives for addressing contaminated surface water or groundwater can include, but are not limited to:

— natural attenuation and degradation where the contaminated groundwater poses a low risk and is not migrating to areas where it can pose a risk;

— extraction of non-aqueous phase liquids on groundwater – such as petroleum hydrocarbons – using wells or trenches;

— groundwater extraction and treatment for a period of time;

— installation of sub-surface groundwater flow barriers; and

— installation of surface water diversion and drainage systems.

It is important to note that on occasions, it may not be feasible to restore impacted groundwater to either baseline or usable standards. In such instances, controlling access to groundwater for use as supply (by either land-use restrictions, deed restrictions or other means) should be considered.

Alternatives for addressing contaminated soils can include, but are not limited to:

— natural attenuation for constituents, such as hydrocarbons and other volatile compounds;

— in-situ treatment of hydrocarbons and other volatile compounds by land-farming methods;

— cover with clean soils to a sufficient depth to prevent the identified risks;

— excavation, ex-situ treatment and replacement;

— excavation and placement in the WRD, the TSF, or a waste repository built for the long-term containment of soils; and

— excavation and offsite disposal in an appropriately licensed landfill.

Alternatives for addressing identified wastes can include, but are not limited to:

— excavation, ex-situ treatment and replacement;

— placement in an on-site repository constructed for long-term waste disposal; different waste types require different levels of engineering to provide for safe long-term containment;

— excavation and placement in the WRD, the TSF; and

— excavation and offsite disposal in an appropriately licensed or authorized landfill.

It is important to note that measures should also be introduced to protect any soil covers and on-site dedicated landfills that are provided for soil or waste storage. Controlling access to these areas (e.g. by physical access restrictions such as fences or rock fill berms, land-use/deed restrictions, or other means) should be considered.

Often, several alternatives can be applied to control risks, requiring that comparative alternatives analyses be performed and documented. In comparing alternatives, it is important to consider the extent to which the alternatives meet the mine closure and reclamation plan objectives. In some cases, the alternative should be submitted during the engagement process to obtain stakeholder input.

4.8.7 Closure and reclamation plan

4.8.7.1 General

A mine closure and reclamation plan should include the selected measures for managing contaminated surface water, groundwater, soils and any wastes that remain at closure. The activities described in 4.8.7.2 to 4.8.7.6 should be considered.

4.8.7.2 Lubricants, fuels, greases

Prior to removal/dismantling of equipment, fuels, greases and lubricants should be removed from equipment – including from transformers, mining equipment, generators and any other equipment. These compounds should be placed in secure and labelled containers. The containers should be removed off-site and taken to a designated facility for disposal/recycling/reuse. Records of handling should be kept.

4.8.7.3 Fuel tanks

Fuel tanks should be emptied. Remaining fuel should be taken off-site to a designated facility for recycling/reuse. Fuel tanks should be cleaned. Once cleaned, tanks should be dismantled and taken off-site for recycling/reuse. Records of handling should be kept.

4.8.7.4 Chemicals

All chemicals on-site should be sorted and labelled. They should be taken off-site to a designated facility for recycling/reuse or disposed of if recycling/reuse is not available options. Records of handling should be kept.

4.8.7.5 Buildings/equipment

All equipment, wiring, insulation, and other materials should be removed from buildings. These materials should be sorted for disposal. Incineration and landfilling can be used to dispose of some materials/waste. All metals should be sorted and taken off-site for recycling/reuse. Items that can be recycled/reused should be taken off-site to a designated facility.

Buildings should be dismantled, deconstructed or demolished. Materials should be assessed for contamination and potential re-use/recycling. Wood may be burned or allowed to decompose, which can be addressed in local regulations. Metal cladding, roofing and other similar materials should be sorted and taken off-site for recycling/reuse.

Concrete foundations should be cleaned, where contaminated, with water and/or chemicals as required. Foundations should be broken and removed off-site or buried with clean soil or non-acid generating rock. This can be covered in regulations.

Pipes, wires, poles and exterior lighting should be dismantled. Materials should be sorted for disposal, which can include landfilling, incineration or recycling/reuse, which can be covered in regulations. Some buried pipelines may not be removed.

4.8.7.6 Sediment ponds

Sediment ponds should be drained unless maintained for a longer period while landforms stabilize. Contaminated sediment should be taken to a designated land fill on-site or off-site. Liners should be breached to eliminate ponding or removed and placed in a designated landfill or off-site. Sediment pond areas should be backfilled and reclaimed.

4.9 Temporary closure

4.9.1 General

Temporary suspension occurs when mine production ceases for several months – even a year or more. A period of inactivity is considered to be longer than temporary suspension and can extend over several years. Both of these possibilities are referred to as a "temporary closure" phase. Final mine closure and reclamation plans are not typically suitable for temporary closure and are not desirable from an economic point of view.

4.9.2 Objectives

The objectives of temporary closure plans include, but are not limited to:

— provide for a reasonable economic solution for managing a mine site during periods when it is no longer economically viable to operate, or to provide time for major reconstitution actives and/or development of new ore reserves;

— allow for the restart of operations with minimum level of effort; and

— provide for protection of human health and the environment during the suspension period.

4.9.3 Status and condition assessment

For the temporary mine closure and reclamation of the mine site, sufficient information needs to be obtained to allow for effective plans to be established. This information is described in 4.2 to 4.8 for each relevant mine site feature and is not repeated here.

4.9.4 Risk and opportunity assessment

Existing risk assessments performed for the site can be utilized to determine the major risks that require management during the temporary closure period. A major risk that should be considered is the impact to the workforce – specifically, the ability of the mine operator to retain sufficient personnel to both manage the site during temporary closure and to re-mobilize personnel for the re-start of operations.

The potential opportunities associated with temporary closure of the mine should also be considered. These can be to maximize the use of the existing labour force to maintain the mine's facilities, maximizing progressive reclamation and using the personnel to construct improvements to certain facilities.

4.9.5 Closure and reclamation alternatives analyses

Typically, there are limited alternatives to be considered when establishing a temporary closure plan.

4.9.6 Closure and reclamation plan

Temporary suspension occurs when mine production ceases for several months or possibly a year or more. In these situations, the mine operator should consider the following minimum mine closure and reclamation measures in a temporary suspension plan:

— access to the site, all buildings and other structures should be restricted to authorized persons only;

— shafts, raises and stopes open to the surface should be secured;

— portals of adits and declines should be secured;

— other mine openings to surface that create a mine hazard should be stabilized and secured;

— surface and subsurface mine workings should be assessed by a qualified professional engineer to determine their stability; any surface areas disturbed or likely to be disturbed by such mine workings should be stabilized. If stabilization is not practicable, the surface areas should be protected against inadvertent access if such disturbance is likely to endanger the public or property;

— mechanical and hydraulic systems should be maintained in a no-load condition;

— essential electrical systems should be protected from inadvertent access and non-essential electrical systems should be de-energized;

— tailings, rock piles, overburden piles, stockpiles, landfill sites and other waste management sites/systems should either be monitored and maintained, or closed;

— petroleum products, chemicals and waste (including PCBs) should be removed, disposed of, isolated or otherwise managed on site;

— explosives should be disposed of or removed from the site;

— impoundment structures should be maintained in a stable and safe condition; and

— materials, or conditions created as a result of mining that produce/can produce acid and metalliferous drainage or metal leaching should be dealt with in accordance with an approved management plan.

The mine operator should inspect the site at least once every six months to confirm that all required rehabilitative measures are in place and performing as required. There can also be ongoing monitoring programmes to manage.

5 Land reclamation and water management

5.1 Landforms

5.1.1 General

Specific attention should be paid to the final shape of the mine site surface for closure and reclamation. The mining activities, progressive reclamation and the design for mine closure and reclamation all contribute to the landforming (also referred to as 'reshaping') process.

Landforms typically include slopes, plateaus and ridges resulting from large mine infrastructure such as waste rock dumps, overburden dumps, tailings storage facilities, heap leach facilities and sediment ponds. There can be design choices at the landform or landscape scale that are large enough to warrant a formal alternatives' analysis. Landform design for mine closure and reclamation planning should involve the mine operator, technical experts, and indigenous peoples and stakeholders to develop clearly defined end land-use goals.

5.1.2 Objectives

The overall objective of landform planning and design is to allow stability and meet the mine closure and reclamation objectives. The specific objectives are to:

— remove any significant safety hazards to humans and local fauna;

— remove the potential for negative environmental effects;

— minimize erosion potential;

— allow for access, as necessary;

— provide for a surface topography that blends in with the surrounding terrain, if possible; and

— support revegetation (as appropriate) to facilitate post-mining land use.

5.1.3 Approach

Landforms should be developed based on the surface shapes resulting from the mining activities; changes to this approach can be considered in order to meet the objectives described above. Specific mining facilities that should be considered for landforming include, amongst potentially others:

— open pits;

— overburden stockpiles;

— waste rock dumps;

— water dams and other impounding facilities;

— tailings storage facilities;

— heap leach facilities; and

— access roads.

The design of post-mining landforms should be integrated into the life of mine plan so that waste materials are deposited as close to final landform design as possible to prevent double handling of material and therefore reduce closure costs. Landforming includes, as required:

- pit slope flattening, partial or complete backfilling, as well as access prevention by perimeter berms or rock barriers;
- regrading of overburden stockpiles;
- regrading of WRD and tailings surfaces; and
- buttressing of embankments and dams that remain after closure.

Aspects that should be considered in landforming are as follows:

- constructability of each landform;
- environmental impacts that can occur during construction of the landform (e.g. the amount of additional acid and metalliferous drainage generated when WRD with acid and metalliferous drainage potential are graded);
- geotechnical stability;
- erosional stability;
- provision of a base for other mine closure and reclamation elements, such as covers on the WRD and tailings storage facilities;
- surface water runoff quantity, intensity and quality;
- rainfall runoff patterns;
- impact on groundwater levels (location of phreatic surface);
- borrow sources and availability; and
- long-term monitoring and maintenance requirements.

In some cases, field trials can be required as part of the design, permitting, or monitoring process and conducted at a small pilot or prototype scale.

5.1.4 Plan

The landform plans and designs should be incorporated into the overall mine closure and reclamation plans and designs. Updates to the landform designs are required with each update to the overall mine closure and reclamation plan.

5.2 Surface preparation

5.2.1 General

Surface preparation involves preparing the existing and regraded surfaces of the mine site during progressive reclamation and upon final closure and reclamation.

5.2.2 Objectives

In addition to meeting the overall mine closure and reclamation objectives, specific key objectives in preparing the mine site's surface for final reclamation can include, but are not limited to:

- providing protection from water or wind erosion;
- limiting precipitation infiltration to the extent necessary;

— providing for positive surface runoff drainage;

— providing protection from contact with the underlying waste materials;

— supporting vegetative growth if necessary; and

— meeting the closure and reclamation objectives and commitments.

In the event a vegetated cover is selected, considerations include, but are not limited to:

— providing seedbeds for revegetation;

— providing sufficient rooting depth of soil on tailings and waste rock dumps;

— reducing surface soil compaction;

— providing drainage to reduce the potential of surface erosion and soil cover loss;

— other objectives specific to local conditions or novel post-mining land uses;

— innovative post-mining uses, and;

— providing for passive revegetation.

5.2.3 Approach

Surface preparation should be undertaken for a range of surfaces including, but not limited to:

— regraded areas;

— regraded WRD surfaces;

— tailings surfaces that remain after closure and reclamation;

— soil and/or gravel covers placed on WRD and tailings surfaces; and

— access roads and other previously disturbed mine site surfaces requiring reclamation.

The approaches to surface preparation for vegetated covers to be considered include, but are not limited to:

— physical: physical preparation can include loosening the soils using mechanical means or placement of the top layers in an engineered cover with a minimum amount of compaction;

— biological: this includes adding biomass to the soils, such as decomposed organic matter from stockpiled vegetation from the site clearing, salvaged native topsoil, or composts or other suitable stabilized organic amendments;

— chemical: chemical preparation involves adding fertilisers and other chemicals (e.g. lime or gypsum) to modify, for example, nutrient poor soils; and

— natural processes: this involves allowing enough time for natural biological processes (i.e. the development of populations of bacteria, fungi, protozoa, nematodes, insects, arachnids, molluscs, worms and mammals) and active plant-rooting to condition the soil over a period of months to years.

Other important considerations for unvegetated covers include, but are not limited to:

— the extent to which the surface of the waste materials become cemented enough or have the particle size distribution adequate to provide for protection from erosion by water or wind;

— the practicality of adding cementing reagents during the final years of waste placement to provide for enough erosion protection;

— surface sloping by either waste placement or subsequent grading to limit runoff flow velocities and water erosion potential;

— extent to which consolidation settlement of the waste material occur after closure and affect the surface slopes;

— availability of suitable materials for cover construction; and

— the need for conduction cover test trail during the mine's operational phase.

For vegetated covers, the following are important considerations:

— suitable overburden should be used for reclamation purposes where there are limited soils for reclamation. These materials are often low in certain nutrients (e.g. nitrogen and phosphorus) and have poor structure for plant establishment. If available, appropriate organic amendments should be added to this material to improve its fertility and structure;

— mixing of materials of varying quality can result in more suitable reclamation material and increases the volume of soil reclamation materials available;

— the crushing and sieving of oversize suitable rock can be carried out where limited coarse material required for a capillary break for a store and release cover is available;

— suitable manufactured liners can be used over reactive mine wastes where there are insufficient natural materials to separate reclamation material from the effects of underlying reactive wastes;

— where soil reclamation material is limited, its use should be focused on areas where it can result in the greatest opportunity for successful revegetation to meet the end land-use objectives; and

— considerations should include soil depth suited to the revegetation type, in addition to factors such as precipitation, evaporation, seasonal temperatures, slope, aspect, and adjacent land use; and

— the need for conduction cover test trials during the mine's operational phase.

5.3 Vegetation establishment

5.3.1 General

Vegetation is generally established on closed mine facility surfaces; these types of surfaces can also occur during operations when an area is no longer required for mining (progressive reclamation). In such instances, the surfaces are often required to meet the mine closure and reclamation objectives, particularly erosion control. It is a cost-effective means of providing a stable and durable surface in the long-term. It is also resilient in that the vegetation can cover and stabilize areas damaged by wind or water erosion, or shallow slope failures.

In some instances, vegetation may not be required or possible.

5.3.2 Objectives

In addition to meeting the overall mine closure and reclamation objectives, the specific objectives of revegetation vary based on local conditions and reclamation goals. These objectives can include, but are not limited to:

— using species for enhancing biodiversity;

— supporting defined end land uses;

— restoring larger habitat elements (e.g. vegetation structure);

— restoring productive wildlife habitat and/or agricultural or forestry crops;

— contributing to water removal through evapotranspiration;

— reducing surface erosion;

— assimilating carbon;

— enhancing visual aesthetics;

— providing phytoremediation; and

— other objectives specific to local conditions.

5.3.3 Approach

The basic approach to vegetation establishment during mine closure and reclamation involves:

— evaluating site-specific conditions for revegetation;

— selecting vegetation species and mixes to meet the end land-use objectives;

— avoiding weed contaminated seed mixes;

— selecting the approaches to revegetation;

— identifying risks associated with revegetation and developing corresponding mitigation and contingency measures; and

— preparing the revegetation plan.

These topics are discussed further in 5.3.4 to 5.3.7.

5.3.4 Evaluating site conditions for revegetation:

Site conditions should be evaluated to determine the potential for revegetation, including, but not limited to:

— climate (precipitation and temperature amounts and variability);

— climate change potential and impacts;

— effective rooting depth and water holding capacity: coarse textured soils require more depth than finer textured soils to provide sufficient water storage capacity for plant growth;

— soil compaction;

— soil texture, fertility, and pH;

— soil organic matter content and soil structure;

— salts and sodicity;

— quality of plant material;

— timing of seeding vs. climate;

— slope and aspect;

— microbial populations of topsoil or substitute;

— adjacent vegetation; and

— wind speed, direction and fetch.

5.3.5 Selection of revegetation approaches

The following aspects should be considered, but not be limited to, when selecting revegetation techniques:

— short-term site stabilization needs along with long-term post-closure and reclamation land-use considerations;

— specific species in targeted areas;

— enhancement of primary successional processes;

— use of fast-growing pioneer species for initial stabilization along with longer-lived species that are compatible with final post-closure and reclamation land use;

— initial establishment of vegetation should not compete strongly with final intended longer-term species;

— establishment and maintenance of a diverse plant community similar to the native vegetation or the intended agricultural or forestry systems;

— establishment and maintenance of legume species in mixed herbaceous communities to ensure long-term availability;

— minimization of the use of herbaceous grass and competitive legume species in association with forest plantings – except where grasses are a natural part of the local ecosystems; and

— establishment of pioneering species naturally or via seeds, cuttings or nursery stock.

The following considerations and recommendations apply to sourcing vegetation materials:

— use inspected/certified seed sources;

— limit the introduction of non-native;

— use of native species with local provenance, where possible and applicable;

— use species suitable to local climatic conditions;

— carry out seed collection during appropriate times of the year from pre-mine sites, non-disturbed areas in mine area, and adjacent areas;

— carry out cold stratification or heat/smoke treatment for adequate germination of collected seed where necessary; and

— before transplanting to the mine site, consider the required timing for collection, greenhouse and nursery protocols, media/container selection, use of irrigation, and seedling development for propagation.

Establishment and revegetation procedures that should be considered include, but are not limited to:

— seedbed preparation vs. rough grading considerations;

— time of seeding;

— broadcast seeding;

— drilling;

— hydraulic seeding and mulching;

— aerial seeding;

— hand planting of individual seedlings (e.g. trees and shrubs);

- direct haul and placement of litter and/or soil layers with associated seedbank;
- enhancement of seed from adjacent vegetated areas;
- tree shelters and tubes;
- use of coarse woody debris or rocks for sun and wind protection;
- use of mulches (e.g. organic and textile/fabric/geomats);
- weed control (mechanical and chemical);
- irrigation and timing; and
- soil stabilizers.

5.3.6 Revegetation plan

A revegetation plan should be prepared in accordance with 5.3.5 that describes the following:

- temporary and permanent revegetation objectives;
- types of vegetation to be established in the various parts of the mine site;
- site preparation and mulching/amendment requirements;
- seedbed preparation;
- monitoring and maintenance plan; and
- specifications, application rates and timing for the various vegetation species mixtures with a linkage to completion or success criteria.

5.3.7 Monitoring and adaptive management

Monitoring protocols should be consistent with local regulatory requirements with a link to completion or success criteria. This includes:

- assessment of ground cover, diversity, and vegetative structure on a regular schedule, which can be done annually in the first several years and less frequently once the vegetation is established;
- habitat assessments in addition to direct vegetation measures; this can include the identification of scat and browsing patterns, counts, and nesting; and
- identification of invasive species issues and/or excessive competition of early successional species on desired final community composition, annually, for the first several years.

Adaptive management can include:

- tillage;
- weed control;
- controlled fires;
- over-seeding;
- seed alternative species;
- temporary irrigation;
- reseeding of poorly established areas; and
- temporary fencing.

5.4 Water management

5.4.1 General

Water management is an important aspect of mine closure and reclamation and should be included in mine closure and reclamation planning, design and implementation to address the following:

— characterization of pre-mining surface water and groundwater quality and quantity to establish the baseline conditions prior to commencing operations;

— planned or existing operational water management system design and operation;

— planned water management for the mine closure and reclamation implementation, for adaptive management and for post-closure and reclamation phases; this helps meeting mine closure and reclamation objectives and water quality goals; and

— post-closure and reclamation surface water and groundwater quality and quantity monitoring to demonstrate successful water management.

5.4.2 Objectives

The objectives of water management are to meet the mine closure and reclamation water quality goals in both groundwater and surface water. These objectives can include, but are not limited to:

— water exiting the site in consideration of local or international jurisdictional requirements;

— the water management system should be able to handle extreme precipitation, runoff, or drought events;

— the combination of the storage facilities and water treatment flowrate should be designed to handle required design flood events;

— the site should have a negligible impact on surface water, the groundwater and local aquifers; and

— long-term maintenance requirements should be minimised.

5.4.3 Approach

Mine closure water and constituent mass balance analyses should be used as a basis for establishing suitable water management plans. The water and chemical balance of the entire mine, both during operations and for the post-closure and reclamation phase, should be quantified to establish effective water management plans. The balance analyses should include key chemical constituents such as major ions and metals. Computerized balance models should be established, calibrated based on past performance at the mine site, and have the ability to both simulate water quantity and quality on a monthly (or smaller increment) basis, as well as simulate the effects during both dry and wet conditions with durations of up to a year or more.

Site closure water balances should be used to:

— evaluate strategies for optimum use of limited water supplies;

— establish procedures for limiting site discharge and complying with discharge requirements, particularly control of the quality of the water and the quantity of contaminants discharged from the site;

— control erosion due to flow over exposed surfaces or in channels, swales, and creeks;

— estimate the demands on water treatment plants, holding ponds, evaporation ponds, or wetlands;

— consider water management under average and extreme dry and wet periods; and

— estimate the post-closure and reclamation water quality and quantity.

Water balance modelling and planning should be conducted for the following five phases of mining:

— phase 1: initial mine design and construction;

— phase 2: mine operations;

— phase 3: closure and reclamation implementation;

— phase 4: adaptive management phase; and

— phase 5: post-closure and reclamation operations and maintenance.

Phase 1 provides input into the mine closure and reclamation planning process and mine site facilities by implementing the "design for closure and reclamation" concept. Phase 2, the mine operations phase, informs the parameters necessary to build an accurate water and chemical balance model. Water management can vary between the last three phases and variations in each of these phases should be evaluated.

The following key aspects should be followed in setting up, refining, and using a water and chemical balance model:

— the model should be effective, robust, calibrated, easily updated and adjustable; it should simulate the complex relationships that occur at the mine;

— a water quality and quantity monitoring program should be put in place to regularly test the model's accuracy and update it as necessary;

— the model should incorporate, or be easily adapted to incorporate, the range of water management procedures at the mine, such as water collection, storage, treatment, evaporation, process water consumption, water releases, etc.;

— the model should be able to project future conditions for several decades, subject to varying climatic conditions; and

— in some instances, the model should be peer-reviewed and stakeholders should confirm that the model is appropriate for their purposes.

The following are typical data needs for a water and chemical balance model:

— climatic data, to quantify precipitation, snow depths and melt patterns, evaporation, evapotranspiration, wind, and solar radiation;

— surface water data, including local stream flow, surface runoff patterns and quantities, and water quality;

— groundwater flow patterns and rates, including seeps to surface, inflows to open pits and underground mines, and groundwater quality; these flows should be measured and predicted using groundwater modelling;

— facilities' layouts (including their change over time), including as necessary, processing areas, ore and waste storage areas, TSFs, including estimates and/or measurements of the surface flows and infiltration amounts from these;

— water quality data for the water flow paths being modelled. Emphasis should be placed on parameters such as heavy metals, cyanide, total dissolved solids (TDS), sulphate (SO_4), chloride (Cl) and other parameters that can affect the regional biodiversity, particularly acute and chronic toxicity;

— laboratory or field scale test data from leaching tests, for example;

— performance of any water treatment processes being used; i.e. removal of the constituents being modelled;

— attenuation factors for certain key constituents that experience geochemical reactions; should be calculated for the available data or expected chemical performance, or laboratory testing; and

— in some instances, chemical equilibrium modelling can be helpful in assessing likely constituent concentrations (e.g. in pit lakes).

5.4.4 Water management plan

Having an effective water and chemical mass balance model for the various phases of mining allows suitable water management plans to be established. For closure and reclamation, water balance management plans should be established during the initial mine closure and reclamation planning phase, then routinely updated as more information from the operations becomes available.

A basic premise of mine closure and reclamation water management is that it is more cost effective, environmentally protective and sustainable to prevent and/or control water entering the mine site than it is to treat the water – both temporarily or over the long term. The premises of good water management include:

— “keep clean water clean” by maximizing the diversion of natural surface water and groundwater that has not come into contact with any mine facilities or wastewater (“non-contact water”) around the mine site thereby minimizing the amount of water that has been impacted by mining (“contact water”) that requires management;

— minimize the generation of contact water; suggestions for this include (but are not limited to) appropriately managing WRD and tailings to reduce infiltration, as well as placing covers to prevent impacts to surface waters;

— place oxygen-reactive WRD and tailings underwater; and

— maximize the recycling of contact water through the process facilities during operations.

In establishing a closure and reclamation water management plan, consideration should be given to the following options:

— surface water diversion ditches to prevent non-contact runoff from entering the mine site;

— flooding of open pit and underground mine workings;

— selective placement of more reactive WRD and tailings within the disposal facilities to minimize the generation of impacted leachate;

— covering of WRD and tailings facilities to reduce information and prevent impacts to surface water runoff;

— closure and reclamation of tailings (and potentially WRD) under a water cover created by an impoundment or a flooded pit, if feasible;

— physical conditioning of tailings, as practical, to reduce the amount of pore water that is released (e.g. by thickening or filtration);

— chemical conditioning of tailings as they are placed in the tailings’ management facility (e.g. desulfurization, lime addition);

— placement of waste rock in a pit and tailings in underground workings, as practicable;

— seasonal storage of impacted water, as well as controlled release to the receiving waters and to a water treatment facility;

— short-term (e.g. rip-rap placement) and long-term (e.g. vegetation) erosion control to limit sediment generation;

— short- and long-term sediment control facilities such as detention ponds and wetlands; and

— impacted water collection impoundments, sumps, pumps, pipelines and trenches to convey water, as necessary.

5.5 Water treatment

5.5.1 General

Water treatment should be considered as a last resort in controlling water quality; treatment is more complex to sustain in the long-term, compared to other methods that keep clean water clean and minimize the amount of water impacted.

Where water treatment is used, the planning, design, construction and operation of water treatment systems should incorporate and apply a quality management system.

5.5.2 Objectives

The objectives of water treatment are to reduce the concentrations of specified constituents to specific levels (also referred to as effluent standards) needed to achieve receiving water quality goals or standards. Commonly, this is to minimize toxic impacts of released water on local surface water bodies.

5.5.3 Approach

The need for treatment should be determined as part of the overall site-wide water management plan as discussed in 5.5.2.

Enough data should be developed to fully characterize both the water streams to be treated, as well as the receiving water flow into which the treated water is discharged, since the receiving water flow can control the level of treatment required. Characterization includes the following (but is not limited to):

— identifying flow ranges and variation in water quality, both seasonally and over the long-term; and

— defining the flow ranges maximum design volume, such as a low frequency event; for example, the 100-year frequency event (and the potential impacts to water quality), and a minimum design flow rate such as during an extreme dry period [where water quality can be significantly worse for certain constituents (e.g. TDS and SO_4)].

The types of treatment systems needed should be based on the following:

— water quality to be treated;

— flow fluctuations; and

— required effluent (discharge) concentrations and the duration of treatment required.

Types of treatment that should be considered include:

— in-situ passive treatment systems, such as natural or constructed wetlands. Two cautions with these systems is that their level of effectiveness varies with temperature and inflow conditions and that they can require long-term maintenance to remove metals that accumulate in the bed sediments;

— in-situ systems, such as those that can be installed in naturally occurring wetlands and bogs, open pit lakes, flooded underground workings and constructed bio-reactors. These systems typically include treatment reagents that are provided on an ongoing basis; treatment media may have to be replaced from time-to-time. These in-situ systems should not be considered as passive and should be accompanied by planned operations and maintenance activities – or scientific demonstration that they operate without intervention for the planned duration; and

— active, in-plant systems, which can include coagulation/precipitation/filtration to remove dissolved metals, nano-filtration and reverse osmosis to remove metals and dissolved salts, ion exchange for metals removal, carbon adsorption for removal of organics, and aerobic/anaerobic biological treatment. This type of treatment is generally conducted in physical/chemical plants specifically designed for the target constituents.

Water evaporation systems are often used to reduce brine waste streams from a reverse osmosis plant, e.g. to a much smaller, higher-concentrated or dried salt deposit that allows for more effective long-term permanent disposal.

5.5.4 Design

As a first step, the treatment objectives should be established. These should be based on the outcome of the water and chemical mass balance modelling, and typically include:

— effluent standards;

— receiving water toxicity requirements;

— other regulatory requirements; and

— other requirements of stakeholders using or affected by the receiving waters.

Once objectives are established, the selection of treatment unit processes should be carried out and should consider:

— demonstrated technologies;

— developmental technologies; in the event these are selected confirmatory bench or pilot testing should be undertaken; and

— establish the design basis for the treatment unit processes.

The following key elements should be considered in the design of the treatment system:

— flow equalization facilities that allow flow variability to be evened out sufficiently to allow for effective treatment during the design maximum flow event. These facilities also allow for the capacity selected for the treatment plant and allow for planned and unplanned treatment plant outages without the release of untreated water;

— a treatment train that can consist of pre-treatment, primary unit treatment processes, and polishing steps;

— a discharge system that directs the treated water to the receiving waters and that can include, as necessary, a diffuser to achieve the required amount of dilution in the receiving water;

— a treatment residuals management and disposal process and facilities including, as necessary, on-site or off-site disposal and management of either hazardous or non-hazardous wastes;

— infrastructure plans that allow for the necessary access to operate and maintain the treatment systems; and

— monitoring, contingency and emergency response plans to evaluate the effectiveness of the installed systems, to allow for retrofits (as necessary) and to deal with emergencies such as accidental releases of contaminated waters and/or treatment reagents, fuels, etc.

5.5.5 Operations and maintenance

A management and operations team structure should be identified and established to:

— confirm effective design, construction and operation of the required treatment system;

— support the necessary funding for the duration of treatment; and

— provide for operator training and certification.

An operations and monitoring plan should be developed, including (at a minimum):

— commissioning;

— operations control systems;

— operators;

— operations guidelines; and

— plant and influent, effluent and receiving water monitoring.

The following additional plans should be developed:

— maintenance;

— contingency;

— emergency response;

— shut-down and abandonment on completion of treatment; and

— peer review, particularly of developmental technologies.

5.6 Covers

5.6.1 General

Cover systems are one of several operational and mine closure and reclamation technologies that are used to provide for physical and chemical stability of mine wastes and other disturbed areas; they also allow for revegetation establishment on reactive mine wastes or other wastes with poor physical properties.

A vital aspect of cover design that should be considered is the fact that their physical and chemical properties can change considerably with time due to weathering and biological processes. For example, it is not unusual for a cover to be designed and constructed for a specific permeability, which then increases by 10-fold or more over the following years or decades due to freeze/thaw conditions, dry conditions, settlement of materials below the cover, slope instability or movement. It is therefore important that cover designs be based predominantly on the anticipated future condition, rather than the newly constructed condition.

5.6.2 Objectives

In addition to meeting the overall mine closure and reclamation objectives, the specific objectives related to covers can include, but are not limited to:

— provide a growth medium for establishing vegetation and ecosystems;

— isolate chemically reactive waste material;

— divert clean water and reduce the volume of contact surface water managed on site;

— limit upward movement of process-water constituents and oxidation products;

— limit influx of oxygen and oxidation of certain minerals;

— limit influx of meteoric water to limit oxidation of certain minerals, as well as the leaching and dilution of oxidation products;

— control wind and water erosion of waste material as part of the overall landform stability; and

— integrate with natural landform design.

5.6.3 Cover design

Cover systems should be designed on a site-specific basis to achieve the cover system's objectives and performance expectations. The following general categories of cover systems should be considered in conceptualizing a site-specific need:

— soil covers as a base for vegetation;

— store-and-release systems that minimize water infiltration and upward movement of contaminated water sitting on mine wastes;

— barrier-type systems (e.g. geosynthetic liners) that are designed to minimize infiltration and air intrusion;

— erosion-protection systems;

— physical access control, such as gravel and rock covers; and

— saturated soil or rock cover systems.

In some instances, temporary covers should be considered. These are typically required on very soft tailings to allow consolidation over time before the final cover is installed. Installation of temporary or permanent covers can also require measures that enhance trafficability and consolidation of soft tailings. These measures can also include (but are not limited to) placement of geofabrics and geogrids to support placement of subsequent soil layers, as well as the installation of wick drains in the tailings to promote faster consolidations.

The key site-specific factors that should be considered in the design of a cover system include, but are not limited to:

— climate conditions (including the influence of climate change and orographic effects);

— the need for and extent to which water infiltration and oxygen infusion needs to be reduced. Air can infuse into waste piles around the edges of the cover, driven by atmospheric pressure changes and advection in the pile caused by oxidising materials that generate heat;

— physical characteristics of the mine waste coarse material, such as WRD cover that can require a filter layer to prevent cover materials from migrating into voids and crevices in the waste rock;

— hydrological conditions, including water balance and management requirements;

— hydrogeological conditions (e.g. vertical and lateral proximity to groundwater and surface water receptors);

— the mine waste landform itself (e.g. slope angles, bearing capacity);

— site access and constructability;

— availability of suitable of cover construction material;

— accommodation for the effects of natural biological processes (i.e. the development of populations of bacteria, fungi, protozoa, nematodes, insects, arachnids, mollusc, worms and mammals) and plant rooting processes that alter the performance of the cover in the years following closure and reclamation; and

— achieving appropriate quality control and assurance during cover system construction.

The design of "store-and-release covers" should include consideration of the depth and nature of the soil and its physical properties after a period of time, precipitation events and evaporation. The effectiveness of such a cover in reducing infiltration is largely determined by its performance during an extreme wet period extending over months or years.

In instances where covers are placed on tailings storage facilities, it can be necessary to install drains under the cover to convey pore fluids that migrate upwards during tailings consolidation and would otherwise migrate up into the cover.

5.6.4 Modelling and field testing

Performance of covers, where required to be accurately predicted, should be supported by cover modelling, field testing and/or the use of natural reference sites.

Available computer models can be used to assess water infiltration, evapotranspiration and air infusion rates. Suitable estimates of the future physical characteristics (e.g. permeability, grain size, soil structure, etc.) should, however, be estimated and used. Modelling should be performed for a realistic climate fluctuation, including extreme dry and wet years. Modelling cannot be used to directly assess how vegetation becomes established, but it can provide useful soil moisture information to assess suitable types of vegetation. There is typically large uncertainty associated with modelling results; these should be used to guide – rather than dictate – the design of the cover.

Field testing can provide information on both the engineering properties of a cover as well as its ability to support vegetation. If field testing is considered, it should involve large-scale long-term tests, rather than small-scale lysimeter-type testing. The scale should be sufficiently large to establish constructed conditions with equipment and construction methods similar to full-scale construction. Long-term tests (several years or more) are required to assess the cover performance after the cover soils are modified by natural processes and to observe the establishment of vegetation. Implementation of progressive reclamation should be considered to achieve this larger scale field testing.

Small-scale field testing can be considered but the results should be carefully interpreted and, as with modelling, used only as a guide for the full-scale cover design.

5.6.5 Monitoring and maintenance aspects specific to covers

Closure and reclamation plans should include the following monitoring aspects that are specific to assessing the conditions and performance of covers and the associated vegetation:

— inspections for erosion damage, including criteria for characterizing the extent of damage; inspections should be carried out both routinely and after a severe rainfall event that exceeds a specified intensity;

— cover surface topography to confirm it is, for example, still free-draining;

— cover soil structure, physical properties and potentially the biome, to assess whether the cover is meeting its long-term objectives;

— extent of vegetation, including criteria (e.g. number of stems per hectare) to quantify its condition;

— inspections for exposed liner and water egress, which can be due to a damaged geosynthetic liner; and

— erosion related to rock covers.

Closure and reclamation plans should include the following maintenance aspects specific to covers:

— replacement of vegetation;

— replacement of, or repairs to, portions of the cover; and

— construction of erosion control measures, such as erosion-protected ditches or swales, etc.

5.6.6 Consideration of climate zones

Different climates affect the performance of covers differently. In the design of covers, therefore, specific attention should be paid to the climatic conditions and the effect of these on the design.

5.6.7 Objectives

The objectives are to customize the cover designs to specific climatic regimes, as much as possible.

5.6.8 Wet and tropical climates

The following factors should be considered where mining takes place in wet and/or tropical climates:

— it is unlikely that store-and-release type covers significantly reduce infiltration, compared to more conventional soil covers;

— cover construction and vegetation, if present, should be carried out in drier seasons, if possible, since reclamation during the wet season can result in soil and seed loss through surface erosion;

— erosion control should be an important part of the cover construction and vegetation plan;

— locating durable rock to be used for erosion protection can be difficult in a tropical environment; and

— vegetative growth in tropical climates can be rapid, which can reduce the adaptive management phase of closure and reclamation.

5.6.9 Arid climates

The following factors should be considered where mining takes place in arid climates:

— native species should be used for reclamation, if possible, as these are more adaptable to the harsh climate;

— soils are susceptible to wind erosion; mulches and other covers should be available to reduce soil erosion;

— vegetation can be susceptible to damage by sandblasting;

— reclamation planning should include options to reduce both wind and water erosion;

— design of soil covers should include the consideration of upward migration of contaminants (salts and possibly metals) from underling reactive materials through capillary rise;

— store and release covers can be suitable in an arid environment where infiltration is to be reduced;

— a cover crop should be used in conjunction with the native seed mix to allow for a rapid establishment and protection of the soil from erosion;

— regular monitoring should be carried out for vegetation success and soil chemical degradation when in contact with reactive mine wastes;

— the opportunity for vegetation establishment in arid climates can be limited as little moisture is available and as bare soils can be susceptible to wind and water erosion; and

— native species and seeds suited to the climate should be used (e.g. in arid climates, cacti leaves can be cut and used to propagate new plants).

5.6.10 Cold climates

The following factors should be considered when the mining activity takes place in cold climates:

— frost heave in soils that are not well drained can damage the cover;

— the opportunity for reclamation is very short in cold climates; plants are slow-growing and generally stunted;

— native vegetation should be used for reclamation purposes, if possible;

— vegetation can be more successful if started in growth chambers;

— timing of planting is important, as plants transplanted over winter can have less chance of survival;

— vegetation trials should be part of the reclamation planning and this should be carried out during the operations phase;

— cold climates can support increased constructability;

— the modelling of infiltration should account for seasonal frozen ground; and

— the presence and depth to permafrost should be documented as this affects the closure and reclamation of the mine site. Soils should typically be salvaged when frozen.

5.6.11 Temperate climates

The following factors should be considered when the mining activity takes place in temperate climates:

— if possible, reclamation should be initiated during the appropriate time of year for the vegetation types and site climatic conditions, to support vegetation establishment;

— reclaimed sites should be monitored in the spring to assess for surface erosion and vegetation establishment; and

— native species or species suited to the local climatic conditions are preferred for reclamation.

5.7 Climate change effects

5.7.1 General

Climate change over time will affect the future design criteria (such as design flood peaks, long-term temperature regimes) and the local flora and fauna. The range of potential future changes should, therefore, be considered both in the design and monitoring to assess the impact of the closed mine on the adjacent environment. In addition, ICMM's 'Adapting to a Changing Climate' can be used to both identify physical climate risks and measures to address climate change effects.

Future climate change can result in changes to terrestrial and aquatic environments, due to increases or decreases in temperature and or precipitation. The types of climatic change can also affect the natural ground and surface water quality due to changes in streamflow and groundwater levels. It is important to understand what these climate-induced changes are, so they can be distinguished from effects caused by the closed and reclaimed mine site. Consideration should be given to monitoring for climate change-related effects in the mine's post-closure and reclamation monitoring program.

In cases where climate change effects are anticipated to be significant, monitoring systems should be installed. These systems should track the effects of climate change in neighbouring surface water bodies, groundwater, and terrestrial ecosystems that cannot be affected by the closed mine to serve as a basis for comparison.

The data analyses provided in the monitoring report should also include a clause on the effects of climate changes and a discussion of how these changes need to be accommodated in assessing the mine's compliance with the monitoring goals.

Other climate change effects include the potential for increased storm intensities. This can require that the design flood peaks for diversion ditches or the spillways associated with the tailings' management facility, be increased compared to those based on statistical analyses of rainfall and runoff at the time the closure and reclamation plans and designs are developed.

Another climate change effect, air temperature warming, can cause thawing of currently stable permafrost. This can lead to slope failures and settlement of mine facilities and needs to be accommodated in the designs of the closure measures.

To the extent possible, adjustment should be made to the hydrologic design parameters such as the long-term drought flows (where it is important to maintain a water cover on a tailing management facility, for example), flood peak flows (for the design of surface water diversion systems), air temperature changes (which can cause thawing of stable frozen foundations), changes in long-term streamflow that affects aquatic ecosystems, among others. In cold climates, the geotechnical design of the facilities that remain at closure should be checked for future warming trends and appropriate design adjustments made to ensure long-term stability.

The effect of climate change on terrestrial flora and fauna and the aquatic ecosystems should, at a minimum, be qualitatively discussed and, to the extent possible, quantified. These effects should be included in the closure and reclamation monitoring plans so that the effects of the closed mine can be separated from the effects of climate change.

6 Stakeholder engagement

6.1 General

Stakeholders should be engaged throughout the entire mining lifecycle, to support the ultimate process of social transition and on the following aspects of mine closure and reclamation:

— recognising stakeholder knowledge as valuable;

— closure and reclamation planning;

— closure and reclamation objectives;

— selection of mine closure and reclamation alternatives;

— evaluation of mine closure and reclamation alternatives;

— risk identification and preventative measures;

— closure and reclamation schedule;

— post-closure and reclamation custodianship of the mine site;

— post-closure and reclamation socio-economic agreements and benefits; and

— monitoring and mine closure and reclamation effectiveness assessment, including the use of completion or success criteria.

Stakeholder engagement and communication is integral to developing plans for social transition, through all process of the project. Planning for social transition should include provision for social transition costs, such as ongoing consultation and engagement, workforce adaption, and community financial preparedness, and for potential social investment projects that support communities when mining ends and the transition to a post closure land use and relinquishment occurs.

The focus of stakeholder engagement can vary throughout the mining lifecycle. The engagement type and frequency can also change between lifecycle phases.

6.2 Objectives

The objectives of mine closure and reclamation stakeholder engagement should include the following:

— an exchange of information between the mine operator and the stakeholders about the goals and objectives of mining, mine closure and reclamation, cultural resources, and the socio-economic structure and conditions affected by the mine; and

— achieving a mine closure and reclamation plan that balances and satisfies as many of the mine operator's and stakeholders' goals and objectives as practicable, while avoiding significant detrimental impacts to any of the parties or the environment.

Stakeholder engagement should incorporate the following, but not be limited to:

— inclusivity: participants should be able to have a say in the decisions that may impact them;

— materiality: decision makers should identify and be clear about the issues that matter;

— responsiveness: organisations should respond to, and transparently share information on, material issues;

— collaboration: establish and achieve common objectives and goals;

— sufficient time periods: to consider and respond to stakeholder concerns before specific plans are carried out;

— documentation: knowledge of stakeholder issues, concerns and consultation requirements should be thoroughly documented;

— a formal complaint and response system: providing for follow-up and tracking of responses to complaints; and

— senior management involvement: the results of the engagement and dialogue processes should be reported at least annually for the mine operator's senior management to determine if and how to act upon them.

6.3 Approach

6.3.1 General

Formalized engagement, indigenous (if applicable) and community outreach protocols and plans should be developed, published and followed in order to achieve informed participation. National and international guides by government, reputable organizations, or mining associations should be used as guidance where applicable.

The mine operator should take the lead in establishing and conducting a stakeholder engagement program. The following activities, amongst others, should be carried out:

— stakeholder identification;

— stakeholder mapping;

— engagement methods;

— response mechanisms; and

— post-closure and reclamation stakeholder agreements.

These topics are discussed in 6.3.2 to 6.3.10.

6.3.2 Stakeholders identification

Stakeholders should be identified as either internal or external, based on their relationship to the organization. Stakeholders should also be identified as either direct or indirect, based on the extent to which they affect or are affected by mine closure and reclamation. This process is typically completed as part of the environmental assessment process through which environmental, socio-economic, and cultural effects of the mine and mine closure and reclamation are assessed.

Indigenous peoples and stakeholders that are affected by the mine and its closure and reclamation can include the following, but are not limited to:

— local indigenous peoples;

— local, regional and national officials;

— affected communities;

— civil society organizations;

— vulnerable social groups;

— political and religious leaders;

— trade representatives;

— suppliers;

— contractors;

— customers;

— employees;

— NGOs;

— regulators; and

— local resource agencies.

The following questions provide examples that can support stakeholder identification:

— who directly and indirectly affects/is affected by the mine site?

— what is the scope of impacts associated with the mine closure and reclamation (locally, regionally)?

— who are the beneficiaries of any mine operator-led social programs currently in place?

— who is adversely affected by mine closure and reclamation?

— who can help support mine closure and reclamation objectives?

6.3.3 Special rights holders

Special rights holders are any group with a legal right to land access, resource harvesting, or input into decisions that can affect land or resource access. Special rights holders vary by jurisdiction.

Internationally, the United Nations Declaration on the Rights of Indigenous Peoples (see Reference [7]) identifies rights of indigenous peoples, including to determine and develop priorities and strategies for the development or use of their lands, and to provide free, prior and informed consent of any project affecting their lands, territories or other resources.

6.3.4 Indigenous peoples

Indigenous peoples can be differentiated by:

— if indigenous/traditional lands and/or treaty rights are potentially affected by the mine site; and

— if there is ongoing traditional use of the land for hunting, fishing, trapping and related harvest activities around the mine site development.

6.3.5 Stakeholder mapping

Individual engagement requirements for stakeholders should be formally mapped. Maps should be used to chart stakeholder groups, identify and track progress on emerging issues, support regular communication and identify stakeholders both before and during the engagement process.

6.3.6 Engagement methods

Different engagement mechanisms can be used depending on the stakeholder's degree of interest and the mine operator's engagement objectives. The identified stakeholders should be categorized as either having a very high, high, moderate or low level of interest and stake in the closed mine. The extent and frequency of engagement depends on each stakeholder's level of interest.

Engagement methods that should be considered, include, amongst others:

— press announcements and articles;

— newsletters;

— social media;

— opinion surveys;

— stakeholder meetings;

— stakeholder workshops;

— permanent or temporary exhibits; and

— mine site tours and meetings.

6.3.7 Response program

The mine operator should implement a transparent response program, which is at the heart of an engagement program. The comments and suggestions received during the engagement process should be clearly documented. Also, the mine operator should document their proposed responses and rationale to stakeholder comments and suggestions.

6.3.8 Social transition — Post-closure and reclamation stakeholder agreements

To support a process of social transition to the extent required as an outcome of the consultation process, the mine operator should enter into closure and reclamation, and post-closure and reclamation stakeholder agreements that can include, amongst others:

— rent, lease or transfer of reclaimed/closed mine areas to local communities;

— training and employ local communities for ongoing site and environmental monitoring;

— contracts to carry out activities to restore/support natural resources to local stakeholders such as support for wildlife populations, fish, good water quality and water sources, or other needs of local stakeholders; and/or

— agreements with local indigenous peoples and community groups to support new agriculture or other business ventures.

6.3.9 Engagement plan

Each mine operator should prepare an engagement plan that describes the results of the above evaluations and considerations, and which describes how the consultation process will be undertaken. This plan should be available to all stakeholders and be updated on a regular basis.

6.3.10 Engagement and reporting frequency

Engagement should be conducted on a continuous basis and in accordance with the current engagement plan. Progress reports to the stakeholders and others should be issued at least annually during mine closure and reclamation and the adaptive management phases.

7 Decision and analysis tools

7.1 Design levels

7.1.1 General

The level of design used in mine closure and reclamation planning ranges from conceptual to detailed construction level designs. As-built information provides a complete record of what was constructed. As the level of design evolves, more field data is collected and the level of certainty for the design constructability and construction costs increase. Planning and design processes typically utilize the lower level design initially, while alternative approaches are still being explored. Once the preferred alternatives are selected, the design levels increase to provide additional accuracy on the design details and associated costs.

7.1.2 Objectives

The objectives of describing specific design levels are to:

— facilitate understanding of the level of confidence and/or accuracy of the designs presented and the factors considered in developing to that design level; and

— define the factors that should be considered for the various mine closure and reclamation planning and design stages.

7.1.3 Approach

The following design levels used throughout the mine closure and reclamation planning process should be considered:

— conceptual;

— pre-feasibility;

— feasibility;

— detailed; and

— as-built.

These design levels are specifically established to provide for sound planning and design decisions, based on design details with an acceptable degree of uncertainty. At each design level there should also be no identifiable fatal flaw; and as the design levels progress, the certainty with which fatal flaws can be ruled out increases.

Various countries and international agencies use a different nomenclature for these design levels. When working with these guidelines, users should consider level of detail contained under the description of each design level rather than what the design level is called.

7.1.4 Conceptual design level

The conceptual design level should include a series of drawings or sketches outlining the major dimensions of the facilities considered, which can be based on limited field data and available climatic, geological, surface water and groundwater data. Conceptual plans for locating the required borrow materials should be available. A brief description of how the closed facility will be operated, maintained and monitored should also be provided since this can influence the closure design.

No fatal flaws should be suspected. Uncertainties can still occur in design concepts and the estimated costs. The level of project definition should be in the range of the Association for the Advancement of Cost Engineering (AACE) 1 % to 15 % and the expected level of accuracy in mine closure and reclamation cost estimations should be in the range of AACE -50 % to +100 %.

The above ranges for level of project definition and cost estimation correspond to the AACE[5] Classes 4 and 5 respectively. A higher level of project definition (Class 4) should be achieved to confirm that sufficient detail is available to support effective stakeholder engagement and alternatives analyses.

7.1.5 Pre-feasibility design level

The pre-feasibility design level should include a description of the basic design criteria and drawings outlining plan views, which include the facility dimensions. The pre-feasibility design should be based on sufficient field data (including geological and geotechnical) and climatic, geologic, surface water and groundwater information to allow a determination of constructability and operability. Reasonable assumptions should be made where no geologic or geotechnical field data are available. Sources of borrow material should be identified and characterized with some preliminary field data. Availability of sufficient quantities of borrow sources, including reasonable contingencies, should be demonstrated. A framework showing how the closed facility will be operated, maintained and monitored should be provided.

There should be no indication that fatal flaws can exist. Most uncertainty should be associated with the estimated construction material quantities that influence construction costs. Construction specifications should be scoped out and key components defined. The level of project definition should be in the range of 10 % to 40 % and the expected level of accuracy in mine closure and reclamation cost estimations should be in the range of -30 % to +50 %.

The above ranges for level of project definition and cost estimation correspond to the AACE Classes 3 and 4 respectively. A higher level of project definition (Class 3) should be achieved to provide sufficient detail in support effective stakeholder engagement, analyses of selected options, and effective mine closure and reclamation plans and designs.

7.1.6 Feasibility design level

The feasibility design level should demonstrate further development and detail compared to the pre-feasibility design level. Sufficient field data (including geological and geotechnical) and climatic, geologic, surface water and groundwater data should be used to allow a determination of constructability and operability, using minimal assumptions for the areas where no geologic or geotechnical field data are available. Borrow sources should be defined and characterized by field data; sufficient quantities of borrow sources, including reasonable contingencies, should be demonstrated to be available. A facility operations, maintenance and monitoring plan should be provided.

There should be a high degree of confidence that fatal flaws do not exist. There should be limited uncertainty associated with the estimated quantities that influence construction costs, and contingency plans and measures should be identified to deal with any remaining uncertainties. Construction specifications should accompany the design. The level of project definition should be in the range of

30 % to 70 % and the expected level of accuracy in mine closure and reclamation cost estimations should be in the range of -20 % to +30 %.

The above ranges for level of project definition and cost estimation correspond to the AACE Classes 2 and 3 respectively. A higher level of project definition (Class 2) should be achieved to provide sufficient detail to support effective mine closure and reclamation plans and designs and adequate closure budgets and funding plans.

7.1.7 Detailed design level

The detailed design level should demonstrate further development and detail building from the feasibility design level. Final field data (including geologic and geotechnical) and climatic, geological, surface water and groundwater data should be available to allow detailed and tender ready design. Borrow sources should be fully defined and characterized by field data; sufficient quantities of burrow sources, including reasonable contingencies, should be demonstrated to be available. A facility operations, maintenance and monitoring plan should be provided.

Construction specifications should accompany the design. The level of project definition should be in the range of 50 % to 100 % and the expected level of accuracy in mine closure and reclamation cost estimations should be in the range of -5 % to +20 %.

The above ranges for level of project definition and cost estimation correspond to the AACE Classes 1 and 2 respectively. A higher level of project definition (Class 1) should be achieved to confirm that construction can proceed as effectively as possible (i.e. minimize finalization of design detailing in the field during construction, as this can lead to unnecessary delays and cost increases).

7.1.8 As-built documentation

It is essential that as-built drawings be prepared immediately after construction, since after mine closure and reclamation is complete. These provide the only record of what the internal features of the various constructed facilities are. Selected detailed design drawings should be modified to show the as-built details and note any changes made to the original detailed design.

7.1.9 Application of design levels to mine closure and reclamation planning

The recommended use of the various design levels described above are as follows:

- conceptual design level:
  - screening of alternatives,
  - preliminary comparison of alternatives,
  - preliminary mine closure and reclamation cost estimates, and
  - comparative risk assessments;
- pre-feasibility design level:
  - alternatives analyses and selection of preferred option,
  - environmental assessments,
  - risk assessments and the development of mitigation measures, and
  - preliminary mine closure and reclamation cost estimates;
- feasibility design level:
  - closure and reclamation permitting, as appropriate to the jurisdiction,
  - risk assessments and the development of mitigation measures, and

  - closure and reclamation cost estimates for establishing funding plans;
- detailed design level:
  - closure and reclamation construction, and
  - refinements to the reclamation cost estimates established for tender;
- as-built design level:
  - vital information for the effective long-term management of the closed mine.

7.2 Alternatives identification and analysis

7.2.1 General

Alternatives identification and analysis is fundamental to mine closure planning and provides a basis for demonstrating that the most appropriate mine closure and reclamation approaches have been selected. Furthermore, it removes inherent biases of the team undertaking the mine closure and reclamation planning and design, supports the engagement process, and demonstrates to stakeholders that all options have been considered with rationales for the preferred options.

7.2.2 Objectives

Alternatives identification and analysis should be used to identify different approaches to closing each major mine facility, such as the process plant site, the TSFs, WRDs, HLFs, open pits, underground workings, contaminated soils, surface water and groundwater, non-mining waste, and other mine assets (e.g. assets for re-use). Closure and reclamation of these facilities can have differing stakeholder and engineering objectives. An alternatives analysis should be used to select the preferred alternatives that, on balance, best meet the site conditions, the mine operator's requirements and the various stakeholder objectives.

An alternatives identification and analysis exercise should be clearly documented to facilitate opportunities for governments', communities', indigenous peoples' and independent review boards' participation in the options evaluation and selection process.

7.2.3 Approach

Alternatives identification and analysis should be performed during the initial development of the mine closure and reclamation plan. The plan should be updated and integrated with operations resulting from changes in the mine's production plans or site conditions (e.g. significant increases in capacity, new WRDs, new extraction processes, significant changes in the physical and chemical characteristics of the mine waste, etc.).

The process requires input from appropriately qualified and experienced professionals. Numerical scoring and ranking should only be used as a guide and should not be considered as the only factor in selecting preferred alternatives.

The approach should include one or more of the following steps:

- technology screening: identification of technologies that can be considered for mine closure and reclamation, and a screening-level analysis of these to select the potentially feasible and more promising technologies;
- alternatives screening: developing site-specific mine closure and reclamation alternatives for each of the major facilities, and subjecting these to a screening-level analysis to select a preferred or several potentially preferred alternatives; and

— alternatives analysis: developing site-specific mine closure and reclamation alternatives for each of the major facilities or selecting the alternatives shortlisted in the second step (dash above), and subject these to a detailed multi-criteria analysis to support selection of a preferred alternative.

The number of steps to be included depends on regulatory requirements, the size and complexity of the mine facility being analysed, and the level and sophistication of stakeholder involvement.

The range of technologies selected should not be based only on technical considerations, but also include those identified for consideration by the stakeholders.

Details of each of the above steps are discussed further in 7.2.4 to 7.2.8.

7.2.4 Technology screening

A list of potential technologies that can be suitable for the facility being closed should be compiled, irrespective of site-specific conditions. It is important to consider a broad range of options, to include stakeholder interests adequately and to allow the process to rule out those technologies that are not feasible under site-specific conditions.

The basic parameters and unit costs for each of the selected technologies should be evaluated at a conceptual level for the site-specific conditions. Major dimensions and the influence of climatic conditions on the alternatives should be assessed. Unit costs can be based on industry standards with assumed allowances for site-specific conditions.

Screening criteria should then be developed to allow the selection of those technologies warranting further evaluation and, in some cases, to identify the preferred technology. Alternatives can be excluded from further consideration if they fail to meet one or more of the following criteria:

— feasibility: alternatives that cannot be implemented under site conditions;

— technical effectiveness: alternatives that do not meet the needs of required objectives throughout the post-closure and reclamation periods and beyond; and

— cost-effectiveness: alternatives for which there is a more cost-effective means of achieving the same long-term objectives.

A thorough justification and rationale for selected technologies, the screening criteria and the short-listed technologies should be provided.

7.2.5 Options screening

The alternatives screening step should be considered when there are many possible options and it is impractical to develop pre-feasibility level designs for each and to conduct the more detailed analysis discussed in 7.2.6.

A list of potential mine closure and reclamation options should be developed that should include all those potentially suitable for the facility being closed and be capable of accommodating the site-specific conditions. The options can be developed from the short-listed technologies resulting from the technology screening steps described in 7.2.4 or can be established independently of these steps.

Conceptual designs (7.1.4) and cost estimates (7.5) for each of the selected technologies should be established. Where applicable, water and chemical balance analyses should be conducted. Costs can be based on industry standards with assumed allowances for site-specific conditions.

Evaluation criteria should be developed to allow the comparative ranking of the options, the selection of those warranting further analysis and, in some cases, identify the preferred option. The evaluation criteria should address the following aspects of closure and reclamation:

— constructability: options that are straight-forward to construct and where construction risks are low receive higher scores;

— long-term performance risks: options that are more durable and involve lower risks of failure receive higher scores;

— feasible post-closure and reclamation land uses: options with higher quality post-closure and reclamation land-use potential receive higher scores;

— stakeholder preferences: provided there is enough coherence and a common theme, options that better align with stakeholder preferences receive higher scores; and

— costs: lower cost options receive higher scores.

Weighting needs should be established for each of the criteria being assessed. The basis for the score should include a measurable performance indicator based on a clearly defined scale. Total scores for each alternative should be obtained by multiplying the individual scores under each criterion by the weight of that criterion. Screening out options based solely on cost can be justified when it renders the option uneconomic.

Options that rank the highest in total score should be considered for further analysis. In selecting these, extensive sensitivity analyses should be conducted at a minimum to address the following:

— which option ranks highest under each criterion?

— how do the options rank if cost is not a consideration?

— how do they rank if cost is the only consideration?

— which option ranks highest considering the criteria weighting scheme?

Where each question results in a different option being ranked the highest, a larger number of options with higher scores under each of the criterion should be considered for further analysis. Where a smaller number of options, or an individual option, scores consistently higher than the others, a smaller number should be considered. It may be possible to select a single preferred option and forgo the next options analysis step.

A thorough justification and rationale for selected options, the evaluation criteria and the short-listed options should be fully documented.

7.2.6 Options analysis

The options analysis follows the options screening process described in 7.2.5 with the exception that significantly more detailed information is required, as described.

A list of potential mine closure and reclamation options should be developed and should include all those potentially suitable for the facility that accommodate site-specific conditions. The options can be developed from the short-listed technologies resulting from the technology screening (7.2.4) or options screening (7.2.5) steps, or can be determined independently.

Pre-feasibility level designs (7.1.5) and cost estimates (7.5) should be developed for each of the options considered. The information needed to generate pre-feasibility level design and cost estimates should include (but is not limited to):

— basic site characterization information, including geology, geochemistry, soils, climate, hydrology, hydrogeology, surface and groundwater quality, air quality, terrestrial and aquatic ecology, cultural heritage and indigenous matters, as well as population and community data;

— environmental and socio-economic impact assessment;

— technical characterisations, i.e. the engineered elements of each option such as size, volume, capacity, chemistry, techniques, water and chemical balance (average and for extreme conditions) supporting infrastructure, etc.;

- economic characterisation, i.e. the economics of the option over its life cycle, including investigation, design, construction, operation, mine closure and reclamation and post-closure and reclamation; and
- socio-economic characterisation, i.e. the potential influences on local and regional land users (e.g. land use, cultural and traditional use, employment and/or training opportunities, etc.).

A multidisciplinary team of appropriately qualified and experienced experts should be formed to undertake the characterisations. Statements of judgement, risk or uncertainty should be explicitly defined and qualified.

The evaluation criteria should be developed to allow the comprehensive comparative ranking of the options. Generally, the evaluation criteria should address the following aspects of closure and reclamation:

- protection of human health and the environment;
- compliance with applicable regulations;
- long-term performance and risks;
- stakeholder considerations and preferences;
- compatibility with regional land use and development plans;
- environmental and social impacts during closure and reclamation; and
- costs.

Each of these criteria, or a similar set of criteria, can be expanded by incorporating sub-criteria. For example, "long-term performance and risks" can be sub-divided into:

- maintenance effort needed in the long-term;
- level of sophistication needed for long-term monitoring, inspections and maintenance;
- risks and consequences of catastrophic failure; and
- potential conflicts with future land uses.

A preferred option is typically selected from the highest-ranking options. To support selecting the preferred option, sensitivity analyses should be conducted as described in 7.2.5. A thorough justification and rationale for the selected option, the evaluation criteria and the short-listed options should be provided. A detailed summary should be provided of what specific trade-offs were made between the criteria in selecting this option.

7.2.7 Stakeholder engagement

Stakeholder engagement is an important part of the options analysis process. Stakeholders should be engaged on any or all aspects that can impact them either directly or indirectly. Aspects of interest can include those related to impact on future land uses, protection of cultural resources, extent of long-term maintenance requirements, geotechnical risks, etc.

7.2.8 Documentation

Results should be documented through a technical options assessment report that describes the outcome of each of the separate steps above i.e. the design and operation phases. This should be separated into two different sections: design and operations. Detailed supporting information should also be presented separately.