Environment and Sustainability

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Summary
This chapter draws attention to all topics related to environment and sustainable development in the mining world. In this sense, financial aspects (e.g., the Equator Principles) are essential to meet the sustainable development objectives. The description starts with some comments about the final stage of the mining cycle: closure and reclamation, and the concept of an Environmental Management System. The «social license to operate,» which is the acceptance of a mining operation by stakeholder communities, is featured below. The potential environmental and social impacts and their management are then discussed. Environmental and social impact assessments are also emphasized because the integration of environment into development scheduling is the essential tool in achieving sustainable development. Finally, eight reclamation case studies are developed at the end of the chapter.

7.1 Mining and the Environment

7.1.1 Introduction

Society needs mining industry since products derived of this activity improve our wealth and quality of life and allow society to growth. In parallel, new technologies that help to minimize human impact on the Earth's environment require metals and other mineral products (Stevens 2010). However, the environmental impacts of mining are perhaps part of the price that humankind has to pay for the benefits of mineral consumption because some environmental degradation due to mining is unavoidable.

In the recent past, mining was carried out with little concern for its effects on the environment, resulting often in significant environmental damage. As political and cultural norms evolved and new legal requirements were enacted, almost all major mining companies adopted rigorous policies and procedures for sustainability, community engagement, and environmental risk assessment and mitigation. These companies apply such policies throughout their operations, many of which are worldwide. Up to date, many mining companies work actively to remediate environmental damage caused by historic mining operations in areas where they developed operations and/or have current activities. Thus, environmental considerations are an important part of the modern mining industry. They must be included in all project plannings, and feasibility studies must account for the influence of environmental considerations on project schedules and costs (Nelson 2011). It is clear today that a zero-harm environment is achievable and that all fatalities, occupational diseases, and injuries are preventable.

The mining industry has followed the same trend as our society. Big mines affect surrounding environment similar to other industrial operations. In the second half of the twentieth century, the mining industry developed a better understanding of its impact on the environment. Today, mines are designed, developed, operated, and closed in an environmentally sound manner, and considerably effort is put into continually improving environmental standards (Stevens 2010). Consequently, the mining industry has changed in the last decades. It is not the industry it was 100, 50, or even 30 years ago. Modern mines operate under modern laws that place far greater importance on environmental protection and use knowledge and technologies that limit the impact of a mine on the environment. Moreover, the modern mining industry also considers the environment in a broader context than in the past. Today, it is not just about the physical environment but also the social and economic environment in which a mine operates. Therefore, the policy makers and organization conducting the mineral development must foster the social well-being of the people living in the mining areas. Mines must have the support of the communities and countries in which they operate in order to be successful. This support is garnered ensuring high standards of environmental stewardship (Haldar 2013).

Large mining operations affect surrounding communities, flora and fauna, land and water, similar to other major industrial operations. The extent to which mining becomes an environmental impact depends largely upon the number of people that a mine affects. High quantities of waste are a consequence of most mining and quarrying operations. Although the major part of this waste is inert and nonhazardous, disposal is often a space problem, at least in densely populated areas. Since economic growth cannot take place without mineral raw materials, the rational conclusion is that the exploitation of mineral resources is not the problem, but it must be developed in a green and modern execution (Pohl 2011). Obviously, the larger the size of a mining operation, the larger the impact is likely to be because it will produce more waste, occupy more land, and have a greater number of buildings.

Old mining works commonly dumped wastes without interest for their physical or chemical stability and the disposal of waste has led to the pollution of surface streams and groundwater. Moreover, urban areas have suffered subsidence damage by underground mining. Thus, although the mining companies generally showed a lack of concern for the environment, this does not indispensably mean that society was not aware of the environmental issues that could be generated with mining. For example, in 1306 a Royal proclamation prohibited the use of coal in London for domestic and industrial purposes because of the nuisance caused by smoke, but it proved impossible to enforce. In addition, Agricola (1556) commented the environmental issues generated by mining such as the devastation of fields and the contamination of streams.

The greater awareness of the importance of the surrounding environment has led to tighter regulations being implemented by many countries to lessen the impact of mining operations. The concept of reclamation of a site after mining works has entered definitely in the country laws. Thus, in most developed countries, mining is closely regulated now, and environmental impacts are increasingly being controlled. Modern mines are bound by present environmental legislations that are becoming strict in the developed world. In this sense, it is important to remember that there is legacy of older operations in most countries worldwide, many of which have been abandoned. Therefore, there is a combination of modern impacts (the impact of current mining in developing countries is still more marked) matched with ancient legacies.

Due to the above, mining companies are carrying out considerable efforts to decrease the environmental impact of mine works and diminish the footprint of their operations throughout the mining cycle, including working to reclaim ecosystems post-mining. To achieve this objective, many mining companies have developed their own codes of practice to assure that mining operations do not so significant harm to their surroundings.

7.1.2 Closure and Reclamation: The Final Stage

All mines have a finite life, and, once the ore is extracted, the mine will close, and the mine site will be reclaimed to a productive natural state. Thus, generally the final step in the operation of mine works is closure and reclamation, the procedure of closing a mine and recontouring (Fig. 7.1), revegetating, and restoring the water and land features to the previous configuration. Closure and reclamation plans are part of mine planning and environmental assessment and must be in place prior to mine development (Stevens 2010).

Before the incorporation in the 1970s of mine closure requests and best practices in the laws, mines were commonly abandoned (Fig. 7.2). Thus, mine land reclamation and closure planning are actually needed by regulatory agencies worldwide, and they are frequently a part of the environmental impact assessment procedure carried out in many countries. Regarding the financial assurance requirements of a closure and reclamation plan, it is the responsibility of the mining company to pay for closure and reclamation costs. To avoid mine abandonment, mining companies are ever more requested to supply financial warranty in the form of a deposit or bond to governments and communities as a guarantee that the resources to meet closure needs will be available.

Closure

In a perfect world, mine works only finish their activity if the mineral resources are exhausted and a mine closure planning is gradually implemented. However, in the real world, mines extract reserves not resources, and the grade and tonnage of reserves change daily based on the commodity price, mineralization grades, geotechnical issues, and other features that can produce the closure before the calculated reserves have been wholly mined. In these cases, the reputation of the mineral industry is dependent on the legacy it leaves. The reasons why mine works close preterm are numerous, including low commodity prices or high expenditures, reducing grade of the mineralization, unfavorable geotechnical conditions, policy changes, social or community influences, and many others. This closure position

Fig. 7.1 Recontouring the waste dumps for reclamation (Spain)

Fig. 7.2 Abandoned facilities without reclamation (Image courtesy of Miguel Cabal)

previous the entire extraction of the mineralization can generate important issues for the mining enterprise, the community, and the regulator (Commonwealth of Australia 2006a). The concept of «community» is usually used in the minerals industry to describe those who live in the geographic region of an operation, either in defined settlements or dispersed settings.

A mine closure plan including physical rehabilitation and socioeconomic aspects must be an integral portion of the project life cycle and should be determined so that (a) the future public health and safety are not compromised, (b) the after-use of the site is beneficial and sustainable to the affected communities in the long term, and (c) the adverse socioeconomic impacts are minimized and socioeconomic benefits are maximized (IFC 2007). Moreover, the closure plan is a dynamic document that must be constantly updated to express variations in mine development and operational planning as well as the environmental and social conditions. Closure and post-closure planning should incorporate adequate aftertreatment and continuous monitoring of the mine site. The duration of post-closure monitoring can be organized on a risk basis; however, site features commonly need a minimum period of 5 years following closure or longer.

Whether an operation has 10 or 50 years of operational life remaining, implementing closure plan into the mining business originates a great value for both the company and the wider community. For this reason, mining companies must involve governments, communities of which they are part, and other stakeholders in closure planning to achieve a successful closure outcome. External mining stakeholders such as local communities, conservation groups, and biodiversity advocates are becoming more and more sophisticated about the outcomes of good and bad closure planning practices (Bingham 2011).

Planning for a successful closure is a complex, multidisciplinary task that is essential to minimizing long-term risk for the mining company, the environment, and the affected stakeholders. Assessing closure risk requires a systematic, structured evaluation. Thus, the risk assessment forms the basis of the closure plan and cost estimates. The focus of the closure risk assessment will be to establish an acceptable risk profile for the company and all other stakeholders upon completion of the closure project. To address closure planning issues and meet business objectives to manage risk, it is necessary to assure that closure planning is wholly integrated in the core business of the asset (Bingham 2011). Additionally, the detail and accuracy of closure plans must change through the life cycle of the asset, starting out as conceptual and progressively becoming more detailed over time.

Closure Objectives

Closure objectives establish the closure results for the mining project and must be realistic and attainable. They can form the requirement to restore a site to its original state and rehabilitating the site to a condition compatible with the surrounding terrain. These goals are designed in accordance with the suggested post-mining land use(s) and are as precise as possible to afford a specific indication to the government and the community on what the proponent commits to attain at closure. Timing and the methods to achieve these objectives are through the life of the asset; life cycle is commonly very specific. For example, some of mines may not enable for any concurrent or progressive reclamation during the operating stage since the disturbed areas are in constant utilization during the mining works, while other mining operations (e.g., several types of coal mines) display generally the possibility to carry out reclamation activities during the life of the asset.

The Environmental Protection Authority of Western Australia summarizes the main closure objectives of a mining project:

1. Landforms: constructed waste landforms will be stable and consistent with local topography; constructed tailings storage facilities will be nonpolluting and non-contaminating, and toxic or other deleterious materials will be permanently encapsulated to prevent environmental impacts; surface water bodies shall not be left in mining voids unless the operator demonstrates there will be no significant environmental impact (e.g., salinization, reduction in water availability, toxicity, algal problems, attraction to pest species, or a local safety hazard) (Fig. 7.3).
2. Revegetation: vegetation in rehabilitated areas will have equivalent environmental values as surrounding natural ecosystems; soil properties will be appropriate to support target ecosystem.
3. Fauna: rehabilitated areas will provide appropriate habitat for fauna; abundance and

Fig. 7.3 Water sampling (Image courtesy of Kinross Gold Corporation)

diversity of fauna must be present in appropriate proportions given the specified post-mining land use.

4. Water: surface and groundwater hydrological patterns/flows will not be adversely affected; any water runoff or leaching from tailings dams, overburden dumps, and residual infrastructure shall have quality compatible with maintenance of local land and water values.
5. Infrastructure and waste: during decommissioning and through closure, wastes will be managed consistent with the waste minimization principles; no infrastructure left on-site unless agreed to by regulators and post-mining land managers/owners; disturbed surfaces must be rehabilitated to facilitate future specified land use; the location and details of any buried hazards will be clearly defined, and robust markers will be installed and maintained (EPA 2015).

Financial Assurance

In recent years, numerous specialty documents and guidelines have been prepared by governments, industry associations, and nongovernmental organizations (NGOs) on the subject of financial assurance for the closure activities, including those available through the International Council on Mining and Metals (ICMM). Although these documents and guidelines vary greatly country to country, it is essential that the closure team properly reviews the site-specific regulatory requirements for estimating financial assurance. Minimum considerations about this item must incorporate the accessibility of all funds to cover the costs associated to mine closure at any stage in the mine life, including provision for early or temporary closure. In the case of a financial guarantee, an acceptable manner of financial guarantee must be presented by a renowned financial institution (IFC 2007).

Governments should apply the financial assurance requirements for contributing to the goal of environmental protection but do not put pressure to existing operators and result in premature closure. The timing and nature of new requirements as well as transition provisions should be set accordingly (ICMM 2005). In this sense, it is important to note that efficient environmental financial assurance policies reduce the scope for public criticism of mineral industry practices (ICMM 2005). Since predictive mine works' reclamation costs are very difficult since they are usually inexact, especially where long-term care is needed, governments commonly include a «safety factor» into the amounts of EFA environmental financial assurance applied.

Closure Plan Stages

In general, there are three basic stages to developing an effective closure plan. The first stage is the development of a target closure outcome and goals, which are manifested in a conceptual closure plan. This plan is developed and used during exploration, pre-feasibility, feasibility/design, and construction to guide the direction of activities.

Fig. 7.4 Restoration of the land surface (Spain) (Image courtesy of Carlos García)

Its active life can be 3–5 years. If well defined and based on effective community and stakeholder engagement, it cannot change much during this time. The second stage involves the ongoing development and implementation of a detailed closure plan, which increases the understanding of specific goals and milestones as well as the actions and outcomes of activities to meet these. This plan is used continuously during operations and has an active life that could range from 5 to 30 years or more; obviously, during this time it must be updated. The final stage is the effective transition to closure, which can be manifest as a decommissioning and post-closure plan. Its active life can be as little as a year or two, although it can extend many years past that time depending on post-closure responsibilities (ICMM 2008).

Reclamation

Mine reclamation is the procedure of taking land after utilized by mining operations and changing it into land with alternative uses. Reclamation includes aspects related to surface and groundwater and air purity, erosion issues generated from storm water and sometimes wind, revegetation of appropriate plant species, and wildlife habitats. The best time to start the reclamation procedure of mine works and associated installations is just before the first excavations are undertaken.

In planning for the reclamation of a given mine, there are many issues that must be considered. The first of these is the safety of the mine site, especially if the area is open to the general public. The second major issue is rehabilitation of the land surface (Fig. 7.4), the water quality, and the waste disposal zones so that long-term water contamination, soil erosion, dust production, or vegetation issues do not occur. The final concern is the subsequent use of the land after mining is completed. The last stage in reclamation is monitoring. In this process, all reclaimed areas are monitored and assessed for vegetation survival and growth rates. Plants in areas that are to be used for grazing will be tested to ensure that they contain acceptable levels of metals and other possible contaminants (Stevens 2010).

Reclamation has been used in a general way simply to mean returning a mine site to some other land use whether it be the same as before mining began or different. It includes the physical stabilization of the land (e.g., waste rock piles), landscaping, rehabilitating topsoil, and return of the land to a helpful finality. The art of mine reclamation has progressed from straightforward revegetation operations to a more complex discipline that includes utilization of native plants to mimic natural ecosystem. In most cases, entire reclamation is almost impossible, but sound remediation and rehabilitation can result in the opportune setting of a functional ecosystem.

By planning the mine for a subsequent development, it is possible to improve the value of the disturbed land and help to change it to a utilization that the public will consider clearly positive. Thus, old mine sites can be converted to wildlife habitat and refuge (Box 7.1: Cabárceno Natural Park)

Box 7.1

Cabárceno Natural Park (Santander, Spain)

Cabárceno Natural Park (Fig. 7.5) is located in Pisueña Valley, 17 kilometers from Santander (Spain), being probably the biggest tourist attraction in Cantabria (Spain). It is so successful than more than five million people have visited it since its opening in 1990. It is a man-made space created from the karst landscape of a former open-pit iron mine. Iron mining was the oldest and most common one in Cantabria, as shown by the abundant remains of exploitations. The Peña Cabarga iron mines in Cantabria, Spain, were active for more than 2000 years (Pliny the Elder wrote about these mining works). The mining exploitation of Peña Cabarga (Cabárceno) stands out in the central area of Cantabria. This mine benefited from iron oxides and hydroxides filling the karstic cavities, coming from oxidation and hydration of the iron sulfides (pyrite and marcasite) within the dolostone rock. As the iron ore was developed, the column shapes from the karst were almost cleaned. The result is a ruin-like landscape of great beauty that nowadays is used as a natural park. Cabarceno's iron was extracted until 1989, when the mine was no longer profitable, and the conditioning of the Natural Park started.

The natural park is home to a hundred animal species from five continents living in semi-free conditions, which are distributed in large enclosures where one or more species coexist. Cabárceno covers an area of more than 750 hectares and is the largest park of its kind in Europe. More than 20 kilometers of roads cross the park, leading to gorges, lakes, and rock figures, and several lakes that were open-pit exploitations complement this exceptional space. Cabárceno Park has two main objectives: (a) conservation of endangered species and (b) environmental education. A network of roads, very well laid out and tens of kilometers in length, make it possible to contemplate a variety of fauna that finds protection, refuge, and food in the park. The visitor can observe at close distance, in 21 ample areas, hundreds of all the zoological

Fig. 7.5 Cabárceno Natural Park (Santander, Spain)

community's animals: jaguars, giraffes, lions, Siberian and Bengal tigers, leopards, hyenas, bisons, elephants, hippos, rhinos, dromedaries, camels, llamas, zebras, ostriches, and many others as well as Cantabria's fauna including wolves, deer, wild boars, and the most important Hispanic reserve of brown bears.

The facilities that host animals are internationally recognized as one of the best existing in the world. The Park welcomes different animal species from five continents in a semi-free environment, which have been distributed in boxes of large areas where one or more species can coexist. The Nature Park's life develops in the most natural environment for these animals. Besides the food provided them, the rest of the activities are marked, almost, by their complete freedom and instinct as wild as in their natural habitat. The park collaborates with zoos and partnerships in the conservation of endangered species like tigers, lions, bobcats, rhinos, etc. For instance, the park has pioneered, in collaboration with the Deutsches Primatenzentrum and the University of Göttingen (Germany), in the development of techniques that have allowed the knowledge of the sexual cycle in female African elephant by noninvasive methods.

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recreational areas (Fig. 7.6), shopping mall, golf course, airport, lake, underground storage facility, solid waste disposal area, mining and power plant waste storage, museum, site of special scientific interest and regionally important geological site, industrial land, pisciculture pond, and many other economically or ecologically productive land utilizations that can benefit society. The conversion of an abandoned mine for practical commercial purposes depends upon the geological and hydrogeological conditions as well as the nature and geometry of the mining that took place.

There is a great variety of terms used in mining reclamation. The terms remediation, restoration, rehabilitation, and reclamation itself are all applied to express mine closure activities that attempt to alter the biological and physical state of a site. However, they have slightly different meanings. They are many times utilized interchangeably, but refer to different stages in the preparation of the site for another utilization. Thus, remediation is the cleanup of the polluted area to safe levels by extracting or isolating contaminants. At mine sites, remediation commonly consists of isolating contaminated material in pre-existing tailings storage facilities, capping tailings and waste rock piles with clean topsoil, and gathering and processing polluted mine water. As far as restoration

Fig. 7.6 Aggregate quarry reclaimed to recreational area (Las Madres, Madrid, Spain)

is concerned, it commonly refers to returning a mined area to its previous condition and land use such as where a surface mine is filled and the restored land returned to agriculture.

The meaning of rehabilitation and reclamation in the context of mining is not as widely accepted as the meaning of restoration. Nevertheless, rehabilitation (also referred to as regeneration) can be regarded as the establishment of a stable and self-sustaining ecosystem, but not indispensably the one that existed previous mining works started. Therefore, rehabilitation is the procedure utilized to remedy the impacts caused for the mining activities on the environment. The long-term aims of rehabilitation procedure can change from merely converting an area to a safe and stable condition to restoring the pre-mining conditions as closely as possible to support the future sustainability of the site.

7.1.3 Environmental Management System

An Environmental Management System (EMS) is an essential part of a larger management system or an organization. The EMS is utilized to define an environmental policy and to control the environmental aspects of the organization activities, products, and services. This control includes interrelated components such as responsibilities, authorities, relationships, functions, processes, procedures, practices, and resources. A management system utilizes these components to define policies and goals and to develop ways of using these policies and achieving these objectives.

Thus, EMS is a group set of procedures and practices that allow an organization to decrease its environmental impacts and increment its operating effectiveness, being a powerful tool for managing the unfavorable impacts of activities of an organization on the environment aspects. The profits of an Environmental Management System are the following: (a) diminishes the environmental responsibilities applying well-defined mitigation techniques, (b) increases the effective utilization of resources, (c) decreases waste production by appropriate planning, (d) proves a well-accepted corporate image, (e) motivates awareness of environmental concern, (f) increments better knowledge of environmental impacts of business activities, and (g) increments the skill and effectiveness generating higher productivity at lesser costs and higher benefits.

Applying an EMS, the company can prove to all people that they take environmental impacts actively. Moreover, an efficient EMS can also enhance company operations and generating economic profits. The bigger organizations decide certification is more meaningful when taking into account the potential trade and market benefits of an internationally identified and certified EMS. For this reason, ISO 14000 families of certifications assure diminishing the negative effect of operations on environmental aspects and comply with applicable laws, regulations, and other environmentally oriented mitigations. All these standards are periodically reviewed by ISO to assure that they still meet market needs.

It is important to note that Environmental Management Systems do not by themselves define environmental objectives. Rather, they only lead the management procedure of a company to assure that environmental programs can be efficiently developed. Setting of policies and goals is one of the important functions defined within such a management system. ISO 14001, issued in 2004, offers standards by which an organization may put in place and implement a series of practices and procedures that, when taken together, result in an Environmental Management System (EMS) (Box 7.2: Environmental Management – ISO 14001). Other relevant families of certification used in an EMS are ISO 9000 and ISO 18000. For

Box 7.2

Environmental Management – ISO 14001

The ISO 14001 standard is the most important within the ISO 14000 series, and it sets out the criteria for an Environmental Management System (EMS). ISO 14001 is the internationally accepted environmental management standard that certifies that an organization is committed to reducing the environmental impact of its products and operations and is constantly monitoring and seeking to identify ways of reducing that impact further. It prescribes controls for those activities that have an effect on the environment. These include the use of natural resources, handling and treatment of waste, and energy consumption. Thus, the standard requires the company has a procedure for monitoring that regulatory requirements are being met.

International standard ISO 14001:2004 from the International Organization for Standardization (ISO) defines an Environmental Management System (EMS) as «Organization structure, responsibilities, practices, procedures, processes, and resources for implementing and maintaining environmental management.» It is a flexible, risk-based, plan-do-check-act continual improvement approach that requires formal documented processes for many of its elements.

Most mining companies are committed to managing its environmental aspects, impacts, and risks through adherence to the internationally recognized ISO 14001: 2015 EMS standard. It is known as a generic management system standard, meaning that it is relevant to any organization seeking to improve and manage resources more effectively. Today, many large-scale mines operating worldwide have already attained ISO 14001 certification. The ISO 14001 EMS standard requires every mining company the highest, most acceptable level of efficiency in terms of extracting minerals while at the same time ensuring that the environment is not compromise.

The five main stages of an EMS, as defined by the ISO 14001 standard, are (Fig. 7.7):

1. Commitment and policy: top management commits to environmental improvement and establishes the organization's environmental policy.
2. Planning: an organization first identifies environmental aspects of its operations and then determines which aspects are significant by choosing criteria considered most important by the organization.
3. Implementation: an organization follows through with the action plan using the necessary resources (human, financial, etc.); an important component is employee training and awareness for all employees.
4. Evaluation: a company monitors its operations to evaluate whether targets are being met.
5. Review: top management reviews the results of the evaluation to see if the EMS is working; management determines whether the original environmental policy is consistent with the organization's values; the plan is then revised to optimize the effectiveness of the EMS.

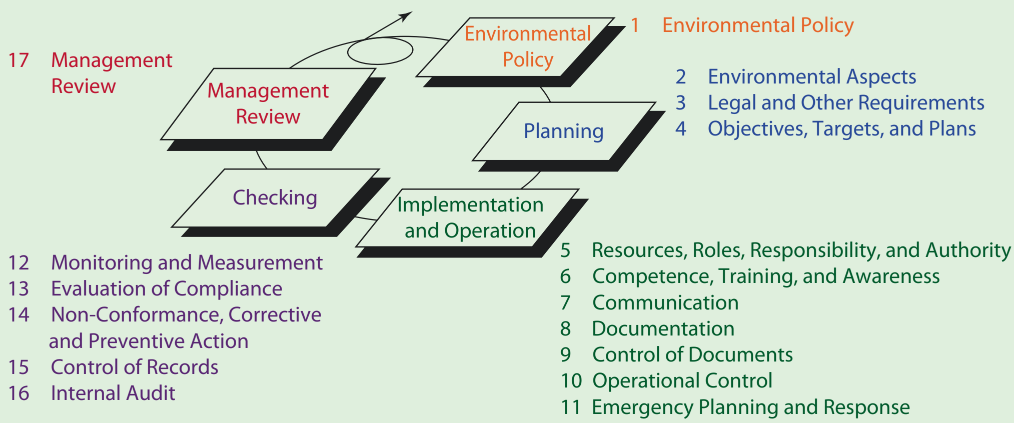

Fig. 7.7 Main stages of an EMS as defined by the ISO 14001

example, the former ensures quality system management, and it is established to help organizations that they satisfy the requirements of customers.

7.2 Mining and Sustainable Development

In the last three decades, the terms «sustainable development» and «sustainability» have been in use by the governments and policy makers worldwide. It is commonly agreed that sustainable development was early defined in 1987 by the Brundtland Commission (Our Common Future, World Commission on Environment and Development, United Nations) as «a system of development that meets the basic needs of all people without compromising the ability of future generations to meet their own life-sustaining needs.» Since then, a rich discussion has ensued about what this means in practical terms. Though many other sets of words have been suggested for defining sustainable development, the Brundtland Commission definition has stood the test of time. In mining world, these words were possible first utilized in the early 1990s in the Rio Summit (1992).

In recent years, the word sustainability has also found its way into common use. The ideas of sustainable development and sustainability are different but synchronous. Sustainability is a more general term that captures the idea that we need to maintain certain important aspects of the world over the long term. These features vary from primary requirements of human society such as air, water, food, clothing, shelter, and basic human rights to a group of perceptions that would collectively be termed «quality of life» and not only for people but also for other forms of life. Sustainable development is the human or action part of this set of ideas. Together, these ideas are very appealing, but their translation to practical action remains much debate. This is not surprising since there are about 200 countries across the world, and the global ecosystem is complex and not fully understood (Hodge 2011).

At the base of the interlinked ideas of sustainability and sustainable development is the easy perception that the human activities, obviously including mining, should be carried out in such a way that the activity itself and the products originated together afford a net contribution to human and ecosystem well-being over the long term. An optimum balance clearly requires to be maintained between sustainable development and eco-friendly environment (Haldar 2013). Since the release of «Our Common Future,» including the aforementioned Brundtland Report, many of the major industries in the world, including mining companies, many of its governments, and the United Nations have adopted a policy of sustainable development.

In this sense, the mining industry has been a particularly active locus of sustainability-related policy and practice innovations because: (a) the potential implications of mining activities and the minerals and metals that result are significant; (b) many interests are touched by mining; (c) the role of many of these interests in decision-making is growing (e.g., communities and indigenous people); (d) the nature of contemporary communications systems has brought the often dramatic nature of mining operations into the public eye; and (e) industry, governments, civil society organizations, and the public, in general, are all anxious to ensure mining makes a positive contribution that is fairly shared (Hodge 2011). However, the focus is not on how mining can be sustainable, identifying that mining operations has a finite useful life, but on how mining industries can help to sustainable development. This is a conceptual change from a singular analysis and mitigation of impacts to a more complete study that looks at the broader contribution of the industry and its products (ICMM 2012a). In this sense, financial aspects are essential to meet the sustainable development objectives (Box 7.3: the Equator Principles).

Box 7.3

The Equators Principles

Before financial institutions invest in mining projects, they require that companies produce evidence of a business program that adequately addresses sustainability issues in their projects; they apply stringent rules on resource companies looking for funding. In this sense, many banks belong to the Dow Jones Sustainability World Index (DJSWI). The index was launched in 1999 as the first global sustainability benchmark, and it tracks the performances of sustainable companies and provides money managers with tools to better manage their eco-conscious portfolios. Moreover, many financial institutions have also adopted the Equator Principles (EP), which ensure that projects are developed in a manner that is socially responsible and reflects sound environmental management practices. However, it needs to be recognized that the DJSWI and the Equator Principles are voluntary and nonbinding, and many investors, particularly in developing countries, are not required to adhere to them.

The Equator Principles are a voluntary set of standards adopted by financial institutions for determining, assessing, and managing environmental and social risk in project finance activities.

They are considered the financial industry gold standard for sustainable project finance. The Equator Principles Financial Institutions (EPFIs) have adopted the Equator Principles in order to ensure that the financed projects are developed in a manner that they are socially responsible and reflect sound environmental management practices. Thus, the importance of climate change, biodiversity, and human rights is recognized, and negative impacts on project-affected ecosystems, communities, and climate should be avoided where possible. If these impacts are unavoidable, they should be minimized, mitigated, and/or offset. EPFIs review the Equator Principles from time to time based on implementation experience and in order to reflect ongoing learning and emerging good practice.

The EP are primarily intended to provide a minimum standard for due diligence to support responsible risk decision-making. According to this, EPFIs commit to implementing the EP in their internal environmental and social policies, procedures, and standards for financing projects and will not provide project finance or project-related corporate loans to projects where the client will not, or is unable to, comply with the EP. Where a project is proposed for financing, the EPFI will, as part of its internal environmental and social review and due diligence, categorize it based on the magnitude of its potential environmental and social risks and impacts (principle 1 – Review and Categorization). Such screening is based on the environmental and social categorization process of the International Finance Corporation (IFC). Using categorization, the EPFI's environmental and social due diligence is commensurate with the nature, the scale and stage of the project, and the level of environmental and social risks and impacts. The categories are as follows: (a) category A, projects with potential significant adverse environmental and social risks and/or impacts that are diverse, irreversible, or unprecedented; (b) category B, projects with potential limited adverse environmental and social risks and/or impacts that are few in number, generally site-specific, largely reversible, and readily addressed through mitigation measures; and (c) category C, projects with minimal or no adverse environmental and social risks and/or impacts. Obviously, the Equator Principles have greatly increased the attention and focus on social/community standards and responsibility since 2010. They include robust standards for indigenous peoples, labor standards, and consultation with locally affected communities within the project finance mining market. The most important lending institutions worldwide, many of whom provide financing for mining activities, have adopted the Equator Principles. Thus, currently 83 EPFIs in 36 countries have officially adopted the EP, covering over 70 percent of international project finance debt in emerging markets.

Today, mining companies employ the principles of sustainable development in their environmental policies. This has resulted in positive development for the industry and has allowed mining companies to view the impacts of their operations in a more comprehensive manner. The process has not been easy; conflict is still present and consensus is not always possible (Stevens 2010). In summary, a sustainable mining operation must be safe, proves significant practices in EMS and community engagement, is financially robust, and which, very importantly, effectively utilizes the mineral resource. Thus, mine managers establish a sustainable mining operation if they focus on the five areas: safety, environment, economy, efficiency, and community (Laurence 2011). At present, almost all mining companies include in their Web pages a heading or subheading entitled «Sustainability» or «Sustainable Development.» Thus, headings such as socioeconomic development, environment, community, or indigenous relations are common, and annual sustainability reports updated regularly are available in almost all mining Web pages. But application of sustainability concepts to the mining, minerals, and metals industry needs attention paid to the full project and mineral life cycles, that is, including exploration, design and construction, operation, closure, and reclamation.

In the late 1990s and faced with growing concern about access to capital, land, and human resources, the chief executive officers of nine of the world's largest mining companies took an unprecedented step. Working through the World Business Council for Sustainable Development, they started the Global Mining Initiative (GMI). They commissioned the International Institute for Environment and Development (London) to carry out a global review that would lead to identification of how mining can contribute in the best form to the transition to sustainable development. The resulting project, «Mining, Minerals, and Sustainable Development,» sparked a large and rich literature, including the final report of the project, entitled «Breaking New Ground: Mining, Minerals, and Sustainable Development.»

As a direct result of MMSD, the International Council of Mining and Metals (ICMM) was founded at 2001. It is an international organization devoted to enhance the social and environmental performance of the mining industry.

Formed by 23 mining and metal companies and 34 regional and commodity associations, ICMM represents the views of most of them in addressing the core sustainable development issues facing the industry. In May 2003, ICMM's CEO-led Council committed member companies to implement and measure their performance against ten sustainable development principles. They are based on the issues identified in the Mining, Minerals, and Sustainable Development project, and all ICMM member companies have committed to following this set of ten principles.

The ten principles published by ICMM are the following:

1. Implement and maintain ethical business practices and sound systems of corporate governance.
2. Integrate sustainable development considerations within the corporate decision-making process.
3. Uphold fundamental human rights and respect cultures, customs, and values in dealings with employees and others who are affected by our activities.
4. Implement risk management strategies based on valid data and sound science.
5. Seek continual improvement of our health and safety performance.
6. Seek continual improvement of our environmental performance.
7. Contribute to conservation of biodiversity and integrated approaches to land use planning.
8. Facilitate and encourage responsible product design, use, reuse, recycling, and disposal of our products.
9. Contribute to the social, economic, and institutional development of the communities in which we operate.
10. Implement effective and transparent engagement, communication, and independently verified reporting arrangements with our stakeholders.

Regarding the role of the United Nations in sustainable development and mining, in «The Future We Want» Resolution (Res/66/288 – 2012), the United Nations contributed with the following considerations: (a) that minerals and metals make a major contribution to the world economy and modern societies; (b) that mining industries are important to all countries with mineral resources, in particular developing countries; in this sense, mining offers the opportunity to catalyze broad-based economic development, reduce poverty, and assist countries in meeting internationally agreed development goals when managed effectively and properly; (c) that countries have the sovereign right to develop their mineral resources according to their national priorities and responsibility regarding the exploitation of resources described in the Rio Principles; and (d) that mining activities should maximize social and economic benefits and effectively address negative environmental and social impacts. The Resolution claims to governments and businesses to foster the continued enhancement of responsibility and transparency and the efficiency of the significant existing mechanisms to avoid the illicit financial flows from mining activities.

Moreover, building on the Millennium Development Goals (MDGs), the 17 Sustainable Development Goals adopted by all United Nations member states in 2015 after extensive global consultation process seek to rebalance and integrate the economic, social, and environmental pillars of sustainable development, with a central focus on people, planet, prosperity, and peace. In order to align the activities of the mining sector with these global goals, the United Nations Development Programme (UNDP) has conducted a mapping exercise that identifies the key ways in which mining activities can have a positive or negative impact on the achievement of each of the SDGs. The mapping exercise they have undertaken has identified those positive direct and indirect impacts of mining on sustainable development that should be enhanced and those negative impacts that must be mitigated. Mining activities do not always produce economic and social profits to the countries in which the operations are located since the mines in some cases are situated where there is bad governance, including corruption.

7.3 Social License to Operate

At a meeting with World Bank personnel in Washington in 1997, Jim Cooney, at that moment director of international and public affairs with Placer Dome, proposed that the industry had to act positively to recover its reputation and gain a «social license to operate» in a process that, begin-

Fig. 7.8 Local community members are essential to obtain and maintain the social license to operate (Image courtesy of Anglo American plc.)

ning at the level of individual mines and projects, would, over time, create a new culture and public profile for the mining industry (Thomson and Boutilier 2011). The concept of a social license to operate (or simply social license) soon entered in the vocabulary of the industry, civil society, and communities that host mines and mining projects. Thus, the concept is in fact an outcome of sustainability. The social license has been defined as existing where a mine or project has the ongoing approval within the local community and other stakeholders. This includes not only local communities (Fig. 7.8), indigenous people, and governments but also the international community. Inherent in this concept is the belief that local communities should benefit from the mining project (Stevens 2010). Therefore, mining companies must communicate openly with all interested parties and stakeholders, and they must have a solid sustainability record in order to have the social license.

Social license to operate is intangible, dynamic, and nonpermanent because beliefs, opinions, and perceptions are subject to vary as new information is obtained. Hence, the social license has to be gained and later retained. It is commonly granted on a site-specific basis. Thus, a company can have a social license to operate for one mine but not for another one. Obviously, the larger the effects, the more difficult it becomes to get the social license to operate. Moreover, the term «to operate» is in some cases confusing with the exclusively operational phase of a mine life cycle where mineralization is extracted for processing. A better sense of the term to operate is to continue the project, no matter where in the mine life cycle, from starting exploration to closure and reclamation (Thomson and Boutilier 2011). The exploration stage is especially important because that is when first impressions are made. It is a challenging period that can affect community relations during the whole mine life cycle. A positive relationship can lead to the early acquisition of a social license. If that is maintained, it can create the tolerance and mutual understanding needed to deal with conflicts and different interests during the whole life of the mine.

The normative components of the social license include the community/stakeholder perceptions of the legitimacy and credibility of the mine or project and the presence or absence of true trust. These elements are obtained sequentially and are cumulative in building toward the social license. The mine or project must be seen as legitimate before credibility is of value in the relationship, and both must be in place before meaningful trust can develop. These concepts are extended in the following subheading. Sometimes, the social license can transcend approval if an important part of the community and other stakeholders include the project into their identity. At this level, it is common for the community to become defenders of the mine or project since they consider themselves to be co-owners and emotionally involved in the future of the mine or project.

The license is granted by the community, a term used generically to describe the network of stakeholders that share a common interest in a mining or exploration project and make up the granting entity. Use of the terms community and stakeholder network implies that the license is not granted by a single group or organization. It is a collective approval granted by a network of groups and individuals. Therefore, the existence of a handful of supporters in the middle of a larger network of opponents would mean that the license has not been granted. However, the condition that the license be a sentiment for a very different group of individuals originates great complexity into the process. In this sense, individuals and groups will cooperate with the company for many reasons, including courtesy, a desire for gain, a perception of having no alternative, or, as is common in many cases, a sense of obligation with authorities. Cooperation for these motives does not indispensably need a confidence relationship.

7.3.1 Phases of Earning a Social License

As aforementioned, a social license has distinguishable levels. At the same time, the process of moving from one level to another can be thought of as a smooth gradient of continuous relationship improvement through increasing social capital. Figure 7.9 shows the four levels of social license and the three boundary criteria that separate them. The levels represent how the community treats the company. The boundary criteria depict how the community opines on the company, principally based on the behavior of the company. The levels and boundary criteria are organized in a hierarchy, and it is possible to go both up and down the hierarchy. For example, if a company loses legitimacy, the project will be shut down. If full trust is gained, the community will support and protect the project as its own (Thomson and Boutilier 2011).

Starting from the base, the rejection level of a social license is the worst-case scenario. This is when the community stops progress on the project. Many mineral deposits cannot be exploited because the community does not grant any level of social license to proceed. The withholding/withdrawal level is shown as narrower than the acceptance level above it in order to symbolize the possibility that, globally, more projects are accepted than rejected. Regarding legitimacy boundary criterion, legitimacy can be defined in the context of stakeholders and politics as the approval by the individuals and by relevant organizations of an association's right to exist and to pursue its affairs in its selected way (Knoke 1985). This adequately summarizes the bare minimum of legitimacy even when the company has no social license.

Where legitimacy is established, the community response is that they will listen to the company and consider its proposals. If, by their own standards, they have no reason to doubt the company's credibility, they can allow the project to tentatively proceed. This constitutes the acceptance level of social license. It is a minimal objective for any company. The acceptance level is bounded by the legitimacy criterion and the credibility criterion. This represents how acceptance requires that the company's legitimacy must be firmly established and its credibility should at least not be damaged. Legitimacy can be earned by just listening; credibility requires doing something about what has been heard. Credibility is the basis of confidence, and where an enterprise is considered as credible, it is seen as following through on promises and dealing with everyone. An essential component of credibility comes from openness and transparency in the provision of information and decision-making.

Where a company has established both legitimacy and credibility, a community is likely to grant approval of the project. This means the company has secure access to the resources it needs. The community regards the project favorably and is pleased with it. This level of social license depicts lack of sociopolitical risk. Regarding the full-trust boundary criterion, in management research trust has been shown to be essential in relationships between and within organizations. Trust is especially important where bridging the boundary between businesses and civic sector organizations, which include many community groups. Credibility is a basic level of trust related to honesty and reliability. Communities that have a complete level of trust in a company think that the company will always behave according the interest of the community.

Consequently, both parties come to view project's success as a co-ownership arrangement. The

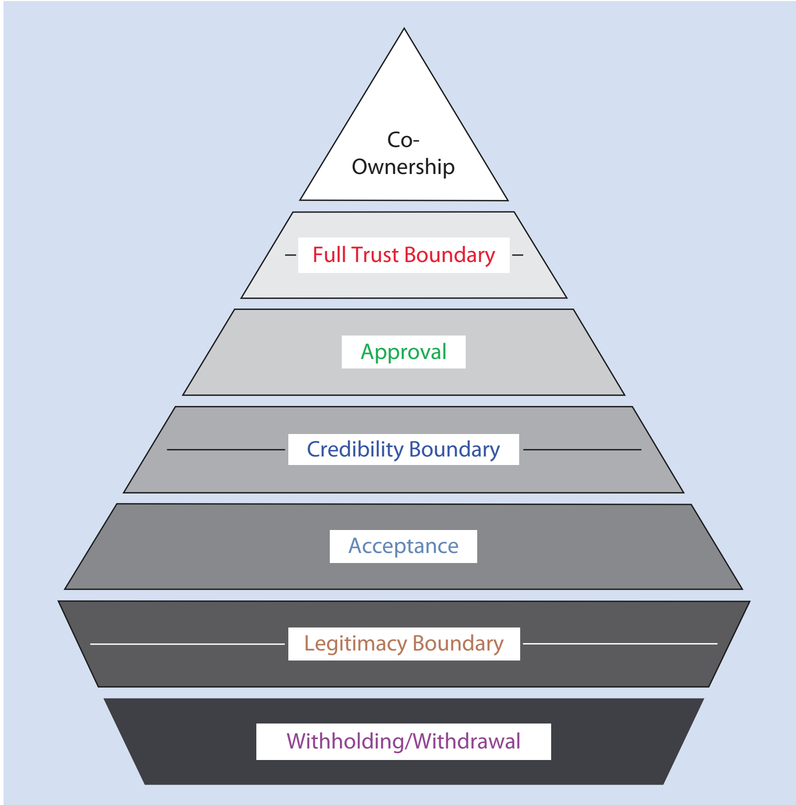

Fig. 7.9 Levels of social license with boundary criteria between them (Thomson and Boutilier 2011)

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limits of the responsibilities of each party are clear, as are ultimate decision criteria. At this co-ownership level of social license, the company becomes an insider in the community social network. Working closely together, the company and community often develop creative solutions to all types of challenges. If outside stakeholders, like the national government or an international non-governmental organization (NGO), move against the interests of the company, the community will mount a campaign in defense of the company. There have been cases where community members have traveled to foreign countries to challenge false information being promoted by NGO critics. Few mining companies have taken their community relations to the co-ownership level. Many have difficulty seeing beyond the immediate transactions to the much greater benefits of establishing strong collaborative relationships. Nonetheless, as awareness of the potential benefits grows, more companies are attempting to win a higher level of social license (Thomson and Boutilier 2011).

7.4 Potential Environmental Impacts and Their Management

7.4.1 Mining Project Phases and Environmental Impacts

Potential environmental issues associated with mining activity such as water use and quality, wastes, hazardous materials, biodiversity, noise and vibrations, and visual impacts (Fig. 7.10) can take place during all phases of the mining cycle, from exploration to closure and post-closure phases. The issue is that mining involves many stages that commonly begin from deposit prospecting and exploration stage, mine development and preparation phase, mine exploration stage, and treatment of the mineral itself with each of these phases involving specific environmental adverse effects.

Therefore, since there are different phases in a mining project, each phase of mining is associated

Fig. 7.10 Visual impact of mining

with different sets of environmental impacts. The adverse effects exploration stage on the natural environment are generally minimum, but it is worth initiating surveys of the present state of the environment before starting any activity that will impact the environment. Thus, activities at ground level commonly need the utilization of boreholes, pitting, and transect lines. For example, the drilling fluids utilized in diamond drilling can get into the water utilized to bring cuttings to surface; this water therefore must be adequately disposed so that it does not pollute the groundwater. The application of support equipment also affects the environment since prospecting vehicles request access tracks. For this reason, application of high-standard environmental management procedures in mineral prospection is critical to assure that such activities are adequately managed with the protection of environmentally delicate zones and community concerns efficiently addressed. Moreover, some countries request independent environmental evaluations for the exploration stage of a mining project since subsequent phases of mining cannot assure if prospection fails to find sufficient amounts of high-grade mineralization.

Once an ore body of sufficient grade has found, then the mining company can start for planning the development of the mine. This stage of the mining project has different components and possible environmental adverse effects. Thus, construction works and the greater amount of traffic originate noise and dust. Changes to the land surface raise the risk of soil erosion (Fig. 7.11) and surface runoff, and the further incremented waterborne loads of solid particles increase the turbidity of water bodies. Drainage water and runoff from a mine operation can also increment loads of metals and nitrogen in water bodies downstream if water is not adequately controlled. All of these changes in water body features as well as in vegetation can affect the conditions for organisms and generate significant changes in species biodiversity. On the other hand, if a mine operation is situated in a distant, undeveloped area, the mining company usually requests to start the operations by clearing land for the construction of staging areas that would house project personnel and equipment. Relative to other phases of activity, the design and construction phase is short. However, this intense

Fig. 7.11 Control of erosion using a mechanical erosionometer (Image courtesy of Freeport-McMoRan)

group of activities and related environmental implications can be destructive if not carefully managed.

After the mining company has developed access roads and staging areas, mining can begin. Surficial mining generally includes the extraction of vegetated zones and commonly also includes the generation of an open-pit that extends below the groundwater table. In this situation, groundwater must be pumped out of the open-pit to enable mining to develop. Thus, mining operations at this stage originate discharges to water that can represent the most important adverse effects to the environment. Outflows of water from the mine site can result in changes such as incremented turbidity, acidification, or salinization in water bodies downstream as well as incremented concentration of metals and nutrients. Regarding the mining projects that exclusively include removing of abandoned waste piles, they prevent the environmental adverse effects of surficial mining but still imply environmental impacts linked to concentration of minerals and/or metals from the waste piles.

Underground mining, although it is a less environmentally harmful method to extract the mineralization in an ore deposit, it is usually more expensive and implies greater safety risks than open-pit mining. Mineralization extraction, utilizing specializing heavy equipment such as loaders, haulers, and dump trucks, which transport the ore to concentration installations utilizing haul roads, can produce noise and generate a specific group of environmental adverse effects such as emissions of dust. Finally, disposal of overburden and waste rock is also a source of different environmental impacts, commonly associated to presence of harmful substances. These materials are often located on-site, either in piles on the surface or as backfilling in pits, or within underground operations. Therefore, environmental assessments for mining projects must carefully evaluate the management possibilities and related adverse effects of overburden disposal.

After the ore has been brought to surface, the process of getting the metal out can also create harmful substances. In beneficiation processes, grinding results in tailings that must be designed to avoid harmful components to reach the environment. For this reason, a treatment procedure for capturing chemically the by-products must be included in the design. Thus, they can be safely disposed individually from the principal portion of the mine tailings. For example, sulfides present in the waste rock have to be kept from creating acid runoff. Meanwhile, different concentration techniques create several types of waste, including waste rock dumps, another type of tailings, heap leach products (e.g., in gold treatment), and dump leach products (e.g., in copper leach beneficiation).

The concentration process uses plenty of water, and this water can contain small concentrations of various organic and inorganic reagents used in the concentration process. How this high volume of water and material is disposed is one of the central questions that will establish whether a suggested mining project is environmentally suitable. The essential long-term objective of tailings management is to avoid the release into the environment of toxic components of the tailings. For instance, wastes including sulfide minerals can produce acidic or neutral runoff with elevated concentrations of metals and sulfates as the sulfide minerals are acidified. If water is not adequately managed, this can decrease water quality in surface water and groundwater bodies. In some cases, water flowing from zones where tailings have been disposed can also include traces of chemicals utilized in mineral processing (e.g., flotation). Another issue of concern is the potential migration of pollutants through rock masses; in fracture rocks, the main portion of the pollutants can migrate through a system of joins, bedding planes, and faults producing contamination of soil and groundwater.

7.4.2 Waste Impacts and Their Management

At large mines, the mass of mineral waste generated can commonly be measured in tens of millions to billions of tons. Similarly, the surface area that must be disturbed for mineral waste disposal is often measured in tens to thousands of hectares and can account for the main disturbance. Waste-related perpetual water management and treatment can account for more than half of the total closure cost at some mines (Borden 2011). Public concerns during project permitting are commonly centered on potential exposure risks and water quality impacts from chemically reactive mineral wastes and can result in project delays and costly permitting requirements. Fortunately, significant advances in mineral waste characterization and management have been made over the past several decades. Proactive mineral waste management can significantly reduce the intensity, footprint, and duration of environmental impacts. Companies that practice proactive management can reduce their financial liability, improve their reputation, and become miners of choice, helping ensure access to new mining opportunities.

The environmental adverse effects of mine wastes are controlled by their type and compositions, which change significantly with the raw material being extracted, type of mineralization, and methods utilized to concentrate the ore. As a result, each mine needs its own waste profiling, prediction, monitoring, control, and treatment. Most mine wastes are environmentally harmless and can be utilized for landform reconstruction, vegetation covers, and road and dam construction. According to Rankin (2011), the main environmental impacts from waste disposal at mine sites can be separated into two categories: (a) the loss of productive land following its conversion to a waste storage area and (b) the introduction of sediment, acidity, and other contaminates into surrounding surface and groundwater from water running over exposed problematic or chemically reactive wastes.

Despite the recycling of many waste types at mines, the bulk of waste generated is still located into storage facilities, and the restoration and long-term control of these installations have become an essential part of modern mine development and closure. Governments and other types of regulators can request any waste storage structures to maintain stable at least for 100 or 200 years, which indicate they must withstand utmost events such as floods and earthquakes. Thus, technological improvements and variation in regulations have produced a meaningful enhancement in waste management procedures

Fig. 7.12 Overburden (top soil) used for landscape contouring (Image courtesy of Daytal Resources Spain S.L.)

over the last 10–20 years. Consequently, mine wastes at contemporary mines are usually better managed than they have been in the past. Moreover, governments of many countries request a specific waste management plan before they will issue mining permits. Guidelines on waste management and mine closure have been created at different levels (international, national, and regional) and offer an advisory framework for best practices in mine waste management. Correct control of tailings and waste rock is based on electing adequate waste storage placements and specific material description, including the precise forecasting of long-term chemical behavior. Structures such as waste and tailing dumps and containment facilities must be designed and treated such that geotechnical risks and environmental adverse effects are adequately evaluated and managed throughout the whole mine cycle.

Types of Waste

Solid wastes can be produced in any phase of the mining activity. Type, quantity, and features of solid mine wastes originated at diverse mines can change based on the raw material being extracted, beneficiation method utilized, and geology at the mine site. In general, the principal types of solid mine wastes are the following:

1. Overburden: cover of soil and rock that is extracted to obtain access to the mineralization at open-pit mines; overburden usually has a low potential for environmental contamination and is commonly utilized for landscape contouring and revegetation during mine closure (Fig. 7.12).
2. Waste rock: material that includes mineralization with low grade considered not interesting to be mined at a profit.
3. Tailings: the fine solid waste generated in the beneficiation process (e.g., froth flotation).

Waste rock is typically a poorly sorted mixture of clay, silt, sand, gravel, and boulder-sized material. Although waste rock can be utilized as backfill in earlier mined areas or translated off-site and utilized at construction projects, most of the waste material originated is placed in piles close to the mine site. The most common disposal method for waste rock is placement within dumps and stockpiles, although in-pit disposal is common in strip mines. Not all mine wastes are defined as harmful wastes since they can even be utilized as feedstock for cement and concrete. Such materials cannot be classified as wastes by definition because they really represent meaningful by-products of mining operations.

On the other hand, tailings are the fine-grained waste that remains after the minerals or elements of economic interest have been removed from the ore (Fig. 6.91). Thus, tailings are composed of the gangue minerals in the ore and residual minerals of economic interest that were not recovered along with process water and any reagents that were added during the milling and concentration processes. Tailings commonly leave the process as slurry formed by 40–70% liquid and 30–60% solids; they are usually disposed of in the form of a water-based slurry in specially engineered repositories (on-site impoundments such as tailing ponds) that are capable of containing the fine-grained and often saturated tailings mass without risk of geotechnical failure.

When developing a waste characterization program, operations must identify and understand the physical and chemical characteristics and hazards of all mineral wastes that will be disturbed, exposed, produced, or imported over the life of the operation. The characterization program must be rigorous enough to provide reliable predictions of the long-term physical and chemical behavior of the waste. Ultimately, the program will be used to select appropriate management strategies that comply with pertinent regulations for each waste type, ensure that all repositories are physically and chemically safe and stable, and allow for successful rehabilitation and closure (Borden 2011). The presence of chemically reactive mineral waste can significantly increase the complexity and cost of waste management. Successful management of chemically reactive mineral waste requires thorough understanding of pertinent regulations, well-designed characterization programs, careful site selection, good facility design, and rigorous ongoing management and monitoring.

Potential Impacts

Mineral waste disposal can be responsible for much of the environmental impact caused by mining. Potential impacts that must be assessed, minimized, and mitigated during mine design, operation, and closure include the following:

1. Direct land disturbance: construction of out-of-pit mineral waste storage facilities will typically require burial of the pre-mining surface, its soils, and ecosystems beneath tens to hundreds of meters of waste.
2. Geotechnical instability: unless properly designed, thick waste piles can be prone to geotechnical instability and failure; instability can range from excessive surface erosion to large deep-seated slope failures; geotechnical risks are generally highest for tailings and other fine-grained waste materials that are saturated when deposited.
3. Erosion and sediment release: erosive wastes are prone to the formation of gullies and other erosion features; the release of sediment at much higher rates than surrounding natural landforms can have negative impacts on down-gradient surface water bodies and aquatic ecosystems.
4. Visual impacts: large-scale mineral waste transport and placement can significantly modify the landscape, creating landforms that are taller than the surrounding topography, truncating valleys and drainage lines, and creating unnatural uniform planar landforms that do not blend in with the surrounding natural topography; visual impacts are likely to be a particular concern near population centers and recreational or protected areas.
5. Direct exposure risks: chemically reactive mineral waste can pose direct chemical exposure risks to people, plants, and animals that live on or near the waste; the pH, salinity, or metal content of the waste can also inhibit vegetation establishment and prevent successful rehabilitation of waste surfaces.

6. Water quality degradation: chemically reactive mineral wastes can degrade the quality of water that runs off or seeps through the waste material; unless properly managed, this can cause degradation of surface and groundwater quality, impacts to aquatic ecosystems, and loss of the beneficial use of water resources far from the point of initial waste placement.
7. Dust release: wind erosion and dust release can degrade air quality because of increases in suspended particulate matter; if the dust is derived from chemically reactive waste, wind transport can disperse potential contaminants over a broad area (Borden 2011).

Site Selection

Waste disposal facilities should be located in areas that minimize environmental impacts and long-term environmental liabilities. The selection process should include a review of site regulatory requirements, baseline conditions and environmental considerations, environmental consequences, and direct surface impacts caused by disposal. In general, the following factors should be considered when selecting locations for waste disposal facilities:

1. Only place waste within legally permitted areas.
2. Where practicable, preferentially place waste within inactive open-pits, underground workings, or existing disturbed areas.
3. Avoid permanent disruption of drainage systems.
4. Tie waste repositories into the surrounding topography to maintain natural, free-draining landforms and to reduce visual impacts.
5. Avoid placement on land with high biodiversity or ecosystem services values.
6. Avoid placement in areas with significant archeological or social value.
7. Avoid placement in close proximity to local communities.
8. Preferentially place chemically reactive wastes in drainage basins that already contain reactive waste (thereby avoiding placement in undisturbed drainages).
9. Limit the footprint of chemically reactive mineral waste to the maximum extent practicable. (j) Avoid placement in areas with poor foundation conditions due to topography, underlying geology, or hydrology.
10. Avoid placement of chemically reactive mineral waste over significant aquifers or groundwater recharge zones.
11. Where the choice is available, such as in some mountainous terrains, preferentially place chemically reactive waste in areas with significantly dryer climates.
12. Balance economic considerations such as haul profiles, potential resource sterilization, and pumping costs with environmental, social, and closure considerations.
13. Avoid placement in or near perennial surface water bodies or in large ephemeral drainage lines where practicable, unless this represents the preferred environmental alternative (Borden 2011).

Waste Rock Dump Management

The overburden and waste rock is commonly arranged in engineered waste rock dumps. Controlling the dumps during the mine life cycle is essential to protect human health, safety, and environment. According to the International Finance Corporation from the World Bank Group (ICF 2007), the main recommendations for management of waste rock dumps are the following: (a) dumps should be planned with appropriate terrace and lift height specifications based on the nature of the material and local geotechnical considerations to minimize erosion and reduce safety risks; (b) management of potentially acid-generating wastes should be correctly undertaken; and (c) potential change of geotechnical properties in dumps due to chemical or biologically catalyzed weathering should be considered, reducing the dumped spoils significantly in grain size and mineralogy; design of new facilities has to provide for such potential deterioration of geotechnical properties with higher factors of safety.

Tailings Management

Tailings management strategies change based on the site constraints and the nature/type of the tailings. Because tailings are formed of fine particles (sand, silt, and clay-sized material), and usually including high water content, they have been especially problematic to manage. Thus, tailings management planning must take into account how tailings will be operated and placed, in addition to continued storage after decommissioning. Strategies should include the site topography,

Fig. 7.13 Dust control (Image courtesy of Anglo American plc.)

downstream receptors, and physical features of tailings (e.g., projected amount, grain-size distribution, density, and water content, among others). Critical considerations for leading practice tailings management are location of the tailings storage facility, geochemical characterization of the tailings, choice of the best tailings disposal technique, tailings delivery, water management, and dust control (Fig. 7.13). Leading practices utilizing paste tailings, good water management, and correct drainage and liners, where adequate, would result in completely consolidated tailings. For this reason, tailings management needs the involvement of competent professionals taking action in accordance with sound geotechnical and hydrological engineering principles.

The selection of appropriate management strategies typically begins by comparing the impacts as predicted by conceptual or numeric models to environmental compliance and performance objectives. If needed, a strategy is selected to reduce the potential impacts and ensure that all compliance and performance objectives will be met during start-up, operation, and closure. The selected strategy does not have to completely prevent any solute or contaminant release but must ensure that release rates meet regulatory requirements and are low enough to be assimilated by the receiving environment without causing harm to people, ecosystems, organisms, or resources (Borden 2011).

Monitoring

After a mineral waste management, strategy is selected, and waste storage facilities have been designed; they must be constructed and successfully managed on an ongoing, long-term basis. Monitoring data should be reviewed regularly, and historical trends should be examined so the longer-term chemical behavior of the mineral waste can be assessed. Time series of monitoring data should be maintained so that long-term changes in water quality, flow rate, or other key parameters can be tracked and significant changes can be identified. Monitoring is required to ensure successful implementation of the mineral waste management plan and to ensure that the strategy is leading to the intended results. Monitoring reports should be prepared annually and reporting should be accessible, easily understood, and transparent to stakeholders. Physical monitoring programs for waste disposal facilities will commonly include at a minimum (a) regular visual inspections of surface structures and facilities such as spillways (Fig. 7.14), piping, dykes, ditches, and other water management systems, (b) regular visual inspections for signs of excessive surface erosion and shallow or deep-seated failure on the outer slopes of waste repositories, and (c) monitoring of water levels and pore pressure within embankments and the waste (Borden 2011).

Spillways consist of primary spillways, which are designed to allow smaller flows out of the

Fig. 7.14 Aerial view of Marlin Spillway (Guatemala) (Image courtesy of Goldcorp Inc.)

impoundment, and emergency spillways, which are designed to pass a peak flow and to ensure the stability of the embankment. Most treatment-type reservoirs are designed with both a primary and an emergency spillway, so that treated water can be released on a regular basis while protecting the embankment. Programs to monitor the geochemical behavior of waste disposal facilities will include (a) periodic sampling of runoff water (Fig. 7.15) and water discharging from the facility's toe in order to monitor flow volumes, solute concentrations, and the solute mass that is being released from the waste, (b) periodic sampling of downgradient monitoring wells and surface water bodies to ensure that seepage from the waste is not adversely impacting receiving environment water quality, and (c) periodic assessment of revegetation success such as total cover, species composition, and plant health.

7.4.3 Water Management

Water is utilized in mining in a wide rank of operations such as beneficiation processes, dust elimination, slurry transportation, and employee requests. The water cycle of a mine is interlocked with the global hydrologic water cycle of a watershed (Fig. 7.16). The mining industry has made significant advances in the last decades in developing close-circuit considerations that maximize water preservation. In parallel, operations are commonly situated in zones where there are not only important municipal, agricultural, and industrial needs but also diverse opinions about the role of water. Moreover, the local environments of mine operations rank from very low to the highest rainfall zones in the world. Independently, liable management of water by mining enterprises is an essential component to assure that their contribu-

Fig. 7.15 Sampling of runoff water (Image courtesy of Glencore)

tion to sustainable development is clearly positive over the long term. In this sense, it is necessary to bear in mind that managing water is one of the most important environmental activities at operating mines. Moreover, water control is a collaboratively liability across the operations although collective management does not signify that liability for certain zones cannot be allocated. Global responsibility is best controlled if the operation has someone in charge of committees and processes (Commonwealth of Australia 2008).

The main sources of water on a mine site are from precipitation, dewatering of open-pits or underground workings, and pumping and removal of groundwater specifically around open-pit operations. Precipitation that falls on the mine site must be collected and cleaned prior it can be discharged to the environment. Water from the dewatered open-pit works or underground operations requests to be treated before being released. Regarding management of water utilized on the mine site (e.g., processing the ore or watering of roadways to keep dust down during dry periods), the water is usually recycled so only a small amount of new water is needed every day. For example, chemicals utilized in the concentration process are generally removed or diluted before tailings are sent to the tailings storage facility (Stevens 2010).

Planned water releases from mines into the environment are commonly closely controlled to assure observance with legislation and to diminish adverse effect to receiving waters. Release of process water is systematically managed and must acquire some quality standards and requests in terms of temperature, pH, and conductivity. Other discharges are produced due to normal run-off, utmost storm events, and release from surplus dewatering where water can be contained and discharged appropriately (ICMM 2012b). Surrounding surface and groundwater quality is controlled, and numerous treatment procedures can be utilized to assure mine water complies legislation standards previous to be released.

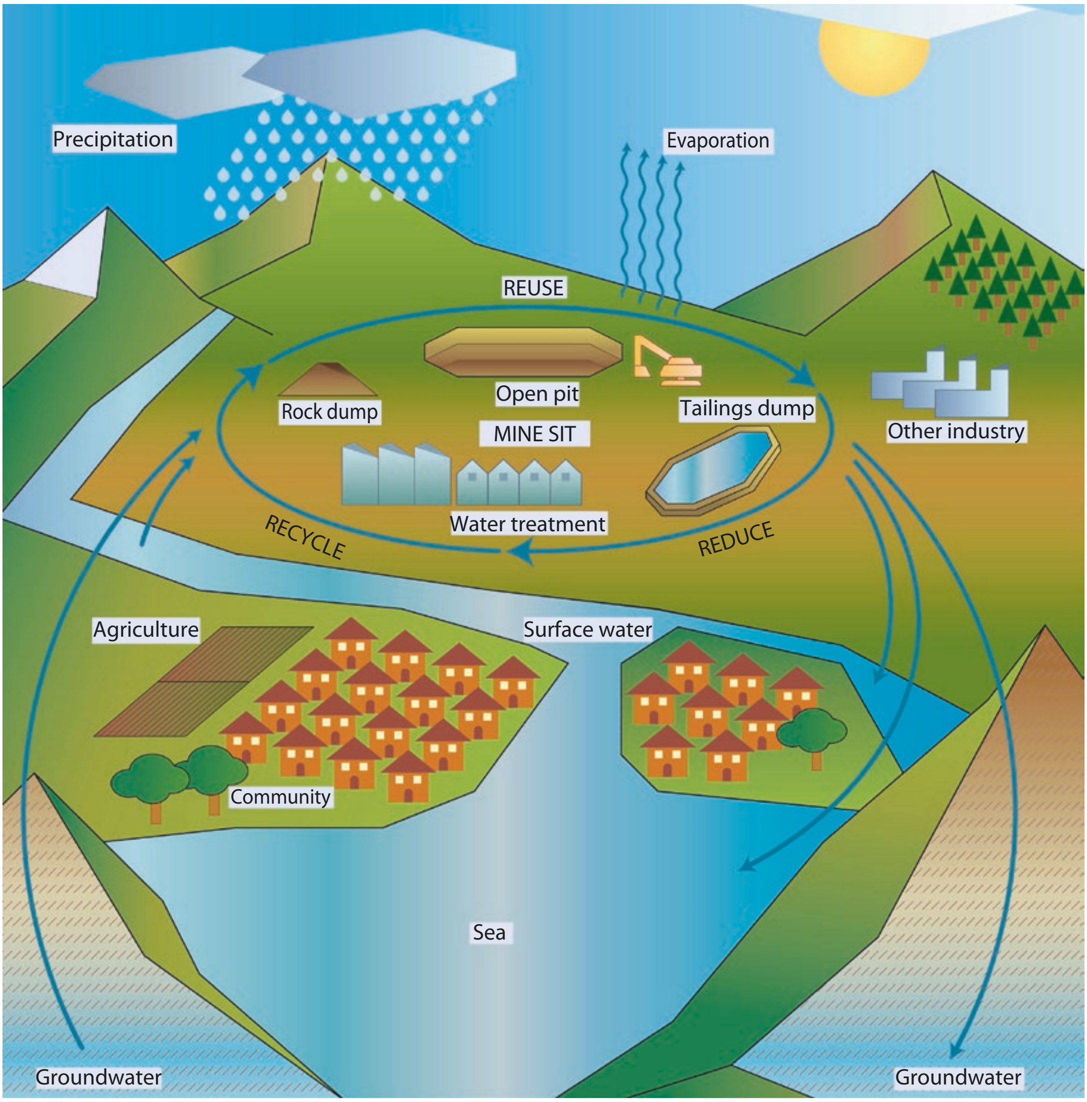

Fig. 7.16 Flows of water to and from a mine site (ICMM 2012b)

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Potential Impacts

One of the principal issues that can be linked to mining operations is the release of contaminants to surface water since many activities of a mining operation can generate toxic and nontoxic components to surface water. Thus, open-pit, tailings pond, mineralization stockpile, waste rock dump, and heap and dump leach pile are all examples of possible important sources of toxic pollutants. The mobility of the contaminants from these origins is increased by exposure to rainfall. Seepage from tailing dump zones and groundwater generating from open-pit mines are another examples by which heavy metals can be mobilized and sometimes released to surface waters. Discharge of contaminants to surface waters can also take place indirectly via groundwater that has hydrological connecting to surface water. Some adverse effects to surface waters include the buildup of sediments that can be polluted with heavy metals, short- and long-term decreases in pH level (especially for lakes and reservoirs), degradation of aquatic habitat, and contamination of drinking water and other human health issues.

The impacts of the mining operations to the surrounding water resources and water-dependent ecosystems are by water withdrawal and dewatering impacts and the discharge of contaminated water. Surface and groundwater withdrawals to dewater the ore body or to supply operations can lower surrounding groundwater water tables, causing seeps, springs, and wells to dry up, harming groundwater-dependent vegetation and ecosystems, and reducing in-stream flow. If necessary, dewatering impacts must be predicted, monitored, and mitigated. Mitigation strategies can include (a) improving water efficiency through process and management improvements so that less water needs to be withdrawn, (b) intentional surface water discharge at key locations to maintain in-stream flow, (c) providing alternative water resources for impacted communities, (d) intentional recharge of groundwater to minimize drawdown impacts, and (e) construction of slurry walls and other subsurface flow barriers to minimize hydrogeologic connections (Borden 2011).

To reduce these issues, an adequate water management plan (WMP) is essential to leading practice water management. Its size and complexity is varied, depending on the nature of the mine, hydrology, and cultural and environmental sensibility of the surrounding area. The WMP defines all water management problems linked to development, operation, and decommissioning a project, integrating also water quantity and quality. The WMP records particular site water goals against which performance can be assessed; quantitative aims are better for an efficient auditing of performance. The WMP also includes any request for internal and external reporting of water performance. Finally, the WMP is dynamic and should be systematically updated and reviewed (Commonwealth of Australia 2008).

Practices for Water Management

Water treatment before discharge can be costly. At large mines with significant acid rock drainage flows, cumulative treatment costs can be measured in the tens to hundreds of millions of dollars. Implementation of internal proactive management strategies that reduce the volume of water that must be treated and/or reduce the solute load in the water can be cost-effective as well as ultimately more protective of the environment (Borden 2011).

Broad water management strategies and control techniques to decrease the potential for water pollution and diminish the amount of water needing treatment include the following: (a) water diversion: capture and diversion of clean surface and groundwater flows up-gradient of the operation can limit the volume of water that can be contaminated by contact with the operational footprint; (b) improved water use efficiency: improvements in water use efficiency can also reduce the volume of water that must be imported into the operation; (c) reagent management: process water quality can be improved by the efficient use of reagents and/or replacement of hazardous reagents with less hazardous but equally effective substitutes; (d) on-site evaporation: evaporative losses within the footprint of the operation will reduce the volume of water that must be discharged; and (e) installing liners and covers on waste rock and ore piles to reduce the potential for contact with precipitation and contamination of groundwater (Lottermoser 2012). Different combinations of strategies can be applied, and the selection of strategies is site-specific. For instance, the interception and diversion of surface water is a more prominent concern in environments with high rates of precipitation, whereas more emphasis is placed on water recycling in arid regions with little water availability.

For water treatment, there are numerous treatment methods forthcoming to clean contaminated water, being these technologies classified as active or passive. Active treatment methods need input of energy and chemicals, while passive technologies use only natural procedures such as gravity, microorganisms, and/or plants in a system, anyone of which requests uncommon but regular maintenance (Younger et al. 2002). In general, the treatment methodology utilized at a mine is based on how contaminated the water is, what chemicals products require to be extracted, how much water needs processing, and the needed release water quality standards. Active water treatments are the most usual manner of water processing at working mines (Fig. 7.17). Thus, mine waters are almost always acidic and need the addition of lime or caustic soda to increase the pH. Once pH has been incremented, dissolved metals can precipitate out of solution and sink to the bottom of settling or sedimentation ponds where they can be extracted. Chemicals called coagulants or flocculants can be added with the aim of converting smaller particles into larger

Fig. 7.17 Active water treatment plant near a coal mine

clumps that settle out of the water more quickly (Brown 2002). Regarding the passive water treatments, they are commonly combined with water monitoring programs and advantage of natural physical, chemical, and biological processes that remove water contaminates without additional physical or chemical inputs. Examples of these procedures are bacteria-controlled metal precipitation, contamination uptake by plants, and filtration through soil and sediments.

Acid Mine Drainage

The term acid mine drainage (AMD) or acid rock drainage (ARD) is used to describe the drainage resulting from the natural oxidation of sulfide minerals that occur in mine rock or waste exposed to air and water. It is important to remember that it is a natural process, not something specifically generated by mining (Box 7.4: Chemistry of Acid Mine Drainage). AMD can incorporate acidity and dissolved metals into water, which is usually very harmful to aquatic life.

Acid mine drainage is responsible for problems of water pollution in major coal and metal mining areas around the world.

Once AMD develops, it can be hard to control and stop. If acid mine drainage is not controlled, it can pose a serious threat to the environment because acid generation can lead to elevated levels of heavy metals and sulfate in the water, which obviously have a detrimental effect on its quality. Stopping AMD development can be very complex since it is a process that, when left unrestrained, will advance, and can accelerate, until some of the chemical components (sulfide minerals, oxygen, and water) are depleted or removed from reaction (Verbug 2011). Thus, the development of ARD is time dependent and sometimes can evolve over a period of decades or even centuries after mining has ceased.

Managing acid rock drainage is a preoccupation at mine workings and after mine closure. Furthermore, AMD is also a major concern for mining companies since nowadays mining operations tend to increment the quantity of rocks

Box 7.4

Chemistry of Acid Mine Drainage

Sulfide minerals in ore deposits are former under reducing conditions in the absence of oxygen. When exposed to atmospheric oxygen or oxygenated waters due to mining, mineral processing, excavation, or other earthmoving processes, sulfide minerals can become unstable and oxidize. Thus, the generation of acid (H^+) occurs typically where iron sulfide minerals are exposed to both oxygen (from air) and water. This process can occur both abiotically or biotically (e.g., microorganisms). In the latter case, bacteria such as *Acidithiobacillus ferrooxidans*, which derive their metabolic energy from oxidizing ferrous to ferric ion, can accelerate the oxidation reaction rate by many orders of magnitude relative to abiotic rates. Sulfide oxidation produces sulfuric acid and an orange precipitate, ferric hydroxide ($Fe(OH)_3$), as summarized in Reaction 1.

Reaction 1

$$FeS_2 + 3.75O_2 + 3.5\,H_2O \Leftrightarrow Fe(OH)_{3(s)} + 2SO_4^{2-} + 4\,H^+$$

$$\text{Iron sulfide} + \text{Oxygen} + \text{Water} \Leftrightarrow \text{Ferric hydroxide} + \text{Sulfate} + \text{Acid (orange precipitate)}$$

There are two key processes involved in the generation of acid (H^+) from iron sulfide: (a) oxidation of sulfide (S_2^{2-}) to sulfate (SO_4^{2-}) and (b) oxidation of ferrous iron (Fe^{2+}) to ferric iron (Fe^{3+}) and subsequent precipitation of ferric hydroxide. These can be represented in the following three reactions (these reactions, when combined, are equivalent to Reaction 1):

Reaction 1a

$$FeS_{2(s)} + 3\,O_{2(g)} + H_2O_{(aq)} \Leftrightarrow Fe^{2+}{}_{(aq)} + 2\,SO_4^{2-}{}_{(aq)} + 2\,H^+{}_{(aq)}$$

$$\text{Iron sulfide} + \text{Oxygen} + \text{Water} \Leftrightarrow \text{Ferrous iron} + \text{Sulfate} + \text{Acid}$$

Reaction 1b

$$Fe^{2+}{}_{(aq)} + O_{2(g)} + H^+{}_{(aq)} \Leftrightarrow Fe3^+{}_{(aq)} + H_2O_{(aq)}$$

$$\text{Ferrous iron} + \text{Oxygen} + \text{Acid} \Leftrightarrow \text{Ferric iron} + \text{Water}$$

Reaction 1c

$$Fe3^+{}_{(aq)} + H_2O_{(aq)} \Leftrightarrow Fe(OH)_{3(s)} + 2\,H^+{}_{(aq)}$$

$$\text{Ferric iron} + \text{Water} \Leftrightarrow \text{Ferric hydroxide} + \text{Acid (orange precipitate)}$$

Once sulfides have been oxidized to sulfates, it is difficult to avoid oxidation of aqueous ferrous iron to ferric iron and subsequent iron hydroxide precipitation. This precipitation stage is acid-generating (Reaction 1c).

The interaction between dissolved ferric iron (Fe^{3+}) and fresh iron sulfide minerals can also lead to significant acceleration of the acid generation process, as represented in the following reaction.

Reaction 2

$$FeS_{2(s)} + 14\,Fe^{3+}{}_{(aq)} + 8\,HO_{(aq)} \Leftrightarrow 15\,Fe^{2+} + 2\,SO_4{}^{2} + 16\,H^+$$

$$\text{Pyrite} + \text{Ferric iron} + \text{Water} \Leftrightarrow \text{Ferrous iron} + \text{Sulfate} + \text{Acid}$$

Under the majority of circumstances, atmospheric oxygen acts as the oxidant. However, aqueous ferric iron can oxidize pyrite as well. This reaction is considerably faster (two to three orders of magnitude) than the reaction with oxygen and generates substantially more acidity per mole of pyrite oxidized. However, this reaction is limited to conditions in which significant amounts of dissolved ferric iron occur (i.e., acidic conditions – pH 4.5 and lower). Oxidation of ferrous iron by oxygen is required to generate and replenish ferric iron, and acidic conditions are required for the latter to remain in solution and participate in the ARD production process.

exposed to air and water, and many metal mineralization and coal deposits are rich in sulfide minerals. In this sense, mining companies are upwardly requested to assess the ARD potential at future mine operations and propose comprehensive planning to prevent or avoid ARD at all stages of mining cycle as part of the environmental impact assessment (EIA) procedure.

AMD Formation

The process of sulfide oxidation and development of AMD is not easy to understand and includes numerous chemical and biological processes that can change importantly in accordance with environmental, geological, and climate characteristics (Nordstrom and Alpers 1999). In unaffected natural situations, acid development is a moderately

Fig. 7.18 Acid mine waters (*red waters*) formed in an old metallic mining area (Image courtesy of María de los Ángeles Bustillo)

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slow process considering geological time. But mine works and concentration of mineralization and materials incorporating metal sulfides hugely increase the acid-generating process because it rapidly exposes those substances to oxidizing conditions.

The most common acid-generating sulfide minerals are pyrite (FeS_2), pyrrhotite (FeS), marcasite (FeS_2), chalcopyrite ($CuFeS_2$), and arsenopyrite (FeAsS). It is clear that not all sulfide minerals originate acidity when being oxidized since sphalerite and galena tend not to generate acidity when oxygen is the oxidant. But it is also very evident that all sulfide minerals are capable of generating acidity if aqueous ferric iron is the oxidant. In this sense, the presence of microorganisms such as *Thiobacillus ferrooxidans* may accelerate the reaction by its enhancement of the rate of reduced sulfur oxidation. If conditions are not favorable, the bacterial influence on acid generation will be minimal. As aforementioned, ARD is a natural process and has been produced in a natural manner over millions of years. Thus, the names of rivers such as the Rio Tinto in Spain, the Norwegian Raubekken, and the Iron Creek in Colorado reflect the historical nature of AMD.

In general, ARD can show the following chemical features: (a) low pH ranging from 1.5 to 4, (b) high-soluble metal concentrations, (c) high (sulfate) salinity, (d) low quantities of dissolved oxygen, and (e) low turbidity or total suspended solids. On the other hand, according to Commonwealth of Australia (2007a), essential indicators of AMD presence include «red colored (Fig. 7.18) or unnaturally clear water, orange-brown iron oxide precipitates in drainage lines, death of fish or other aquatic organisms, precipitate formation on mixing of AMD and background (receiving) water, poor productivity of revegetated areas (e.g., waste rock pile covers), vegetation dieback (e.g., bare areas), and corrosion of concrete or steel structures.» For instance, the most common and very noticeable manifestation of ARD from a dump is the reddish brown staining associated with the effluent and which consists of precipitates of principally ferric salts. These salts are a source of turbidity, but they do not represent an environmental issue.

Locations susceptible to develop acid rock drainage since sulfides can be routinely exposed to air and water are waste rock pile, ore stockpile, tailings storage facility (Fig. 7.19), underground mine, and heap and dump leach pile. However, ARD will not occur if the sulfide minerals are nonreactive or if the rock contains sufficient alkaline material to neutralize the acidity. In the latter instance, pH value of the water may be near neutral, but it may carry elevated salt loads, especially of calcium sulfate. In other words, the acid-generating capability of sulfide minerals is countered by acid-neutralizing minerals. Most carbonate minerals are capable of dissolving

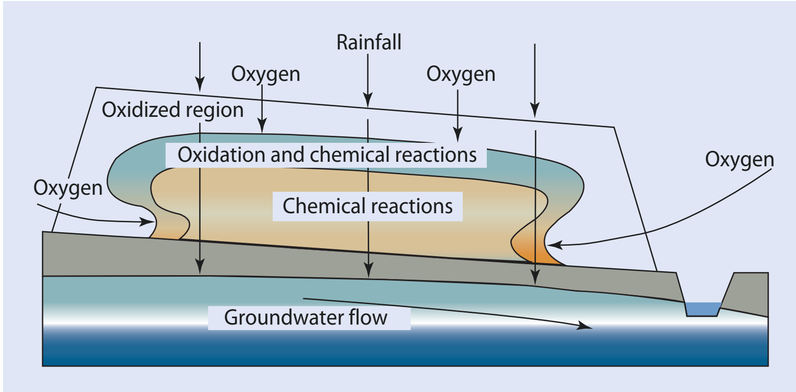

Fig. 7.19 Schematic representation of AMD generation and pollutant migration from a waste rock (Ritchie 1994)

quickly, making them efficient acid consumers. In some cases, calcium-magnesium silicates can buffer mine effluents at neutral pH. In cases of near neutral pH, the levels of major ions such as calcium, magnesium, and sulfate are unacceptably high from an environmental viewpoint.

However, the neutralization of acid generally increases the amount of toxic metal concentrations in the resulting drainage. While increases in pH are desirable, the consequent increase in toxic metal concentrations is not. At most mining sites, there is not sufficient natural neutralizing materials to increase the pH of drainage to near neutral values. Thus, acid mine drainage characterized by low pH and high toxic metal concentrations is the most usual manner of AMD undergone at mine operations (Commonwealth of Australia 2007a).

Lottermoser (2012) affirms that the rate of AMD generation depends on a number of factors such as:

1. Surface area of sulfide minerals exposed: increasing the surface area to air and water increases sulfide oxidation and AMD formation.
2. Type of minerals present: not all sulfide minerals are oxidized at the same rate, and neutralization by other minerals present can occur, which would slow the production of AMD.
3. Amount of oxygen present: sulfide minerals oxidize more quickly where there is more oxygen available; as a result, AMD formation rates are higher where the sulfides are exposed to air than where they are buried under soil or water.
4. Amount of water available: cycles of wetting and drying accelerate AMD formation by dissolving and removing oxidation products, leaving a fresh mineral surface for oxidation; in addition, greater volumes of AMD are often produced in wetter areas where there is more water available for reaction.
5. Temperature: pyrite oxidation occurs most quickly at a temperature around 30 °C.
6. Microorganisms present: some microorganisms are able to accelerate AMD production.

Important progresses in the knowledge of AMD have been carried out in the last decades with advancements also in mine water quality forecast and utilization of preventing methods. However, mine water quality forecast can be complex due to the broad range of the chemical reactions included and potentially very long periods over which these reactions develop. In spite of the uncertainty, quantitative forecasting generated by utilizing realistic scenarios has demonstrated to be of significant value for identifying AMD management options and evaluation of potential environmental adverse effects. Thus, prediction of mine water quality generally is based on one of more of the following procedures: (a) test leachability of waste materials in the laboratory; (b) test leachability of waste materials under field conditions; (c) geological, hydrological, chemical, and mineralogical characterization of waste materials; (d) geochemical and other modeling (INAP 2009).

AMD Impacts

AMD is one of the most sensible and visible environmental problems facing the mining industry because it is often the method of transport for a rank of contaminants, which can affect on-site and off-site water resources, and associated

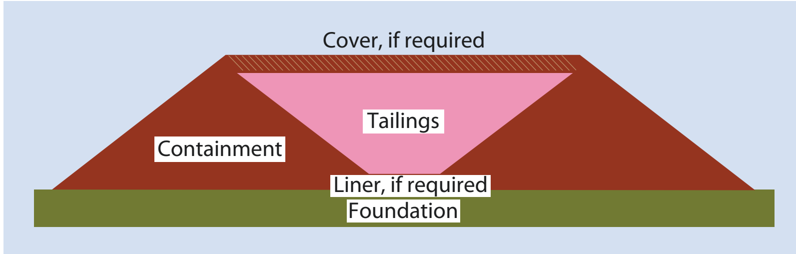

Fig. 7.20 Encapsulation of reactive tailings to minimize sulfide reaction rates (Commonwealth of Australia 2007a)

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human and ecological receptors. The impacts of AMD on near and distant water resources and receptors can also be long term and persist after mine closure. Therefore, AMD prevention, mitigation, and treatment are important components of overall mine water management over the entire life of a mining operation (Verbug 2011).

The environmental adverse effects of AMD depend on the size and sensibility of the water body concerned and the quantity of neutralization and dilution. For instance, the same amount of ARD would have greater adverse effect on the water quality of a small lake than it would have in the ocean, as the ocean has a higher dilution capability and salt water has stronger acid-buffering capacity than freshwater. The dissolved metals associated with AMD are commonly more toxic to fish and aquatic organisms than is the acidity.

AMD Prediction and Mitigation

One of the most important studies that must be carried out in a mining environmental assessment is to evaluate the potential developing of AMD processes. Thus, an accurate prediction of acid mine drainage is required in order to determine how to bring it under control. The objective of AMD control is to satisfy environmental requirements using the most cost-effective techniques. The options available for the control of contaminated drainage are greater at proposed rather than at existing operations, as control measures at working mines are limited by site-specific and waste disposal conditions. The length of time over which the control measurements are requested to be efficient is a factor which requires to be determined previous to the design of a system to control ARD. The prediction of the potential for acid generation involves the collection of available data and the performance of static and kinetic tests. Both tests provide data that can be used in different models to predict the effect of acid generation and control processes.

On the other hand, a risk-based planning and design forms the basis for prevention and mitigation of AMD. The main goal of the risk-based procedure is to quantify the long-term adverse effects of alternatives and to utilize this knowledge to elect the option that has the most convenient combination of attributes. Including the prevention and mitigation effort into the mine operation is an essential factor for successful AMD management (INAP 2009). Therefore, the most cost-effective and low-risk AMD management approach is to prevent AMD development through prediction and mine planning. Prevention of AMD must begin at exploration stage and continue throughout all the mine cycle, being the keystone to avoid costly mitigation. The first aim is to use techniques that minimize sulfide reactions, metal leaching, and further migration of weathering products originated from sulfide oxidation (Fig. 7.20).

Where sulfide mineral extraction is inevitable, a number of AMD prevention strategies have been carried out such as locating waste rock underwater, flooding and sealing underground mines, mixing acid-producing materials with acid-buffering materials, covering waste rock, and treating of sulfide wastes chemically. In the latter, organic chemicals have been used to sulfide wastes with the aim to decrease the rate of AMD; however, there is concern that some of these chemicals can reduce beneficial microorganisms in the environment, thus being pollutants themselves (Price and Errington 1998; Johnson and Hallberg 2005). In this sense, it is far more efficient and usually far less costly in the long term to control acid mine drainage during its early phases.

Prevention and control of AMD is undertaken using primary, secondary, and tertiary control mechanisms. Primary control measures are those that prevent AMD from developing. They commonly include segregating potentially acid origination waste rock or tailings from non-potentially acid-generating rocks and locating it underwater or underground. Secondary control measures are those that do not stop AMD from developing but prevent or decrease the migration of AMD waters. In some cases, secondary control measures can be applied until primary methods can be developed. Finally, tertiary control measures involve the long-term collection and treatment of AMD waters to decrease acidity and remove dissolved metals. This is an unacceptable solution for a new mine and is only utilized for old or closed mines that did not consider AMD-mitigation at the time of the operation or were not planned effectively. This type of measures is costly and can go on indefinitely (Stevens 2010). Obviously, where the entire prevention of AMD process is ineffective, acid mine waters must be trapped and treated utilizing a number of water treatment processes.

AMD Management

The management of AMD and the evaluation of its efficiency are generally considered within the site environmental management planning or in a site-specific ARD management report. The requirement for a formal AMD management planning is commonly motivated by the results obtained in AMD characterization and prediction reports or the results of site monitoring. It is important to note that the development, evaluation, and constant enhancement of an AMD management planning are a continuum throughout the life of a mine (INAP 2009). The principal objective of the management planning must be to minimize or, wherever possible, remove the footprint of potentially acid-forming materials. The AMD management planning detects materials that need special management. To be efficient, the AMD management planning must be completely integrated with the mine plan. Finally, accountability to implement the management planning is verified to assure that those responsible are meeting the requests stipulated in the plan (Verbug 2011).

Strategies to manage ARD can be classified in three main types: minimization of oxidation and transport of oxidation materials, control to decrease contaminants, and/or active or passive treatment to enable water reuse. From a sustainability point of view, minimization is favored to control, and the latter is preferred over treatment. Election of the best minimization and control management strategies depend on climate, topography, mining method, material type, soil/rock types, mineralogy, and available neutralization resources as well as interrelationships between these. The control of acid mine drainage can request different approaches, depending on the severity of potential acid generation, the longevity of the source of exposure, and the sensitivity of the receiving waters. Regarding treatment of waters, there are two phases involved with the design of a system for the treatment of ACM, one during mine operation and another after closure. In any case, conventional active treatment of mine waters needs the installation of a treatment plant, continuous operation, and maintenance, which result in high capital and operational costs. Alternatively, passive methods try to minimize the inputs of energy, materials, and manpower and so decrease operational costs.

7.4.4 Hazardous Materials Management

Hazardous substances are materials that can have adverse effect on human health due to their physical, chemical, and biological properties. Common hazardous industrial wastes include solvents, used oil, oily debris, spent reagents, coolants, greases, batteries, and used paints. Usually these wastes are sent to off-site recycling, treatment, or disposal facilities. Taken into account the previous definition, some materials found in mining and processing operations can be hazardous to human health and the environment. Naturally occurring materials that can be classed as hazardous when exposed by mining include asbestiform minerals, silica, metals, and radioactive minerals. Chemical substances utilized in mining (e.g., explosives and flotation reagents) are hazardous as well. Wastes and by-products of mining operations, such as dusts and acid-generating sulfides, can also be hazardous. The actual risks posed by the handling of these materials depend on their innate hazards, volumes that are present, potential receiving environments, and transport pathways that could connect the point of release with potential receptors (Borden 2011).

Asbestiform Minerals

Where asbestiform minerals are found (Table 7.1), airborne asbestos fibers can be present as minor/trace contaminants in the dust produced during blasting, crushing, and further handling and processing. Concern about the effect on

Table 7.1 Asbestiform minerals

Asbestiform variety	Chemical composition
Serpentine group	
Chrysotile (white asbestos)	$Mg_3(Si_2O_5)(OH)_4$
Amphibole group	
Crocidolite (blue asbestos)	$Na_2Fe_3Fe_2(Si_8O_{22})(OH,F)_2$
Amosite (grunerite) (brown asbestos)	$(Mg,Fe)_7(Si_8O_{22})(OH)_2$
Anthophyllite	$(Mg,Fe)_7(Si_8O_{22})(OH,F)_2$
Tremolite	$Ca_2Mg_5(Si_8O_{22})(OH,F)_2$
Actinolite	$Ca_2(Mg,Fe)_5(Si_8O_{22})(OH,F)_2$

health from long-term, low-level exposure to asbestos needs that adequate procedures be used wherever asbestiform minerals are encountered. The aim is to assure that exposure is as low as is acceptably suitable. To minimize the potential risks from asbestiform material, a competent person (such as a geologist or mineralogist) should analyze exposed rock during the initial studies into the ore body to determine the presence and extent of asbestos. An asbestos management planning can then be prepared for the risk zones determined through asbestos exposure monitoring (Commonwealth of Australia 2009a).

Silica Minerals

Silica minerals make up the matrix or occur linked to the targeted mineral in mineralization. They include quartz, which is a common gangue component of the ores and a very common rock-forming mineral in most igneous and metamorphic rocks. The same natural process that results in sulfide ore bodies often concentrates silica minerals. They are stable until ground or blasted into a dust. Crystalline silica dust is termed as a Group 1 carcinogen by the International Agency for Research on Cancer, being the dust irritant to lungs.

Metals

Metal concentrations increment in waters at low pH values. Thus, dissolved metals can move from mining facilities to local ground and surface water. Once released, metals will continue in the environment. While AMD can improve pollution mobility by fostering leaching from wastes and mine infrastructures, liberations can also take place under neutral pH values. First sources of metals in solution from mining works cover underground and surface mine operations, overburden and waste rock piles, tailings piles, discharges from beneficiation processes, leach piles and processing facilities, chemical disposed areas, and restoration activities. Thus, depending on the local geology, the mineralization and the waste rock and overburden can contain trace levels of numerous elements such as arsenic, cadmium, chromium, copper, iron, lead, mercury, nickel, silver, zinc, and many others as well as naturally occurring radioactive materials.

The presence of certain metals, their liberation potential, and the linked risks are very dependent on facility-specific features such as design and operation of mining and mineral processing operations, waste controlling methods, treatment/mitigation measures, environmental characteristics (e.g., climate, hydrogeology, or mineralization composition, and geochemistry), and nature of and vicinity to human and environmental receptor. To prevent the unintended presence of these metals, dissolved metal concentrations in water can be decreased through physical removing (sorption, precipitation, and biological uptake) (Smith 2007).

Radioactive Minerals

All minerals contain radionuclides that are members of the naturally occurring radioactive decay chains. The impact of these radionuclides needs to be considered in certain types of mining. Radionuclides such as uranium, thorium, radium, and radon can pose exposure risks because of toxicity and/or radiological hazards. Igneous and certain metamorphic rocks are more radioactive than most sedimentary rocks. The release of uranium and its daughter products are an issue at uranium mines. However, radionuclides can also pose hazards at heavy mineral sands, rock phosphate, coal, rare earth ore bodies, and ore bodies associated with granitic rocks. Exposure to elevated radioactivity levels can also occur during rare earth production, bauxite production, and oil and gas extraction, among many examples. The level of possible hazard from radioactive minerals relies on the type of radioactivity and its half-life period.

One of the major radiological risks in mining is associated with inhalation of radon (a radioactive gas with a short half-life) and its short-lived radioactive decay products. Radon is produced by the radioactive decay of radium. Radon exposure can be a particular concern at some underground uranium mines and needs to be carefully considered. The control of radon at underground uranium mines should commence with the process of selecting the mining method, controlling water inflows, and designing a flexible ventilation system. In addition, each mine has to establish safety operating procedures specific for each operating mine. The latter is extremely important, as even the best ventilation system can malfunction because of a power outage, human error, or other unforeseen circumstances. When designing ventilation systems for underground uranium mines, deposits can be divided into two groups: low-grade deposits, usually ranging from 0.1% to 2% U_3O_8, and high-grade deposits, where the grade can exceed 20% U_3O_8 (Apel and Hashisho 2011). In the case of high-grade deposits, the radon emanation rate from the ore would make it practically impossible to dilute the radon daughters using flush-through ventilation, and in these cases, the ore is mined using remote mining methods (e.g., raise boring or mining using water jets).

Regarding management of hazardous materials, it starts with their adequate identification during pre-feasibility studies followed by characterization of the mineralization, waste rock, overburden, mine process residues, and natural soil under the mine installation. If harmful naturally occurring minerals are found during mining, activities should finish until hazard has been adequately assessed and corrective actions have been organized.

Other Hazardous Substances

Other hazardous substances utilized and produced on mine and mineral processing sites can include the following:

1. Acids (sulfuric, hydrochloric): contact with strong acid liquids or fumes is a human health hazard and can also cause structural damage in a facility.
2. Sodium cyanide for gold recovery in large operations: the risk of cyanide poisoning arises from ingestion and exposure to workplace vapors and solutions.
3. Mercury for gold recovery in small/artisanal operations.
4. Metals as ions or complexes from Cu, Pb, Zn, Ni, Fe, As, Hg, and Cd sludges or solutions.
5. Thiosulfates and polythionates, also resulting from acid mine water or processing solutions.
6. Process reagents (acids, alkalis, frothers and collectors, modifiers, flocculants, and coagulants) that contain aluminum and iron salts and organic polymers.
7. Nitrogen compounds from blasting materials: best practice consists of adequate ventilation and monitoring of the workplace atmosphere rather than the use of personal protective equipment.
8. Oil and fuel used for engines, power plants, and lubrication.
9. Solvents used in extraction plants (Commonwealth of Australia 2009a).

7.4.5 Mining and Biodiversity

The protection and conservation of biodiversity is crucial to sustainable development. The United Nations Convention on Biological Diversity defines biodiversity as «the variability among living organisms from all sources including inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems.» Thus, biodiversity is commonly defined at three separate levels: genetic diversity, species diversity, and ecosystem diversity. It is crucial that all partners constituting the mining industry admit that biodiversity has significant environmental, social, and cultural value.

Mining can affect biodiversity throughout the life cycle of a project, both directly and indirectly. Direct or early adverse effects from mining can be produced from any activity that includes land clearance (e.g., access road or tailings dumps construction) or direct discharging to water bodies (e.g., riverine tailings disposal) or the air (e.g., dusts or smelter emissions). This type of adverse effects is commonly easy to identify. Indirect or secondary impacts can be generated from social or environmental variations produced by mining operations and are usually very difficult to identify quickly (ICMM 2006). At the same time, the mining industry has offered considerable effort to the knowledge of biodiversity management. It is essential that the mining industry admits that it not only has a liability to control its impacts on biodiversity but also has the possibility to carry out a decisive contribution to biodiversity conservation through the production of knowledge and the implementation of actions in cooperation with others partners.

Since mining will often have unavoidable negative impacts on biodiversity, it is possible to offset impacts by creating benefits elsewhere to produce an overall conservation outcome that maintains the biodiversity assets of a region. Such offsets can be direct through acquiring comparable land and managing it for biodiversity conservation. This process is sometimes referred to as biobanking (CSIRO 2014). Another form of a direct offset is through funding the implementation of regional conservation plans. Biodiversity offsets can also be indirect such as by conducting relevant research for improved conservation management or through education and training that increases regional capacity for biodiversity management.

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The risks and impacts to business of the failure to correctly manage biodiversity problems can include (a) increased regulation and liability to prosecution; (b) increased rehabilitation, remediation, and closure costs; (c) social risks and pressure from surrounding communities, civil society, and stakeholders; (d) restricted access to raw materials, including access to land, both at the initial stages of project development and for ongoing exploration to extend the lifetime of existing projects; and (e) restricted access to finance and insurance (Commonwealth of Australia 2007b).

Thus, it is very interesting for mining companies to address biodiversity for many different sound business reasons. Consequently, most mining companies have established an ever more complex perspective to managing biodiversity as part of their compromises to achieve and maintain a social license to operate.

Taking responsible decisions regarding to biodiversity management is upwardly considered as very important with respect to (a) reputation, which links to the license to operate, an intangible but significant benefit to business; it can profoundly influence the perceptions of communities, NGOs, and other stakeholders of existing or proposed mining operations; and (b) access to capital, particularly where project finance is to be obtained from one of the investment banks that are signatories to the Equator Principles, which apply the Biodiversity Performance Standard of the International Finance Corporation (IFC) to all investments in excess of US $10 million, recognizing that strengthened commitments to biodiversity assessment and management are likely to be adopted (ICMM 2006). The conceptual approach adopted for a good practice guidance is illustrated in ◘ Fig. 7.21, showing how integrate biodiversity into the mining project cycle (ICMM 2006).

Biodiversity Management

Habitat alteration is one of the most significant potential threats to biodiversity associated with mine operations. Although this alteration can take place at any stage of the mine cycle, there is no doubt that the greatest potential for temporary or permanent alteration of terrestrial and aquatic habitats occurs during construction and operational activities. To integrate conservation requests and development priority in a manner that meets the land utilization requirements of local communities is generally a critical problem for mining projects.

Recommended strategies to solve these issues from the International Finance Corporation (World Bank Group) include consideration of the following (IFC 2007):

1. Whether any critical natural habitats will be adversely impacted or critically endangered or endangered species reduced
2. Whether the project is likely to impact any protected areas
3. The potential for biodiversity offset projects (e.g., proactive management of alternative high-biodiversity areas in cases where losses have occurred on the main site due to the mining development) or other mitigative measures
4. Whether the project or its associated infrastructure will encourage in-migration, which could adversely impact biodiversity and local communities
5. Consideration of partnerships with internationally accredited scientific organizations to, for example, undertake biodiversity assessments, conduct ongoing monitoring, and manage biodiversity programs
6. Consultation with key stakeholders (e.g., government, civil society, and potentially affected communities) to understand any conflicting land use demands and the communities dependency on natural resources and/or conservation requirements that can exist in the area

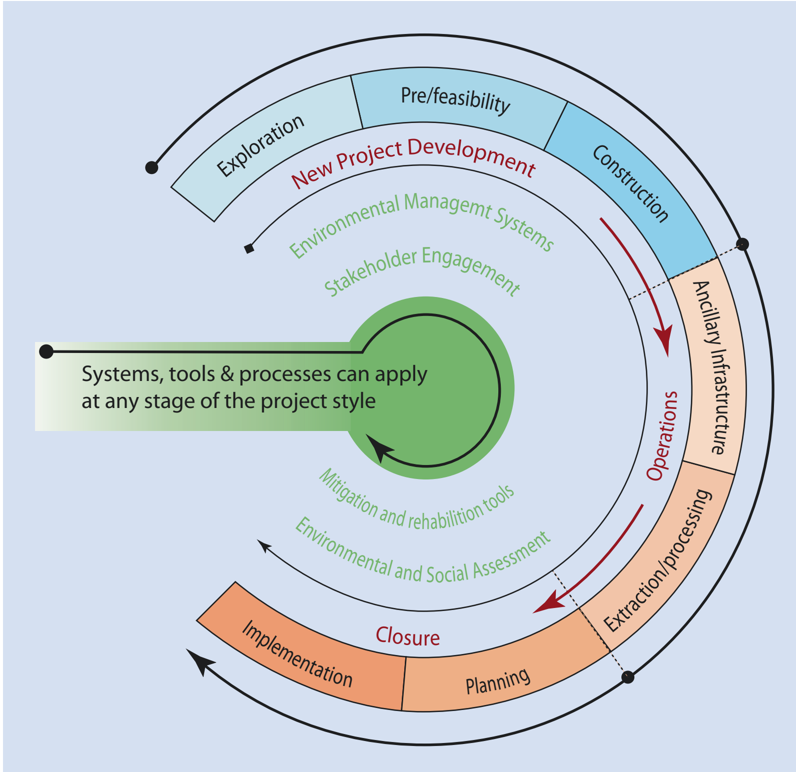

Fig. 7.21 Integrating biodiversity into the mining project cycle (ICMM 2006)

Regarding terrestrial habitat alterations, they must be diminished as much as possible and be consistent with the request to preserve critical habitats. Some controlling strategies include siting access roads in places that prevent adverse effects to critical terrestrial habitat, diminishing disruption to vegetation and soils, and implementing mitigation techniques adequate for the type of habitat. Other strategies are preventing the generation of barriers to wildlife movement and offering alternative migration routes if the generation of barriers cannot be avoided and manage vegetation growth along access roads and at continued above-ground facilities (IFC 2007).

Aquatic habitats are affected through variations in surface water and groundwater flows and generating incremented pressures on fish and wildlife communities. In particular, aquatic habitats in marine environments can be affected by several methods to extract resources such as dredge mining and deep sea mining or other activities such as offshore loading activities, port development, and tailings disposal. Assessment and control of adverse effects for marine environments must be in accordance with suitable host-country obligations to international decisions such as the United Nations Convention on the Law of the Sea (IFC 2007). To an adequate management of potential affections in aquatic habitats, it is essential to maintain water body catchment zones equal or comparable to predevelopment features, preventing stream channel stability by restricting in-stream and bank disturbance and constructing, maintaining, and reclaiming watercourse crossings that are stable and safe for the intended utilization and that decrease erosion, mass wasting, and degradation of the channel or lake bed (IFC 2007).

7.4.6 Airborne Contaminants, Noise, and Vibration Management

Airborne Contaminants

The provision of an adequate air environment to promote the health, safety, and comfort of people has always been and will continue to be an essential requisite for successful mining operations. Airborne emissions can take place during all stages of the mine cycle but specifically during exploration, development, construction, and operation activities. The main sources of these contaminants

Fig. 7.22 Air quality monitoring at a dust collection point near the mine (Image courtesy of Rio Tinto)

are dust from blasting, crushing ore, exposed surfaces such as tailings facilities, stockpiles, waste dumps, haul roads and infrastructure, and, to a lesser extent, gases from combustion of fuels in equipment (Fig. 7.22). Therefore, although dust is the principal emission associated with mines, a rank of gaseous and particle emissions are linked to mining and other on-site processing operations. The adverse effects of air emissions depend on the type of pollutant, its release features, and the nature of the receiving environment. The pollutants can be present in solid, liquid, and gaseous forms. Gaseous emissions generated by fuel combustion or mineral processing include pollutants such as sulfur dioxide and nitrogen dioxide that have well-defined harmful effects and are tightly controlled in the ambient environment and workplace (Commonwealth of Australia 2009b). Since management of air quality at mine operations is essential at all phases of the mine cycle, dust emissions from the dry surfaces of tailings facilities, waste dumps, stockpiles, and other exposed areas should be always minimized.

The sequence of dust control techniques are (a) prevention of generation of dust and its suspension in air, (b) suppression of airborne dust on-site, (c) collection of dust that could not be suppressed, and (d) dilution with auxiliary and main ventilation.

The control strategy for these environmental impacts depends on the type of contaminants, their sources, and rates of emission. It can range from simple dilution with ventilation air to complex procedures for removal of the contaminant prior to mixing with the mine air or suppression/elimination at the source. Thus, the International Finance Corporation (IFC 2007) recommended the following air pollution management strategies:

1. Dust suppression in roads and work areas, optimization of traffic patterns, and reduction of travel speeds.
2. Exposed soils and other erodible materials should be revegetated or covered promptly.
3. New areas should be cleared and opened up only where absolutely necessary.
4. Surfaces should be revegetated or otherwise rendered non-dust forming when inactive.
5. Storage for dusty materials should be enclosed or operated with efficient dust suppressing measures.
6. Loading, transfer, and discharge of materials should take place with a minimum height of fall and be shielded against the wind.
7. Conveyor systems for dusty materials should be covered and equipped with measures for cleaning return belts.
8. Chemical treatment at haul roads.
9. Selection of superquality mine explosives.
10. Installation of dust/gas extraction systems at crushers.
11. Spraying waste rock piles with sealants.
12. Storing crushed ore that is waiting to be processed in the mill in enclosed structures.

Fig. 7.23 Noise control (Image courtesy of Eldorado Gold Corporation)

Noise and Vibration

Noise is an inherent health hazard in mining industry. Raw material exploration, extraction, and processing can generate important levels of noise that can affect the surrounding environment. This is because the mining process is highly mechanized, from the earliest ore removal to final processing, and heavy equipment is essential at virtually every stage of operation. Thus, exposure to noise is a concern for workers who drive mechanized equipment as well as those who operate or work near stationary equipment such as haulage belts or crushing equipment. Moreover, communities can suffer noise and vibration adverse effects from mining operations in many forms, not only from the mine site: noise can take place at all stages of the logistics chain, including rail and truck haulage and activities at ports (Commonwealth of Australia 2009b). Exposure to noise levels above regulatory or recommended limits can result in hearing loss. It is important to emphasize that most hearing loss is preventable. Prevention can be achieved by eliminating noise sources, substituting quieter equipment, installing appropriate engineering controls, implementing administrative controls, using personal protective equipment, and adopting effective hearing conservation programs (Walter 2011).

Good practices in management of the noise sources must be defined based on the prevailing land utilization and the vicinity of noise receptors such as communities or community use areas. Where necessary, noise emissions must be managed (Fig. 7.23) through the application of methods that can include (a) implementation of enclosure and cladding of processing plants; (b) installation of proper sound barriers and/or noise containments, with enclosures and curtains at or near the source equipment (e.g., crushers, grinders, and screens); (c) installation of natural barriers at facility boundaries (e.g., vegetation curtains or soil berms); and (d) optimization of internal traffic routing, particularly to minimize vehicle reversing needs (reducing noise from reversing alarm) and to maximize distances to the closest sensitive receptors (IFC 2007).

The most significant vibrations are usually associated with blasting activities. In this sense, the increasing size and depth of open-pit mines and large diameter long-hole blast in underground mines further aggravate the vibration (Haldar 2013). However, vibrations can also be generated by many types of equipment. Measurement and control of vibration serves two purposes: (1) prevention of premature wear and failure due to structural damage and (2) reduction of noise levels. Measurement of vibration requires specialized equipment and experience in data interpretation.

7.4.7 Other Potential Environmental Impacts

Subsidence

Subsidence of the ground surface can be considered as ground movement caused by the extraction from underground of any resource, whether it be solid, liquid, or gas. It is commonly an inevitable consequence of such activities and reflects the movements that occur in the area so affected. The problems associated with subsidence have been recognized since antiquity. Agricola's De Re Metallica of 1556 talks about «a mountain or hill… subsiding by its weight» as a result of mining. The subsidence effects of mining raw materials are controlled by the type of mineral deposit, the geological features, specifically the nature and structure of the overlying rock or soil, and the mining method applied in the extraction process. In addition, time when subsidence occurs depends upon the type of mining, as does the reliability of subsidence prediction. Thus, the major objectives of subsidence engineering are prediction of ground movements, determining the effects of such movements on structures and renewable resources and minimizing damage. The surface displacements and deformations characteristic of subsidence will affect any use made of the ground surface. Consequently, subsidence can generate serious effects on surface structures, buildings, and communications and can affect agricultural land through the disturbance of drainage and alteration of gradient.

The creation of any subsurface opening produces deformations and displacements of the material, and these changes can cause the rock around a mine excavation to collapse into the mined void. The ground movements associated with such collapse tend to propagate to the ground surface, with the deformations and displacements experienced there being termed subsidence. Surface subsidence generally entails both vertical and lateral movements and can be discontinuous (steps, cracks, or cavities form at the surface) or continuous (the surface deforms smoothly). Discontinuous subsidence is generally of limited areal extent and is characterized by large vertical displacements. It occurs where material overlying an extraction zone collapses into the void, and its form depends on the mining method, the geometry of the extraction zone, and the geomechanical properties of the rock above the extraction zone (Harrison 2011). The presence of weak structural features (e.g., faults or boundaries between different geological materials) can lead to plug subsidence in which a large plug of material falls suddenly and instantly downward into the mine void; the speed and suddenness of the process means this is particularly dangerous. Mining methods such as block caving and sublevel caving also lead to discontinuous subsidence, but in these operations, use of an access to the surface area affected by the subsidence is generally prohibited. In the case of continuous subsidence above laterally extensive extraction zones such as longwall coal mining operations, observations of subsidence profiles or troughs above the mined areas have shown that they can be characterized on the basis of shape, in particular the absence or presence of an essentially horizontal central region.

Regarding the factors affecting mine subsidence, experience has revealed that many geological and mining parameters besides the width of the extraction zone can affect the magnitude of subsidence. The number and interrelation of these factors means that predicting in an accurate, quantitative manner the magnitude and time to subsidence onset is generally not straightforward. The main factors are the following:

1. Extraction thickness: the thicker the material mined, the larger the quantity of possible surface subsidence.
2. Mining depth: magnitude and time to onset of subsidence are dependent on depth.
3. Inclination of extraction horizon: asymmetric subsidence occurs where the zone being mined is inclined.
4. Degree of extraction: reducing the amount of material extracted will reduce the amount of subsidence.
5. Mined area: the critical width of a mined void must be exceeded in all directions if maximum subsidence is to develop.
6. Method of working: the amount of subsidence is largely controlled by the degree of caving induced by the mining method (e.g., complete subsidence for block caving and longwall mining and zero for room and pillar) together with the amount of support offered by any backfilling.
7. Competence of surrounding materials: because subsidence propagates from the mine level, the mechanical behavior of the rock adjacent to the mined void directly affects the initiation of subsidence.
8. Geological discontinuities: the existence of faults can increase and localize subsidence potential so strongly that in areas of adverse geological conditions the effects of the other parameters can be discounted.

9. Near-surface geology: the nature of any near-surface soils and unconsolidated rocks affects subsidence development, with both the thickness and mechanical characteristics of these materials being important.
10. Hydrogeology: the increased groundwater pressure can reduce the effective stress, thereby inducing shear on faults.
11. Elapsed time: subsidence does not occur instantaneously but over a period of time (Harrison 2011).

Measures that can be implemented to control and minimize subsidence damage fall into the categories of adoption of particular mining methods, post-mining stabilization, architectural and structural design, and comprehensive planning. In adopting a particular mining technique, the principal measures to consider are partial mining, changes to the mine layout, harmonic mining, backfilling, and changing the extraction rate. For post-mining stabilization, stabilization of complete mine sites extending over many hectares can be achieved by backfilling (as previously outlined), grouting, or, in the case of shallow voids beneath derelict or unused land, complete excavation and backfilling. Concerning architectural and structural considerations, where structures are to be built in areas of known or future mining activity, designs should be adopted that will tolerate the anticipated ground movements. Many design techniques are available to produce structures tolerant of subsidence.

Visual Impact

Mining activities, specifically surface operations, can generate negative visual adverse effects to resources linked to other landscape utilizations such as recreation or tourism. Potential contributors to visual impacts are roads and highways, erosion, changes in water color, haul roads, waste dumps, slurry ponds, abandoned mining installations (◘ Fig. 7.2), garbage and refuse dumps, open-pits, and deforestation. Regarding color changes, in areas where the color of the rock matches with the natural color of the terrain, visual impacts will be less than with sharp color contrasts.

The impact on landscape by surface mining depends on various factors; location, size, extracted volume, and mining methods can influence the impact of mining activities on the visual appearance of the land (Haney G 2010). Restored lands must conform to the visual features of the surrounding landscape. The reclamation planning should consider the vicinity to public viewpoints and the visual effect within the context of the viewing distance. Alleviation methods can incorporate specific location of screening materials including trees and utilization of adequate types of plants in the reclamation stage as well as changes in the location of ancillary installations and access roads. In this sense, visual absorption capability is described using three physical factors: slope, vegetation (including landscape texture), and geology (landform dissection). Visual absorption capability classifies the relative ability of a landscape to accept human alterations without a loss of landscape character or scenic quality. A typical example of visual impact is that produced from mine waste dumps and leach pads. This is because this adverse effect is a major concern for mines located in the proximity of populated areas or where the facilities are clearly visible from roads and highways.

Landscape alteration can generate an adverse opinion among potential observers and compromise the possible development of the surrounding territory. In fact, the evaluation of landscape and visual impact often is based more on the subjective perception of the observers, which includes cultural and social issues, individual opinions, aesthetic tastes and visual comprehension, and less on the real features of the visible alteration (Nicholson 1995). For instance, Las Médulas Roman Mine (◘ Fig. 1.7) was one of the most important visual impacts of mining two millennium ago, and at present UNESCO includes Las Médulas Cultural Landscape in the list of the World Heritage Sites. However, several aspects of landscape modification require to be objectively assessed to estimate the magnitude of change and offer an objective evaluation of the adverse effects originated by pre-existing mines or to be generated by new mining operations involving surface excavation. Landscaping can be undertaken about mineral workings to reduce their visual impact. For instance, a mine can be screened from view to some extent by the construction of embankments around it that are subsequently planted with grass and trees (Bell and Donnelly 2006).

To prevent visual impact, a Visual Resource Management (VRM) should be carried out. It was

Fig. 7.24 Revegetated waste rock areas (Image courtesy of Eldorado Gold Corporation)

originally created by the Bureau of Land Management (US Department of Interior), and the main goal is to manage public land in a manner that protects the scenic values of the lands. Thus, VRM includes inventorying scenic values and determining management aims for those values through the management planning procedure and then assessing suggested activities to establish whether they conform to the management purposes. The VRM system is split in two parts. The first step is the identification of visual values to determine the appropriate level of management. This step, called VRM inventory, has three components: scenic quality evaluation, sensitivity analysis, and distance zone measures. The second part of the VRM system is the analysis stage. It includes establishing whether the potential visual adverse effects from suggested surface-disturbing activities will meet the management goals defined for the area or whether design adjustments will be requested.

Fire and Explosions

Fires and explosions have the potential to kill people in addition to causing an environmental impact. Presence of methane is probably the most characteristic source for this issue although flammable and combustible liquids are often stored underground in most mines and pose a special fire hazard (WorkSafe New Zealand 2016). The content of methane is specific to underground mines where operations are focused on the exploration or extraction of coal or metalliferous mines and tunnels where methane is present at levels greater than 0.25%. For this reason, it is essential to develop fire and explosion risk assessments and to identify the measures required to prevent, manage, and mitigate those risks.

7.4.8 Revegetation

Reclamation management must consider soil structure and fertility, microbe populations, top soil developing, and nutrient cycling with the objective to convert the ecosystem as closely as possible to its early conditions (Sheoran et al. 2010). Thus, establishing vegetation is essential in reclaiming mined lands (Fig. 7.24). The establishment of vegetation can reduce erosion, significantly increase evapotranspiration, and reduce the amount of water that infiltrates the underlying waste material. Direct revegetation may allow many of the benefits of a store-and-release cover to be realized without the need to import large volumes of cover material (Borden 2011). For instance, revegetation of tailings impoundments can be particularly important to prevent dust generation from inactive tailings surfaces as they dry out. In this sense, some waste surfaces may be directly revegetated after minor physical or chemical modification, such as ripping to reduce compaction, addition of alkaline materials to increase the pH to near neutral, or the addition of organic matter. Thus, revegetation tests for mineral wastes may progress from nutrient analyses and grain-size distribution, to greenhouse trials, and to field revegetation test plots and plant tissue sampling (to determine metals uptake) (Borden 2011).

Revegetation fosters soil development, generates aesthetically landscapes, and facilitates post-mining land use. Thus, revegetation is the most broadly admitted and helpful manner of restoration of mine works with the objectives to decrease erosion and protect soils against degradation. The revegetation must be established with the plants elected in accordance with their capability to subsist and regenerate in the particular environment and on their capability to stabilize the soil framework. In this sense, numerous factors must be taken into account in an efficient mined-land revegetation procedure such as soil features, time of seeding, species seeded, and soil amendment application rates.

Revegetation in a zone impacted by mining works, once the final landform has been developed and an adequate growing medium generated, includes five main steps: (a) mine soil selection and placement procedures, (b) species selection, (c) planting, (d) seed collection and purchase, and (e) seedbed preparation. In general, the optimum moment to establish vegetation is defined by the seasonal pattern and reliability of rainfall. All the previous works must be finished prior the time when seeds are most likely to experience the conditions they need to germinate (Minerals Council of Australia 1998).

A plan for revegetation includes, but not limited to, descriptions of the revegetation schedule; species and amounts per square meter of seeds and seedlings to be used; methods to be used in planting and seeding, mulching techniques, and irrigation (if appropriate); pest and disease control measures, if any; measures proposed to be used to determine the success of revegetation; soil testing plan for evaluation of the topsoil results; and handling and reclamation procedures related to revegetation (Nelson 2011). Several immediate revegetation establishment options exist, including drill seeding, hydroseeding, broadcast seeding, and transplanting entire live plants or plant cuttings. In addition, the placement of mulch can increase soil moisture, provide a temporary cover to reduce erosion risk, moderate soil temperature, and increase the likelihood of seed establishment.

Mine Soil Selection and Placement Procedures

Correct revegetation processes of active open-pit mines start well early of fertilization and seeding. Thus, the most significant stage in surface mine revegetation takes place where the soil is chosen and located on the land surface. With the objective to obtain an optimum plant growth, the soil must be elected to offer physical and chemical features proper for the aimed post-mining land use. Fertilization and, in some instances, liming are significant elements of revegetation processes. The most efficient manner to attain a correct combination among soil characteristics, species, and post-mining land use is to choose and place surface-soil materials to generate a soil that is beneficial to vegetation congruent with the post-mining land use declared in the mining permission. Election and arrangement of surface spoils will have a crucial impact over vegetation success in post-mining land use. Lime, fertilizer, and organic component additions can be added to remediate issues of low soil fertility and/or moderate acidity.

Species Selection

Frequent issues associated with revegetation defeat are the inadequate election of plant species and their unsuitable mixtures. Sometimes, the chosen species are either not adjusted to the site characteristics or to the suggested land utilization. The species for establishment will be selected based on the future land utilization of the zone, soil characteristics, and weather conditions. Many rehabilitation processes are directed toward the reestablishment of native species. If the main goal is to restore the pre-mining conditions, then the species must be preset (◘ Fig. 7.25). However, a decision must be taken whether to utilize only local origin of the native species or to utilize a broad rank of sources. This decision requires to be made on a site-by-site basis, usually depending firstly on the degree of similarity between the pre- and post-mining environmental features.

Where the aim is the reestablishing of a diverse and permanent cover of local species, the

Fig. 7.25 Predetermined species for revegetation (Image courtesy of Daytal Resources Spain S.L.)

following methods of determining suitable species for the post-mining conditions should be followed:

1. Observe plant species growing naturally on any old disturbed areas near the rehabilitation site so that the effective colonizing species can be identified.
2. Observe the soil and drainage conditions to which the different local species are adapted, and match them with the conditions on the mine site.
3. Identify plant species that produce sufficient viable seed to harvest economically.
4. Consider habitat requirements where return of wildlife to the area is a significant element of post-mining land use.
5. Consider planting local legume species as they are often good colonizers and will improve soil fertility (Minerals Council of Australia 1998).

Three main types of plants are used for revegetation of mine sites: grasses, forbs, and trees. Grasses are the most generally seeded plants in revegetation procedures. They have fibrous roots that maintain soil in place to control erosion. Forbs are commonly utilized in mine revegetation combined with grasses, while trees are the final plant type; they are applied where forested or wildlife habitat land use is selected after mining. Where agriculture is the desired land use, legumes must always be taken into account for their capability to enhance soil fertility. Legumes are significant for revegetating mine sites since they transfer the «fixed» nitrogen to other elements of the plant/soil system. A population of legumes is crucial to an adequate revegetation, mainly on sites where topsoil replacement is not sufficient.

Planting

The planting techniques elected will be based on the size and nature of the mine sites and the species to establish. Direct seeding is potentially a costly effective and reliable technique to establish species that generate sufficient numbers of easily collected, viable seed with high germination, and seedling survival rates. Advantages include low cost, random distribution of plants, and no check on growth rates through planting out. Disadvantages include higher risk of failure through adverse climate conditions, competition from weeds, loss of seed by insect predation, and low seed germination and survival rates. For planting seedlings, a reliable supplier of seedlings or the establishment of an on-site nursery is obligatory (Fig. 7.26). Advantages are the effective utilization of forthcoming seed, control over species mixture and location, and less limitation on the species considered in the revegetation program. Disadvantages include higher costs for planting and/or nursery operation or purchase of seedlings, check in growth rate at planting, need to preorder or sow several months previous to anticipated utilization, longer planting time needed, and seedlings can deteriorate if planting is delayed.

Another option to planting is transplanting (Fig. 7.27). Transplanting of trees and ground covers is adequate for certain sites or amenity planting. Advantages include immediate solution and incorporation of species not amenable to other means of propagation. Main disadvantage is high risk of expensive defeats. Where individual mature trees are needed for the rehabilitation process, transplanting should be ended while suitable earthmoving and lifting equipment is on-site (Minerals Council of Australia 1998). In some

Fig. 7.26 On-site nursery (Image courtesy of Goldcorp Inc.)

Fig. 7.27 Transplanting of mature tree (Image courtesy of Eldorado Gold Corporation)

Fig. 7.28 Spreading mulch (Image courtesy of Tronox)

cases, the most usual method to seed and apply amendments is using a hydroseeder. Fertilizer, lime, mulch (Fig. 7.28), and seed are commonly mixed with water in the hydroseeder tank.

Seed Collection and Purchase

A consistent supply of adequate seed is crucial for the success of revegetation. Seed can require to be obtained from different zones with the aim to match site characteristics since there are many issues inherent in collecting native seeds. Seed of several species needs pre-sowing treatment. Thus, germination of most native legumes and a number of other species is improved by heat treatment. Most companies utilize seed mixtures including at least two or three perennial grasses, two or three legumes, and either a warm-season annual or a cool-season annual for quick cover. Thus, a broad variety of species is suitable for utilization in mine sites rehabilitation.

Seedbed Preparation

Methods selected for the preparation of the seedbed will be based on topography of the site, the required land use, the extent of soil amelioration and fertilizer utilization, and the sowing or planting method suggested. The objective in creating a seedbed is to place the seed in an adequate location for germination. For this purpose, points to consider include:

1. Prevent compaction, crusting, and subsequent erosion by avoiding disturbance to soils when wet and sticky or dry and powdery.
2. Timing of seedbed preparation and sowing is often critical for successful establishment of vegetation.
3. Where the topsoil contains significant quantities of seed of desirable species, care must be taken not to disturb the soil after these seeds have started to germinate, as this will cause a substantial reduction in plant establishment.

4. Where hand planting of seeds or seedlings is proposed, site preparation can best be limited to deep ripping (Minerals Council of Australia 1998).

Biosolids

Biosolids are «the dark, organic, and nutrient-rich materials produced as byproduct of current wastewater treatment practices» (EPA 2001). An increasing option to traditional waste disposal is the land application of biosolids. Since they include many nutrients and metals necessary for plant life, biosolids are capable to serve as fertilizers and as a mine reclamation alternative. Thus, biosolids have been utilized successfully at mine sites to establish vegetation. Not only do the organic matter and nutrients in the biosolids decrease the availability of toxic components commonly encountered in disturbed mine soils, they also build a healthy soil layer where little soil has been left. They can also be applied for treating acid mine drainage from abandoned mines. Biosolids are able to efficiently establish a vegetative cover on contaminated lands and limit the movement of metals through erosion, leaching, and wind. Depending on the amendments added, biosolids can serve many purposes, including pH control, metal control, and fertilization. Moreover, their adaptability enables them to conform to the specific features of any reclamation site.

7.5 Potential Social Impacts

A community is usually a diverse group of people with some common bonds. Diversity can come in the form of gender, ethnicity, religion, race, age, economic or social status, wealth, education, language, class, or caste. As a result, individuals of any community are likely to hold diverse perceptions about a mining operation and its activities as well as most other subjects. Individuals within a community will have different and sometimes overlapping associations with the mine as neighbors, employees, suppliers, and so on. It is not uncommon for disagreement and sometimes conflict to develop between different sections of a community in relation to mining operations (Evans and Kemp 2011). More recently, the term stakeholder has become a common term that is related to but distinct from community. A common definition of stakeholders is those who have concern in a specific choice, either as individuals or representatives of a group. This covers people who influence a decision, or can influence it, as well as those affected by it (MCMPR 2005). Thus, this term can include local community members, NGOs, governments, shareholders, and employees.

The social impacts of mining projects have received increasing attention in recent years. Although it has been commented that mining can be a crucial economic impeller for developing countries because it can facilitate industrialization along with the promises of wealth and jobs, mining can also be a source of social discontent. In fact, the social cost of mining interacts with other cultural and environmental issues that call for concerted efforts in addressing them. Thus, unmitigated negative social impacts have the potential to result in negative publicity, incremented litigation processes, and reputational damage or to delay, prevent, or close down mining in existing and prospective areas because of community concerns. In this sense, it is also interesting to introduce the concept of social risk. A social risk is the potential for an existing or planned project to have an impact on individuals or groups or, conversely, to be impacted by them. Like impacts, social risks are both positive and negative because of the potential for mining to generate social and economic opportunities, such as economic and community development and employment (Franks 2011).

Many factors can have a significant impact on the interactions and relationships between mining operations and communities, including various social and political aspects, as well as the stage of the mining life cycle involved. Mining is a truly global activity, involving many different types of organizations and communities in settings that range from arid mountains in parts of the Andes or remote areas within the Arctic Circle to established agricultural regions in developed countries and to tropical rainforest settings in developing economies in Asia (Evans and Kemp 2011). In this sense, political and legal frameworks within a country will have a significant impact on the scale and nature of the mining industry and can also often be the subject of intense community focus. Government capacity to regulate the minerals industry and manage the benefits of mining for the local communities has been identified as a crucial aspect by recent studies and has been the subject of recent World Bank projects in several developing countries.

In the nineteenth century and most of the twentieth century, all involved entities such as governments and mining companies paid little interest to the adverse impact of mining on indigenous people. Consequently, it has become almost impossible for different indigenous communities to commit successfully with contemporary issues that impact on their communities such as resource development propositions (Commonwealth of Australia 2007c). Based on the above, the social impacts of mining activities and projects have received increasing attention in recent years.

A social impact is considered as «something that is experienced or felt (real or perceived) by an individual, social group, or economic unit; social impacts are the effect of an action (or lack of action) and can be both positive and negative» (Franks 2011). Obviously, social impacts can vary in type and intensity and over space and time. Moreover, many times an environmental impact induces a social impact because mining activities can originate changes to community amenities, health, or accessibility and quality of water and land. Though it has been argued that mining can be a vital economic propellant for most countries, especially the developing ones, sometimes it can also be a source of social discontent. In fact, the social cost of mining interacts with other cultural and environmental issues that call for concerted efforts in addressing them.

If communities think that they are being unjustly treated or improperly compensated, mining projects can originate social tension and violent conflict (ELAW 2010). Communities feel especially vulnerable where links with different sectors of the society are weak or where environmental impacts of mining affect the subsistence and livelihood of local people. Thus, the main impacts of mining projects on social values can include (a) human displacement and resettlement and migration, (b) lost access to clean water, (c) impacts on livelihoods and public health, and (d) impacts to cultural and aesthetic resources (ELAW 2010).

However, it could be stated that well-managed mineral projects can deliver abroad range of long- and short-term profits. Thus, many countries have benefited from foreign exchange earnings, incorporation of new technologies, enhanced investment opportunities, construction of infrastructure, and education of mine workers and their families (Anderson 1997). Moreover, in some cases mine works form the most significant economic resource. In this sense, the closure of mine can have a strong unfavorable socioeconomic impact. The social issues originated by the closure of a mine can be partially mitigated through the retraining of the workers to newer employment possibilities and newer companies (Aswathanarayana 2005).

In spite of the social impacts and concerns, literature reveals that efforts at mitigating the impacts of mining have only focused on the environmental impacts and have been wrongly assumed that dealing with the environmental impacts alone would inevitably reduce the social impacts. The fact that policy initiative responses are usually geared toward environmental impact assessment implies that social impacts are necessarily not considered (Opoku-Ware 2010). Thus, social impacts are commonly mentioned exclusively in the context of environmental impact studies, alluding to impacts that affect communities causing changes in their welfare. Many companies have concentrated much effort on employment especially for indigenous people and have created programs to support them in their shift from welfare to work (Jantunen and Kauppila 2015).

Gender is obviously an essential aspect to understand the concept of community. Mining is usually a male-dominated industry, but women play significant roles in communities as workers, as family members, and as individuals and are generally very active forming groups in the community. In some situations, «special effort can be needed to ensure that women's perspectives are sought and that women are proactively included in community engagement and development programs because women are deprived of the access to the benefits of mining developments, especially money and employment» (Commonwealth of Australia 2006b).

7.6 Environmental Impact Assessment (EIA)

Including the environment into development planning is the most essential tool in accomplishing sustainable development. Because of the increased concern over the impact of human activity on the environment, most countries have adopted legislation requiring that the potential effects of new projects should be assessed. Consequently, environmental protection and economic development must be carried out in an integrated way. For this objective, the environmental impact assessment (EIA) process is essential to provide an anticipatory and foreseeing procedure for environmental management and protection in any development. EIA is a complex study that must be developed and approved by the government authorities where industrial operations are permitted. In other words, the process of establishing potential environmental effects of a proposed project is known as environmental impact assessment, and it must enable the best environmental option to be determined and adequate mitigation to be involved. Nowadays, environmental impact assessment and utilizing the required measures for industrial and mining projects are crucial to prevent and control environmental problems.

The environmental impact assessment procedure is an interdisciplinary and multistage process to assure that environmental characteristics are taken into account in decisions related to projects that can affect the environment. In a simple manner, the EIA process assists to detect the potential environmental effects of a suggested action and how those impacts can be alleviated. Thus, the principal aim of the EIA procedure is to inform decision-makers and the public of the environmental results of implementing a suggested project. The EIA process also helps as a decisive procedural role in the global decision-making procedure by fostering transparency and public involvement. It is important to bear in mind that the EIA procedure does not guarantee that a project will be changed or rejected if the process shows that there will be intense environmental footprints. In other words, the EIA process assures a documented decision but not indispensably an environmentally beneficial resolution (ELAW 2010). At the international level, lending banks and bilateral aid agencies have EIA processes that implement to borrowing and recipient countries (Ogola 2007).

7.6.1 Origin of EIA

Before the First World War, quick industrialization in developed countries generated a rapid decrease of natural resources. This process maintained to the period after the Second World War, originating important issues related to pollution, quality of life, and environmental stress. In early 1960s, investors notice that the projects they were developing were affecting the environment, including people. For this reason, pressure groups constituted with the objective of getting a tool that can be utilized to protect the environment. Consequently, several developed countries such as Australia, Japan, Sweden, or the USA decided to respond to these problems and established different environmental protection laws. For instance, Sweden published the Environmental Protection Act in 1969, Australia the same document in 1974, and the USA developed in 1969 the National Environmental Policy.

In those years, these documents were the first documented as official tools to be utilized to safeguard the environment. Regarding these documents, complications can take place where there is overlapping among regulation at national, regional, and local level. This can be the case in large countries such as the USA or to member states of the European Community. Furthermore, industries working on a global scale may be subjected to a great variety of EIA requirements, specific to each country of operation. However, although EIA legislation changes in complexity from one country to the next, there is a clear underlying theme: potential impacts of certain projects must be assessed and documented during the planning stage.

Likewise, the United Nations Conference on the Environment in Stockholm in 1972 and further conferences formalized EIA. Nowadays, all developed countries and many developing countries have environmental laws to restrict the environmental impacts generated by the industry. Principle 17 of Rio Declaration on Environment and Development in 1992 claim for utilizing EIA as a decision-making component to be applied in evaluating whether suggested activities are likely to have important adverse effects on the environment. Thus, EIA is carried out within the legal and/or institutional frameworks defined by countries and international agencies (Ogola 2007).

7.6.2 EIA Phases

The early stage of an EIA is termed the «Initial Environmental Examination (IEE),» and the second is the «Environmental Impact Studies (EIS)» or merely detailed EIA. IEE is developed to establish whether possible unfavorable environmental effects are important or whether mitigation measurements can be adopted to decrease or even remove the adverse results. The IEE includes a short statement of main environmental problems obtained using forthcoming information, and it is utilized in the first stage of project planning. The IEE also decides if further in-depth studies are required. Where an IEE allows offering a final solution to environmental issues of a project, an EIA is not needed.

EIS or detailed EIA is a process utilized to study the environmental effects, both positive and negative, of a proposed project and to assure that these consequences are considered in project design. Consequently, the EIS is based on predictions. The adverse effects can include all significant items of the natural, social, economic, and human environment. The study needs a multidisciplinary focus and must be carried out very early at the feasibility stage of a project. In other words, a project should be assessed for its environmental feasibility. Thus, EIS should be established an integral part of the project planning procedure.

Finally, the analyses of alternatives are carried out to define the preferred or most environmentally sound, financially viable, and benevolent possibility for accomplishing project goals. The World Bank directives request systematic comparison of suggested investment designs. For each alternative, the environmental cost is estimated as far as possible and economic data enclosed where feasible and the selected alternative stated. The analysis of alternatives must always incorporate the so-called no project alternative.

7.6.3 Impact Analysis and Prediction

Predicting the extent of impacts and estimating their significance are essential in environmental impact assessment processes. Prediction should be based on the available environmental baseline of the project area, being these predictions described in quantitative or qualitative manner. According to Ogola (2007), the considerations in impact prediction must include:

1. Magnitude of impact: this is defined by the severity of each potential impact and indicates whether the impact is irreversible or reversible and estimated potential rate of recovery; the magnitude of an impact cannot be considered high if a major adverse impact can be mitigated.
2. Extent of impact: the spatial extent or the zone of influence of the impact should always be determined; an impact can be site-specific or limited to the project area.
3. Duration of impact: environmental impacts have a temporal dimension and need to be considered in an EIA; an impact that generally lasts for only 3–9 years after project completion can be classified as short term; an impact that continues for 10–20 years can be defined as medium term, and impacts that last beyond 20 years are considered as long term.
4. Significance of the impact: this refers to the value or amount of the impact; once an impact has been predicted, its significance must be evaluated using an appropriate choice of criteria.

7.6.4 Methods for Identification of Effects and Impacts

There are three main methods for assessing environmental impacts: checklists, flow diagrams, and matrices (Sorensen and Moss 1973). Checklists are complete registers of environmental effects and impact gauges established to encourage the analyst to think widely about potential consequences of contemplated actions. However, this strength can also be a weakness because it can lead the analyst to ignore factors that are not on the lists. In any form, checklists are included in almost all EIA methods. In some cases, flow diagrams are utilized to look for action-effect-impact relationships. They allow the technician to visualize the connecting between action and impact. This method is most suitable to single-project assessments, not being recommended for large regional actions. Regarding matrix method, it is probably the most used in the EIA (Box 7.5: Matrix Method in the EIA). The matrix method in environmental impact assessment studies can be very helpful due to its simplicity and understandability of its algorithm.

7.6.5 EIA for Mining Projects

The EIA is the accepted method for evaluating proposed mining projects to obtain regulatory approval and to help companies plan for responsible development. From its early beginnings to its development over the past three or four decades, the EIA has become increasingly exacting, paralleling the development and expansion of international and national standards. Generally accompanied by environmental and social management plans, the EIA has undeniably become the essential regulatory document required of new mines by governments worldwide (Mitchell 2012). Thus, before any mining project can be carried out, it must undergo an environmental assessment as legislated by local or national governments. In this sense, each jurisdiction has different regulations governing environmental review, and some are more stringent than others (Stevens 2010).

Initially, an EIA was only requested in highly regulated circumstances. Nowadays, it is impossible to find a major mining project anywhere in the world that is not requested, either by legislation or corporate standards, to undertake an EIA. In general, an EIA for a mining project must include (a) assessment of the current state of the environment; (b) definitions of various project alternatives, assessments of their environmental impacts, and a comprehensive picture of the impacts of the project and its implementation alternatives, presented together with assessments of the scale and significance of such impacts; (c) plans for the mitigation of detrimental impacts; and (d) the publication of an accurate and coherent EIA report (Jantunen and Kauppila 2015).

Box 7.5

Matrix Method in the EIA

The matrix method was initially developed by Dr. Luna Leopold and others of the US Geological Survey (Leopold et al. 1971) in response to the Environmental Policy Act of 1969. As Gillette previously stated (Gillette 1971) «the law's instructions for preparing an impact report apparently are not specific enough to insure that an agency will fully or even usefully, examine the environmental effects of the projects it plans.» This method consists of a matrix that is primarily a check list designed to show possible interactions between development activities and a set of environmental characteristics. Combining these lists as horizontal and vertical axes for a matrix allows the identification of cause-effect relationships between specific activities and impacts. This matrix has (1) on the horizontal axis the actions that cause environmental impact and (2) on the vertical axis the existing environmental conditions that can be affected by those actions. This provides a format for comprehensive review of the interactions between proposed (anthropogenic) actions and environmental factors (characteristics and conditions). The entries in the cell of the matrix can be either qualitative estimates or quantitative estimates of these cause-effect relationships. The latter are in many cases combined into a weighted scheme leading to a total «impact score.» The original Leopold system was an open-cell matrix containing 100 project actions along the horizontal axis and 88 environmental «characteristics» and «conditions» along the vertical axis. This provides a total of 8800 interactions. However, in practice only a few of the interactions would be likely to involve impacts of such magnitude and importance to warrant detailed treatment.

Matrix methods identify interactions between various project actions and environmental parameters and components. They incorporate a list of project activities with a checklist of environmental components that might be affected by these activities. They should preferably cover both the construction and the operation phases of the project because sometimes the former causes greater impacts than the latter. Simple matrices are useful: (1) early in EIA processes for scoping the assessment, (2) for identifying areas that require further research, and (3) for identifying interactions between project activities and specific environmental components. Matrix method is probably the most used in the identification of effects and impacts. However, it also has their disadvantages since it does not explicitly represent spatial or temporal considerations and does not adequately address synergistic impacts. Figure 7.29 shows an example of an environmental impact matrix.

POTENTIAL IMPACTS	**MINING ACTIVITIES**	**Exploration and construction**	Early stages of exploration	Exploration drilling	Access road construction	Land clearance [for construction, etc.]	Obtaining construction materials	Construction related infrastructure	**Construction of ancillary infrastructure**	Roads, rail & export infrastructure	Pipelines for slurries or concentrates	Energy/power & transmission lines	Water sources, wastewater treatment	Transport of hazardous materials
Impacts on terrestrial biodiversity														
Loss of ecosystems and habitats				●	●	●	●			●	●	●		●
Loss of rare and endangered species				●	●	●	●	●		●	●	●		●
Effects on sensitive or migratory species				●	●	●	●	●		●	●	●		●
Effects of induced development on biodiversity					●	●		●		●				●
Aquatic biodiversity & impacts of discharges														
Altered hydrologic regimes					●	●	●	●		●		●	●	●
Altered hydrogeologic regimes				●			●							
Increased heavy metals, acidity or pollution				●		●	●	●		●		●	●	●
Increased turbidity [suspended solids]				●	●	●	●	●		●	●	●	●	●
Risk of groundwated contamination				●			●	●		●	●		●	●
Air quality related impacts on biodiversity														
Increased ambient particulates [TSP]				●	●	●	●	●		●		●		●
Increased ambient sulfur dioxide [SO_2]								●				●		●
Increased ambient oxides of nitrogen [NO_x]								●				●		●
Increased ambient heavy metals												●		
Social interfaces with biodiversity														
Loss of access to fisheries						●	●			●	●	●		
Loss of access to fruit trees, medicinal plants						●	●	●		●	●	●		
Loss of access to forage crops or grazing					●	●	●	●		●	●	●		
Restricted access to biodiversity resources						●	●			●	●	●		
Increased hunting pressures				●	●	●	●	●		●		●		●
Induced development impacts on biodiversity					●	●	●	●		●		●		●

Fig. 7.29 Example of an environmental impact matrix

EIA of mining projects request an approach of the entire life cycle of a mine, from exploration to mine closure and reclamation. Mining companies have realized that this is the most cost-effective method to planning and managing a mine and, particularly, to managing environmental effects (Weaver and Caldwell 1999). In summary, EIA can help to reduce costs and unscheduled project delays and minimize future economic and environmental liabilities. As aforementioned, a credible approach to EIA by the proponent company can serve to support the reputation of both the company and the mining industry generally as participants in planning for the sustainable development of the world's resources. In this sense, key aspects of the EIA procedure of mining projects must include (a) broad participation; (b) the public availability of documents prepared during the EIA procedure (EIA program, EIA report, and the statements and opinions of the competent authority and other parties), (c) review of the various project alternatives, (d) broad definition of the environmental impacts of the project, and (e) assessment of the environmental impacts that will occur during the various stages of the project (planning, construction and commissioning, operation, and closure) (Jantunen and Kauppila 2015).

In all the EIA procedure, consultations are an essential component of the environmental revision process. Consultations enable experts, government, communities, and indigenous people a possibility to discuss the adverse effects of the mining project, occurring at different phases in the review process. In this sense, mining companies that adhere to the principles of sustainable development commonly include consultations since the early prospection stage of the mineral deposit. As a result, the company will likely have addressed any significant concern with the project before it officially begins the review process.

Depending on the EIA method, liability for generating a mining EIA will be allocated to one of the following: the government agency or the project proponent. For proponents, a correctly coordinated EIA of a suggested mining project can help substantially to efficient planning. If EIA laws permit, either party can opt to recruit a consultant to carry out the EIA or handle certain parts of the EIA procedure. In this sense, some EIA laws accept conflict of interest generated where a mining company or other project proponent recruits an external consultant to draft an EIA. Utilizing a consultant carries the risk that the paper will be influenced in favor of developing the mining project. For this reason, some laws request consultants to be registered with the government and/or a professionally accredited organization in EIA preparation. In some cases, a consultant can be requested to file a statement disclosing any financial or other interest in the result of the project (ELAW 2010).

Stages of the EIA Process

EIA must be a procedure that proceeds throughout the life cycle of a mining project with results that become ever more accurate. ◘ Figure 7.30 shows the EIA process in connection to the commented life cycle of a mine (Jantunen and Kauppila 2015). Pre-feasibility reports usually offer an adequate basis for carrying out an EIA because they classically approach to the geology of the property, types of ore deposits, resource estimations, mining and mineral processing techniques, management of mining wastes, requirement for infrastructure, water and energy consumption, and labor and transportation costs. At this phase, estimates of these factors cannot be awaited to be especially accurate (margins of error can range between 20% and 30%). This is because the information about the project is still clearly imprecise.

To generate a suitable EIA, the planning of the project must be so advanced that its adverse effects can be evaluated accurately and reliably enough. For instance, it is essential to have precise knowledge of the technical solutions that will be utilized in the project to allow accurate quantitative and qualitative assessment of emissions. However, the EIA process cannot be left too late because it must be finished before a mining project can obtain the necessary permits. It is a sound practice to start the permit procedure for a project only after the EIA process has been finished. Thereafter, the EIA document and the qualified authority's statement on the report must be enclosed to the permit applications for the mining project. Thus, the EIA process is commonly formed by a group of procedural stages culminating in a written impact assessment document that will report the decision-maker whether to approve or reject a proposed mining project (ELAW 2010).

The first stage includes the identification and definition of the project or activity. Although this stage can be comparatively easy, definition of a project for the purpose of an EIA can be very difficult and even controversial if a mining project is large and has several phases, or multiple sites must be covered. The aim of this phase is to define the project with sufficient specificity to accurately establish the area of potential adverse effects and to incorporate activities that are strictly linked with the proposition, so that the entire scope of environmental impacts is assessed. In this step, the screening process establishes whether a certain project warrants preparation of an EIA. In some instances, especially if the potential impacts of a project are not understood, a previous environmental evaluation will be outlined to establish whether the project warrants an EIA.

The next step, scoping, commonly involves the interested parties that identify the key environmental problems that should be addressed in an EIA. This phase offers one of the earliest opportunities for members of the public to learn about a suggested project and to voice their opinions. Scoping can also show connected activities that can be occurring near a project or identify issues that request to be mitigated or that can originate the project to be canceled. In this procedure, the terms of reference serve as a roadmap for EIA preparation and should ideally embrace the adverse effects that have been identified during the scoping. A draft «terms of reference» can be

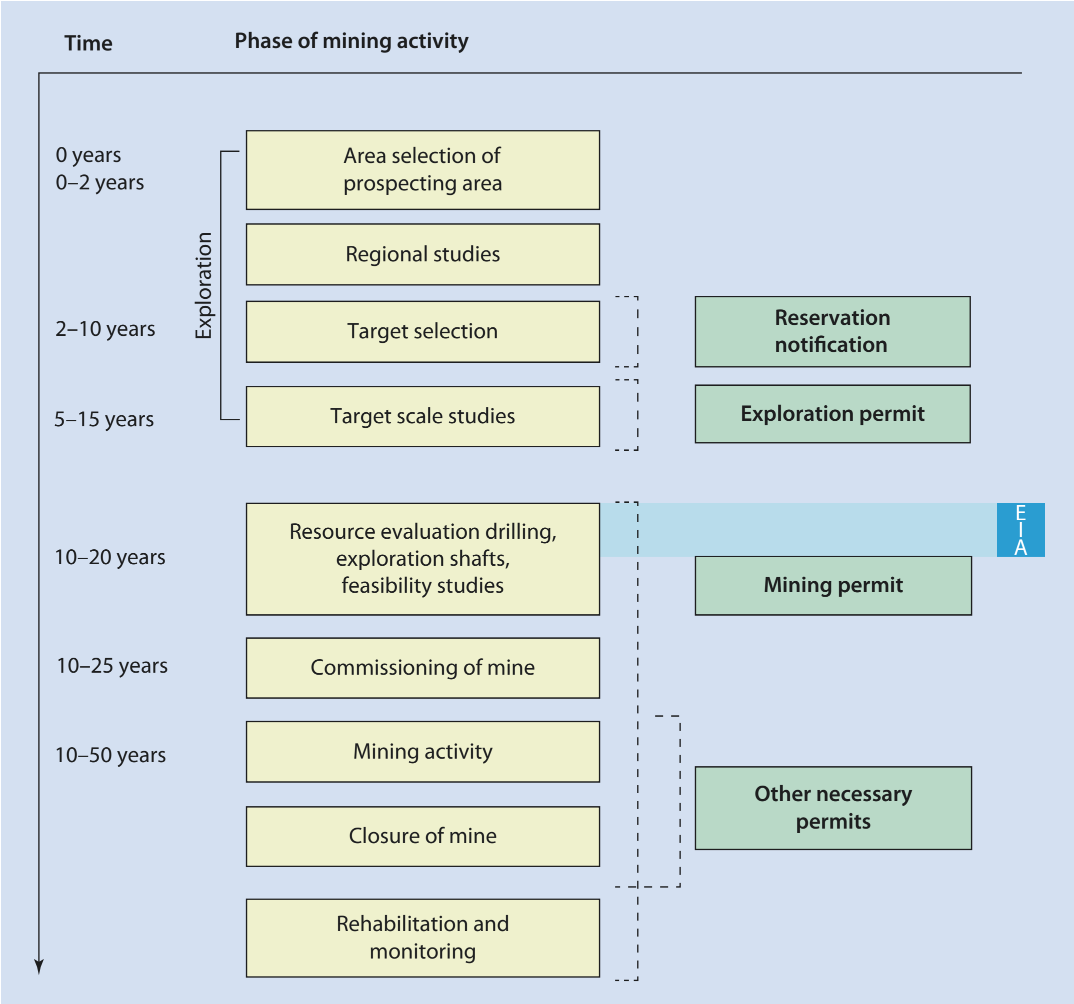

Fig. 7.30 EIA procedure in relation to the life cycle of a mine (Jantunen and Kauppila 2015)

made forthcoming for public revision and comment. Public revision at this first phase of the process originates a good opportunity to assure that the EIA is adequately framed and will address issues of community concern.

Then, a draft EIA is developed according to the terms of reference and/or the rank of problems identified during the scoping procedure. The draft EIA can also meet the content requirements of the global EIA regulations. This phase will ideally take part a broad range of technical specialists to assess baseline conditions, forecast the likely adverse effects of the project, and establish mitigation measurements. Regarding baseline studies, they identify the present status of the physical, social, and economic environment before the project starts, and technical studies define the features of the project. The technical details of the project will be obtained from pre-feasibility or feasibility studies that commonly are finished previous to beginning of the environmental assessment process. Baseline studies generally take several years to complete and, in some cases, commonly start at the beginning of the exploration stage (Stevens 2010).

The next stage generates a final impact assessment document that tackles the points of view and comments of the parties that revised the draft EIA. These comments can promote revisions or additions to the report of the draft EIA. In some instances, this final EIA will include an appendix synthesizing all of the commentaries received from the public and interested institutions and supply responses to those comments. A decision to approve or reject a mining project is commonly based on the information provided for the final EIA, but, in some cases, an environmental clearance can be just one stage in the mine permitting procedure. Once the mine is permitted, monitoring procedure is an important tool of project implementation. According to ELAW (2010), monitoring serves three purposes: (1) ensuring that required mitigation measures are being implemented, (2) evaluating whether mitigation measures are working effectively, and (3) validating the accuracy of models or projections that were used during the impact assessment process.

7.7 Social Impact Assessment (SIA)

Social impact assessment (SIA) can be defined as «the process of managing the social issues of projects.» To be efficient, the management of social issues requires to begin from the moment a project is early planned right through to further closure. Corporations can carry out SIA as part of their liability to address their social impacts and their wish to obtain a social license to operate. The origin of this type of study was in the 1970s, and the main goal of SIA has varied from early concerned about the adverse impacts of a project to being more concerned about how a project can be improved. This is with the aim of increasing the profits to communities so that both communities and companies can benefit from the project. These studies will have more importance in the near future, and its request will continue to increase for several reasons, including the incrementing investment in developing countries. In this sense, a combined action of weak institutions and decreasing land accessibility generates potential for disagreement between companies and communities, mainly if the risks are not early defined and mitigation planning is not implemented or not carried out in cooperation with the impacted peoples themselves.

In addressing the social aspects of sustainable development, social impact assessment early emerged as a component within environmental impact assessment (EIA) used to evaluate, moderate, and invariantly mitigate the impact of planned interventions (Esteves et al. 2012; Mahmoudi et al. 2013). The impact of projects and policies on the social welfare of communities is clearly a topic of increasing concern, which justifies the increased development and practice of SIAs in the last years (e.g., Vanclay and Esteves 2011). Moreover, SIA is a common requirement of regulatory approval processes at the project approvals phase for mining and processing stages in many jurisdictions.

The good practice of SIA accepts that social, economic, and environmental issues are inherently interconnected. Thus, change in any of these fields immediately generates changes in the other domains. According to Esteves et al. (2012): there is consensus on what good SIA practice is: (a) it is participatory; (b) it supports affected peoples, proponents, and regulatory agencies; (c) it increases understanding of change and capacities to respond to change; (d) it seeks to avoid and mitigate negative impacts and to enhance positive benefits across the life cycle of developments; and (e) it emphasizes enhancing the lives of vulnerable and disadvantaged people.

Social impact assessment has been early included within the field of Sociology and related sub-areas (Environmental Sociology, Human Geography, etc.), but different professionals from many disciplines have developed experience in the field. It is essential to consider the SIA in context with the other parts of the project, specifically the environmental impact assessment that must be also submitted with the application for an exploitation license (BMP 2009). Social impact assessment and management are the responsibility of community relations practitioners at most mining operations. However, there is a need for mining engineering professionals to be familiar with such perspectives because efficient management needs integration across all aspects of the operation. SIA and impact management are most effective where carried out in all the life cycle of mining, including all of the activities from exploration, construction, extraction, and processing, through to post-closure, as well as also incorporating recycling and waste management. The diverse social impacts across the mine life cycle stages and the extraction and resource processing phases require a complete rank of approaches to assessment and management.

7.7.1 General Overview of SIA

Social impact assessment involves «the processes of analyzing, monitoring, and managing the social consequences, both positive and negative, of planned interventions (policies, programs, plans, projects) and any social change processes invoked by those interventions.» Its first goal is to achieve a more sustainable and equitable biophysical and human environment (Vanclay 2003). Contemporary SIA arguably began along with EIA in the early 1970s in response to the formal requirements of the National Environmental Policy Act (NEPA) 1969 of the USA. The first SIA document was the publication in 1994 of the «Guidelines and Principles for Social Impact Assessment» by the US Inter-organizational Committee.

A milestone case in the establishment of SIA was the inquiry at 1974 by Chief Justice Thomas Berger into the suggested Mackenzie Valley gas pipeline from the Beaufort Sea to Edmonton (Alberta, Canada). It was the first occasion that social impacts had been formally taken into account in project decision-making. The SIA finally recommended that the project be postponed for at least 10 years to enable sufficient time for land claims to be settled and for new programs to help the native population. «The findings were, at the time, unprecedented and marked the start of a huge growth in SIA» (Joyce and MacFarlane 2002). Today, many institutions and national governments consider SIA as a mandatory activity for project proposals.

Other procedures related to social impact assessment are health impact assessment (HIA) and strategic environmental assessment (SEA). In most EIAs, HIA is usually included under SIA. HIA is a wide concept that implies an interest in the safeguarding and improvement of human health. Regarding SEA, it is carried out much earlier in the decision-making process than EIA, being thus a key tool for sustainable development. SEA aims to include environmental and sustainability aspects into strategic decision-making procedures such as the formulation of policies, plans, and programs.

7.7.2 SIA for Mining Projects

Large-scale mining projects can generate different and intense social impacts. They can differ significantly based on the duration of the project, the position of populated areas related to the project area, and the potential mine expansion planning. Most EIA guidelines require social impact analysis. This implies that specialists in several fields are involved in planning, implementation, and monitoring throughout the mining project life. In this sense, it is essential to take into account the social impacts of mining on the surrounding environment and affected communities and to include social impact assessment into the operational activities of a mine as a management tool.

The social impact assessment should consider baseline information related to at least the four following areas: (1) changes in access to and power over local resources (land, water); (2) changes in the characteristics of a population (size, composition, traditions, productive activities); (3) divergent perceptions between decision-makers, the mining company, and local people about the distribution of economic benefits and social/environmental costs of a large mining operation; and (4) land property and use (ELAW 2010). For instance, relocation of a population is a vital social problem. To resolve this issue, environmental impact assessment must incorporate detailed information about compensation, relocation planning, and information about consideration to guarantee people similar quality of life.

Phases of a Mining Social Impact Assessment

A list of sequential steps should be followed in the SIA process, drawn primarily from the environmental impact assessment (EIA) steps (Arce-Gomez et al. 2015). Thus, Franks (2011) affirmed that mining social impact assessment can include a number of distinct but iterative phases within an adaptive management process (◘ Fig. 7.31): (1) scoping and formulation of alternatives, (2) profiling and baseline studies, (3) predictive assessment and revision of alternatives, (4) management strategies to avoid and mitigate negative social impacts and enhance positive impacts, (5) monitoring and reporting, and (6) evaluation and review.

The scoping stage establishes the criteria for the further stages of assessment and management by determining the scale, timing, and focus of the assessment, establishing who is likely to be impacted and detecting the actions that are likely to result in impacts. In this stage, alternative possibilities must be defined for further studies and a first evaluation of the impacts of these alternatives carried out. The output of this phase can be to consider the aim, scope, scale, priority issues, and terms of reference for the following phases of assessment and management.

The second stage includes understanding the communities and stakeholders potentially affected

Fig. 7.31 Phases of social impact assessment within an iterative adaptive management process (Franks 2011)

by the activity through social and economic research. Profiling includes studies of the social and economic features of an area at a given point of time. In turn, baselines are an evaluation of the state of a community before a mining activity occurs. Thus, baseline information must generate a clear description of present social conditions in the area potentially impacted by the project before it is realized.

Regarding predictive assessment and revision of alternatives, the outcomes of predictive assessment are generally prioritized by their scale and level of significance. They are utilized to offer feedback to stakeholders and project developers with the aim of modifying and revising the project. They allow them to make the decision to which suggested project alternative best accomplish the goals of the project while still improving social outcomes and preventing negative impacts. Different scenarios for the project design might be significant to describe apart from describing the zero alternative where the possible consequences are explained if the mining project is not finally developed.

The monitoring and reporting stage includes collection, analysis, and dissemination of information through time. As a rule, a well-defined monitoring plan shall include:

1. Outline of the monitoring methodologies to be applied to measure progress.
2. Baseline information on which progress can be measured.
3. Well-defined indicators for each program and identified impacts in the SIA: the indicators can be quantitative or qualitative, and they shall be of scientific quality.
4. Frequency: while baseline information provides a picture of the present situation, explicit and verifiable parameters are needed in order to assess the progress made (BMP 2009).

The final phase, evaluation and review, evaluates and reviews both assessment and management processes. The reconciliation of impacts estimated in the assessment stage with the actual impacts undergone during implementation will contribute to refine and enhance future perspectives. A well-defined evaluation plan shall include an outline of the evaluation methodologies to be applied and a plan of action for handling the outcome of the evaluations.

7.8 Reclamation Case Studies

■ **Sanquelim Iron Ore Mine Reclamation (Goa, India): Courtesy of Vedanta**

The Sanquelim group of mines is located in the North Goa District of Goa State (India) covering an

Fig. 7.32 Afforestation using cinnamon (Image courtesy of Vedanta)

area of 203 Ha. Sanquelim group of mines were operated since 1956–1957 for production of iron ore and subgrade ore. The ore deposit was broken in six pits. The mines have been reclaimed since the 1980s with environmental considerations and community infrastructure requirements. Where major mining operations were discontinued in late 1990s, there were no legislations in place for a systematic mine closure planning. However, the company proactively carried out systematic and scientific mine closure plan. The reclamation activities mainly comprised three main aspects: extensive afforestation, conversion of some parts of the pits into water bodies to harvest rainwater, and utilization of existing building infrastructure for benefit of community.

Afforestation

The total area of mine leases is 203 Ha, out of which *about* 105 Ha has been efficiently restored by afforestation. The open-pits were consistently backfilled by constituting benches making it viable for carrying out plantation. Company has planted more than 750,000 saplings on the Sanquelim iron ore mine. Initially, most of the areas were covered by planting fast growing plants like *Acacia auriculiformis* and *Casuarina equisetifolia*. These species were mainly planted as nurse crop to prevent erosion on dumps and stabilize the dumps. The company also tried growing cashew plants based on their experience at Orasso Dongor mine (Sesa's First mine).

After the dumps were stabilized, company selected one of the reclaimed mine pits to experience with diverse afforestation methods utilizing native horticulture and forest species. Most of the horticulture crops growing in Goa (e.g., mango, banana, guava, pineapple, cinnamon; Fig. 7.32) were planted with success. Use of leguminous cover crop like plumeria seeds was used to sow in the areas under acacia and eucalyptus plantation. The plumeria creeper grew luxuriantly over the trees and over the time killed the acacia and eucalyptus plantations naturally, thus making the stabilized land available for plantation of native species.

Pisciculture

Along with afforestation, a major part of mine pits were also retained or converted into water bodies by harvesting rainwater. In order to add value to the water bodies, the company approached the National Institute of Oceanography to establish the option of cultivating freshwater fishes in the

Fig. 7.33 Butterfly park (Image courtesy of Vedanta)

open-pit filled with rainwater. The pisciculture project was taken up in 1990, and, as a result, the cultivation of fish was successfully carried out, and the pit was abundant with freshwater fish like rohu, katla, common carp, etc. The project has also resulted in increase in bird and butterfly activity in the area.

Reclaiming the Old Building Infrastructure

The reclamation was not restricted to growing of plants but also for the old infrastructure like buildings and workshops that were put to productive use for communities. The mine workshop was converted into a technical school imparting education to local youth, and the residential quarters were converted into the football academy to cater to the needs of the local community.

Biodiversity Management Plan

After the results of previous reclamation methods used in one of the mine pits, it was decided to bring the other areas within the Sanquelim mine also under biodiversity plantations, and hence a Sanquelim Mine Management Plan was prepared. In consultation with forest department, the mature acacia plantations were proposed and to plant various native species to improve the biodiversity of the areas. Under this plan, various projects such as a medicinal garden, a butterfly park, and a bamboo serum were conceptualized and implemented.

Two medicinal gardens, namely, Nakshatra Vatika and Charak Vatika based on constellation, zodiac signs, and Ayurveda, respectively, were developed. The idea behind it was to spread awareness among the locals and school students about medicinal plants growing in our surroundings and its benefits. Each plant is identified and provided with other details such as medicinal value. Regarding the butterfly park (Fig. 7.33), in its life cycle, the butterflies require two types of plants to survive, namely, host plant and nectar plant. If both types are available, they naturally attract the butterflies. Various plants identified as host and nectar plants (flowering plants) were planted on the mine site with the aim to attract butterflies. This has added the beauty of the area increasing also the biodiversity.

Bamboo is one of the frontrunners of environmental rejuvenation, being the quickest growing species among all other woody plants. Its capability to rejuvenate itself without being planted is most advantageous because cutting bamboo

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Fig. 7.34 Bamboo Pavilion (Image courtesy of Vedanta)

encourages the growth of new ones; they grow to its fullest height in 60 days compared to the woody plants which take 60 years. With an aim to promote bamboo cultivation, various species of bamboo were collected from across India. More than 25 varieties of bamboos have been grown and each of them was identified. Further to support the cause of bamboo promotion, a huge structure made out of locally available bamboo was constructed. This Bamboo Pavilion (Fig. 7.34) is used as an exhibition hall cum training center for self-help groups.

In order to assess the reclamation status, it is very important to regularly carry out various biodiversity studies. In a recent study, it was observed that there are different species of mammals, birds, butterflies, insects, reptiles, and amphibians in the restored mine zone. This shows that the biodiversity of the area has increased significantly.

Cooljarloo Heavy Mineral Sand Mine Reclamation (Perth, Australia): Courtesy of Tronox Ltd.

The Cooljarloo heavy mineral deposit that lies within the Perth Basin in Australia contains ilmenite, rutile, and zircon, which were produced from igneous and metamorphic rocks in the adjacent Archaean shield, separated in near-shore sediments through different stages of weathering. As the mineralization is extracted, overburden and sands with a small content of valuable minerals are backfilled into the void, clay waste is pumped to solar drying cells, and the surface is recontoured to look like the original landscape, previous to re-spreading topsoil and seeding for reclamation.

Thus, the objective of rehabilitation at Cooljarloo is to establish safe and stable landform (Fig. 7.35) capable of supporting a sustainable native ecosystem similar to that existing in adjacent areas of unallocated Crown land. To meet this objective, rehabilitation standards have been established that indicate how each component of the rehabilitation cycle will be implemented. The standards have been developed over many years of trial and error and now seem to be producing quality results in the field. Outlined below is a broad overview of some of the aspects contained within the standards.

Subsoil Reconstruction

The upper soil profile is formed with a layer of coarse to medium-grained sands, referred to as Class 1 material, which provide suitable conditions

Fig. 7.35 Tailings landforming (Image courtesy of Tronox Ltd.)

for vegetation establishment. The lower soil profile is usually formed with sands containing a higher clay content to assist in water retention within the root zone (referred to as Class 2 materials). Watercourses are constructed during landforming to ensure appropriate surface water flow across the site is maintained. Infiltration embankments are constructed to increase water retention and minimize water erosion on slopes.

Topsoil Placement

Topsoil is stripped ahead of mine path at the time of mining and stockpiled for use where the area is rehabilitated. Topsoil contains a good source of seed that becomes less viable as the stockpile ages. A portion (10%) of freshly stripped topsoil with older stockpiled topsoil is currently blended on all rehabilitation areas, which increases the amount of viable seed that is distributed at the time of topsoil placement.

Topsoil Stabilization

The topsoil must be stabilized to prevent wind and water erosion. This is done by spreading native mulch and sowing a cover crop of oats. Native mulch is a blend of freshly cut native vegetation harvested on mine path and tub ground woody material that is windrowed during clearing (Fig. 7.36). As fresh harvested mulch is becoming depleted, resource alternatives are being trialed, including the use of Terolas, an emulsion that binds the topsoil together while allowing infiltration of water and germination of seedlings. This product will be used in conjunction with tub ground and fresh harvested material over areas on Dam 8.

Native Seed Distribution

Native seed picked by the Billinue Aboriginal Community (Fig. 7.37) and from seed suppliers is spread over all native rehabilitation areas. Several vegetation groups are established into the rehabilitation at Cooljarloo. Each group corresponds with a particular landform characteristic and requires a particular mix of seed. All seed purchased is of local provenance ensuring similar species are grown as the surrounding UCL. The 2010 rehabilitation season will involve the reintroduction of the DRF *Andersonia gracilis* at Site 16 within the Falcon tenement via the return of fresh topsoil stripped from the original plant populations.

Rehabilitation Monitoring

Rehabilitation monitoring is conducted annually to assess the quality of rehabilitation against a set of performance targets, known as Completion Criteria, for various aspects for rehabilitation (e.g., species richness or landform stability). Reporting

Fig. 7.36 Tub grinding (Image courtesy of Tronox)

Fig. 7.37 Billinue seed collection (Image courtesy of Tronox Ltd.)

performance against Completion Criteria gives confidence that the rehabilitation will meet the objectives and not be a lingering liability for the company or the state.

Jabiluka Uranium Mine Reclamation (Jabiru, Australia): Courtesy of Energy Resources of Australia

Jabiluka exploitation is situated within the Alligator Rivers area and is about 230 km east of Darwin and 20 km north of Jabiru, being this area a major uranium-bearing zone. The mine site of Jabiluka and associated facilities are within the Jabiluka Lease surrounded by the Kakadu National Park. Principal land utilization for this region includes national park, fishing, Aboriginal traditional uses, and mining. Work began on rehabilitating the disturbed land on the Jabiluka Mineral Lease in 2003 where the surface and subsurface facilities were dismantled and the open-pit and decline were backfilled.

Revegetation

Revegetation is an essential part of the progressive reclamation activities that have been taking place at Jabiluka. Revegetation of the disturbed areas at the Jabiluka footprint took place in three stages over a decade. The Energy Resources of Australia (ERA) formed a strategic partnership with a local indigenous supplier Kakadu Native Plants, which raised saplings from seeds collected within the lease area. Traditional owners consulted on native species, density, and landforms, and several company indigenous trainees and workers were incorporated in the planting of saplings. Revegetation of disturbed areas began in 2005 with the planting of 7560 local native seedlings, being the seeds from native species collected and germinated. As of February 2014, 36,000 individual tube stocks had been planted within the Jabiluka mine site footprint with survival of 48% noted during the June 2014 routine periodic inspection. In 2015 the final phase of the revegetation project at Jabiluka was completed.

Water Management Pond Rehabilitation

In 2013, ERA committed to rehabilitating the Interim Water Management Pond. The program of work included removal of the pond liner and concrete spillway, relocation of waste rock stockpiles, regrading of fill surfaces, and excavation work. The land was reshaped and recontoured so that it was similar to the previous landform. Erosion matting and rock drainages were used to monitor erosion. The removal of the Interim Water Management Pond was completed in October 2013. Works go ahead to revegetate the primer area of the Management Pond. Thus, during 2014 a further 4678 native tube stock trees were planted at the landformed pond site. ◘ Figure 7.38 shows the evolution of the pond from 2011 to 2016, after complete rehabilitation.

Jabiluka is actually under long-term care and maintenance. Current weed, fire, and water quality management is in place at Jabiluka, incorporating monitoring in the care and maintenance stage that is regularly reviewed. Regarding weed control, in 2015 ERA embraced a qualitative estimation to weed management with the aim of evaluating trends in weed management zones, backed by regular on-ground observations. Thus, weed management operations are controlled by land management approach that addresses priority species such as annual *Pennisetum*, mission grass, and rattlepod. In-field weed monitoring shows that a progressive reduction of weed had been produced.

Ekati Diamond Mine Reclamation (Northwest Territories, Canada): Courtesy of Dominion Diamond Corporation

The Ekati mine site is situated in the Lac de Gras region of the Northwest Territories, about 250 km northeast of Yellowknife (Canada). The Ekati Diamond mine (named after the Tlicho word meaning «fat lake») (◘ Fig. 5.29) is the first surface and underground diamond mine in Canada. It is a remote mine accessible only by air and by winter road for 2–3 months of the year. The company understands the importance of reclaiming the Ekati mine site so that it can be returned to a viable northern environment at the end of operations. The goal of reclamation is to keep the site safe for human and wildlife use. This involves arranging rocks and plant life in a variety of patterns to determine which pattern allows the vegetation to grow best and which offers protection from erosion. Thus, the use of vegetation in the final cover system will enable a more economical cover design and also blends itself into the natural tundra landscape. Similar to the sections of a garden, the test areas have been seeded with various configurations of native grasses to develop an initial ground cover.

Fig. 7.38 Evolution of Water Management Pond rehabilitation from 2011 to 2016

Fine processed kimberlite is discharged as a slurry to Long Lake Containment Facility (LLCF) and Beartooth open-pit. The overall reclamation goal for the LLCF is the design and construction of a long-term cover that will physically stabilize the processed kimberlite with a landscape that will be safe for human and wildlife use. For this purpose, it is essential to define a combination of vegetation and rock cover system to physically stabilize the processed kimberlite. Vegetation is planned to be the main stabilization component. Rock placement is intended to promote a localized environment for vegetation growth and provide larger-scale wind and water erosion protection (Fig. 7.39). Short-term focus of reclamation research has been to establish and evaluate vegetation growth directly within processed kimberlite including natural colonization, vegetation/rock plots, annual cover crop trials, plant species trials, soil amendments, and plant tissue analysis.

Since 2004, native northern alkali goose grass has been naturally colonizing on the east side of the LLCF. Rate of vegetation colonization is annually analyzed. Historical natural colonization and establishment in research areas indicates high potential for goose grass. Regarding annual cover crop trials, temporary ground cover until permanent vegetation is established. Control erosion provides micro-niches for colonizing plants and adds organic matter to the soil environment. In addition, there have been some investigations into the plant species best adapted for revegetation of the processed kimberlite in the LLCF. Preliminary investigations indicate that revegetation with grass has been effective and initial monitoring has indicated specific species that are better adapted to the conditions of LLCF.

Recent soil chemistry test results on new kimberlite in LLCF have indicated elevated sodium concentrations and pH when compared to older processed kimberlite test results. Elevated sodium results in increase in the sodium adsorption ratio (SAR). Thus, elevated SAR values can make it difficult for plants to obtain other essential nutrients due to competition from the excessive sodium. For this reason, in 2013 small field-scale trials were constructed to evaluate the potential of lowering the SAR through the additions of chemical amendments such as alfalfa pellets, gypsum, and/or calcium nitrate.

In summary, the main 2013 to 2014 LLCF reclamation research and monitoring was the following.

Fig. 7.39 2013 goose grass in the boulder field (July 2014) (Image courtesy of Dominion Diamond Corporation)

Vegetation/Rock Plots

Two areas totaling approximately 7 ha were seeded in the fall of 2013. In the winter of 2014, rock was placed in four configurations within the seeded areas. In 2014, vegetation monitoring of the rock/vegetation plots consisted of determining the survival rate of the tussock cotton grass seedlings and collection of field observations by walking through and photographing the site. Additionally, baseline soil chemistry data were collected within the rock plots. Samples were obtained from 0 to 15 cm and 15 to 30 cm from upper, middle, and lower slope locations in each of the three rock pattern areas. The vegetation rock plots were observed in June 2014 following freshet to gain insight into surface water flow. The data suggest that the most important factor affecting tussock cotton grass seedling survival is competition from other plants and is not directly related to the rock pattern, except perhaps indirectly through its influence on vegetation growth.

Plant Species Trials

Historically, the primary role of vegetation in mitigating the effects of disturbances was to provide a readily established ground cover to control surface erosion. To achieve that end, the use of commercially available agronomic grasses was common and widespread. With this objective in mind, plant species trials using native grass cultivars, locally harvested native plant propagules, and combinations thereof have been an important component of reclamation research at Ekati. In 2013, a trial involving eight grass species and one native legume was established. The plant species being investigated were slender wheatgrass, slough grass, tufted hair grass, fall rye, reflexed locoweed, bluejoint reed grass, creeping red fescue, spike trisetum, and Canada wild rye. Each species was hand seeded into a 6 m-long row and one row consisted of a mix of the grass species. With the exception of slough grass, all species have established and are doing reasonably well. Also in 2013, 40 mountain cranberry seedlings, grown from seed collected on site, were planted in the area colonized naturally by goose grass.

In 2014, 563 seedlings grown from seeds collected on the mine site were planted. Of those 563 seedlings, 210 were tall water sedge, 60 were short water sedge, 180 were tussock cotton grass, and 113 were nodding cotton grass. Various numbers of those seedlings were planted at 11 different

Fig. 7.40 Typical wet tundra species planting scenarios in LLCF: 30 tall water sedge and 35 nodding cotton grass seedlings at location EK1 as planted June 28, 2014 (Image courtesy of Dominion Diamond Corporation)

locations. Each of those species has its own habitat requirements, but in general all would normally be found growing on moist to wet tundra or in shallow water (Fig. 7.40). Where seedlings were counted, their height was measured, and percent ground cover was estimated along each row in the plot. In 2014, only seedlings in each row were counted (selective grazing by sik siks had affected many of the plants, rendering height and percent ground cover inapplicable). The cranberry seedlings planted in 2013 were monitored by determining the size of every living shrub.

Annual Cover Crop Trials

In 2013, eight grass species, one native legume, and 40 mountain cranberry seedlings were planted. In 2014, transects were established in each of the treatment areas, percent ground cover was estimated, and plant stems were counted. In this year, a total of 563 seedlings grown from seed collected on the mine site were planted in various locations across LLCF. The seeding operation was conducted in stages. First, the surface of the area to be seeded was loosened by pulling a weighted chain harrow across it with a track-mounted side-by-side ATV. Seed was then broadcast at 100 kg/ha using a large tire spreader pulled behind the ATV. A final pass with the chain harrow and a roller was conducted to incorporate the seed and improve seed to soil contact.

In 2014 and 2015 (Fig. 7.41), annual cover crops were planted over 18 ha in part of the LLCF. These hectares were seeded with barley and fall rye cover crops. Species trials include test growth of native grass cultivars and native plant seed and/or seedlings directly within processed kimberlite. In 2015, 15 new species of seedlings and seeds were planted LLCF. Monitoring results suggest barley is better adapted than fall rye.

Soil Amendment Trials

A small trial plot area was constructed in 2013 to test the effectiveness of various soil amendments in modifying the elevated sodium levels in PK. Gypsum and calcium nitrate were applied at 1.5 tons/ha, alfalfa pellets at 10 tons/ha. In 2013 and 2014, soil chemistry from the samples col-

Fig. 7.41 Seeding annual cover crops (July 2014): harrow and roller following broadcast seeding (Image courtesy of Dominion Diamond Corporation)

lected at 0–20 cm depth was analyzed, and vegetation was monitored by measuring percent ground cover, counting seedlings, and measuring average plant heights. Barley and alkali grass performed similarly in all treatments in 2013, except the two with calcium nitrate, and growth was most successful in the untreated PK. In 2014, vegetation growth in the unamended PK was poorer than in the treated areas.

Glacial Till Topdressing

Another possible solution to address the new PK chemical properties is the use of glacial till as a topdressing over the PK. The objectives of the glacial till topdressing study are to assess the suitability of till as a capping material over PK, thereby providing a better plant growth medium than the uncapped material. The suitability of glacial till as a reclamation substrate has been assessed at several locations on the mine site. In 2013, two small trail test pad areas were constructed using till as a topdressing material. One test pad was with till over PK, and one was with till over Coarse Kimberlite Rejects (CKR). Over the long term, plant growth on till has been satisfactory, but establishment is impeded by the hard surface crust that develops upon its drying. That condition can be ameliorated, however, by roughening or ridging the surface by deep ripping.

Natural Colonization

Over the long term, a key measure of revegetation success at Ekati will be the proportion of ground cover comprising indigenous native plant species. Therefore, creating conditions that encourage colonization of disturbed areas by local native plants is an important objective. Conversely, the unlikely spreading of non-native annual crops would not be desirable. In 2014, site investigations were completed for any evidence of vegetation colonization. Baseline vegetation growth was established by analyzing satellite imagery data using the normalized difference vegetation index (NDVI). The output data were consolidated into three categories with the following results: (a) 81% is PK and does not have any overlying vegetation growth; (b) 12% is covered with vegetation that has been classified as lower biomass vegetation; the majority of this 12% is attributed to the «goose grass» that surrounds the tundra and the 2013 seeded alkali grasses; and (c) 7% is covered with vegetation that has been classified as higher biomass vegetation;

Fig. 7.42 Geese grazing on the barley annual crop (Image courtesy of Dominion Diamond Corporation)

the majority of this vegetation is attributed to uncovered natural tundra that was not covered by PK during deposition activities.

Wildlife Observations

One closure objective for the final LLCF cover is ensuring its safety for wildlife use. In the short term, introduction of wildlife into the reclamation research areas has the potential to lead to positive benefits by initiating the nutrient cycle. Initial wildlife observations were collected during 2014 site visits. Large numbers of geese were attracted to the 2014 annual cover crop trials with substantial evidence of grazing (Fig. 7.42). Arctic hares and sik siks were also frequently seen eating young plants. Observation of grazing by wildlife was evident for all the research areas, most notably for the annual crops.

True North Gold Mine Reclamation (Fairbanks, Alaska, USA): Courtesy of Kinross Gold Corporation

The True North Gold Mine is within the Chatanika River watershed, about 26 miles northwest of Fairbanks Alaska. The region is vegetated with black spruce and surface moss that cover the north and east facing slopes. Because of the climatic conditions, reclamation commonly is carried out at summer months. The True North Mine reclamation process is planned to return the land disturbed by mining works to a stabilized, near-natural condition that will assure the long-term protection of land and water resources. Additional goals include minimizing or eliminating long-term management requests and matching state and federal regulatory requests. In this sense, True North offers a habitat to a wide range of Alaskan species such as moose, wolves, bear, and birds of prey. In 2010, Kinross set out to utilize indigenous seedlings. After establishing that no seedlings are present, the company created a greenhouse to observe if indigenous seedlings could be grown. The selected species were black spruce, white spruce, birch, and alder.

Reclamation has occurred in the following phases, with some overlap: (a) interim reclamation to stabilize and maintain viability of topsoil and growth media stockpiles were completed during and directly after construction; (b) previously disturbed areas including historic exploration trenches, abandoned roads, and exploration drill pads that were not affected by current mining operations were concurrently reclaimed; (c) final contouring occurred upon final cessation of mining operations; and (d) vegetation, slope stability, and water quality monitoring will continue until all reclamation performance standards are achieved.

General Reclamation Procedures

The primary reclamation components of the True North Reclamation Plan included grading and recontouring, storm water conveyance channel construction, growth media placement, seedbed preparation, fertilizing, seeding, and monitoring. Waste rock dumps required major grading, contouring, and possible growth media application. Other disturbed areas were revegetated and some required regrading. Growth media were be applied on all waste rock dumps and areas that require it to successfully achieve a 70% cover. Waste rock dumps were configured to establish drainage and avoid swales and depressions.

Storm water drainage channels were constructed where deemed necessary during recontouring to minimize potential soil erosion while vegetation is reestablishing. Temporary control devices were removed where the site-specific potential for erosion had been minimized through earthwork or revegetation. There were sound reasons to continue maintenance of some control structures depending on final recreational use and other types of use. Growth media were stockpiled at True North in anticipation of future reclamation needs. Approximately 6 inches of growth media were applied generally to those sites requiring additional growth media to be revegetated or to promote natural reinvasion by native plant species. However, application depth varied depending upon the facility. Roads, trails, stock pads, and building sites required little, if any, growth media. Once the implementation of growth media is possible, the specific site was designed for seeding by ripping on the contour to roughen the surface. The goal of preparing the seedbed in this fashion promoted revegetation and enhance evapotranspiration. Prepared seedbeds were fertilized prior to, after, or during the seeding operation. Final fertilizer and application rates considered information acquired from previous reclamation efforts.

Regarding the grass seed mix used, the first aim of this seed mix was to obtain fast vegetative cover that helped to diminish soil erosion and promote succession back to climax vegetation. The seed mix may change over time in response to such factors as internal and external research results, changes in technology, changes in land management philosophy, and commercial availability. Native species were the preferred mix. In some instances, mulch was to be found useful in conserving moisture, moderating soil temperatures, and improving erosion control. The practice of scarifying the seedbed on the contour prior to seeding minimized the potential for erosion. Mulch was evaluated if seed germination becomes a limiting factor in the reestablishment of vegetation. Seeding was conducted as soon as possible following seedbed preparation. Generally, seeding was implemented after spring break up until mid-July. Such seeding allowed the seed to take advantage of the summer moisture period. However, if a seeding was unsuccessful for any reason, the area was reseeded the following year.

Waste Rock Dumps

During the summer of 2005, the identified disturbance in dumps was regraded and ripped with dozers, seeded, and fertilized, including this work different dumps. Seed and fertilizer were used on all restored disturbance utilizing either a broadcaster mounted on a dozer or by aerial application with a fixed wing aircraft (Fig. 7.43). Reclamation consisted of scarifying or ripping of the graded surface on contours apart that created a broken, roughened surface to trap moisture, reduce wind shear, and minimize surface erosion by increasing infiltration of the top surface of the soil, which in turn created micro-habitats conducive to seed germination and development. Figure 7.44a shows North Shepard Waste Rock Dump in 2005, prior reclamation, and Fig. 7.44b the same Waste Rock Dump after reclamation in 2013.

Subsequent to this restoration work, a part of the North Shepard Dump slumped and needed further earthworks and reseeding/fertilizing. The slump area encompassed approximately 7 acres. This problem was corrected in early 2010 by picking up the slide material and backfilling the North Central Pit along the south and west edge of the pit. The material to backfilling was pushed at a 3:1 slope for final grading. The slump area was excavated to a 2.5:1 or shallower slope or until natural ground was found.

Pits

Pits developed during mining have been backfilled. The three remaining pits account for 125 acres of disturbance. The North Central Pit was partially backfilled in 2007 to decrease surface water pooling. The Hindenburg Pit floor was graded and scarified to decrease potential runoff to the North Central Pit. Both of these pits

Fig. 7.43 Aerial seeding via fixed wing aircraft (Image courtesy of Kinross Gold Corporation)

received seed and fertilizer in 2007 to promote revegetation to reduce surface water flow. Due to work within the pits and continued water flow, the North Central Pit and Hindenburg Pit were regraded and scarified once again in August 2010. To prevent water flow, the diversion ditch above the pit was cleaned out and reconstructed to divert water toward the Shepard Road.

Ambatovy Nickel Mine Reclamation (Antananarivo, Madagascar): Courtesy of Sherritt International Corporation

Ambatovy is a large-scale nickel and cobalt mining situated 80 km east of Antananarivo (the capital of Madagascar) near the town of Moramanga. The mine operates since 2010 as an open-pit mining and a processing plant. From the mine, the slurried laterite mineralization is sent via pipeline of approximately 220 km in length to a preparation plant and refinery situated south of the Port of Toamasina. The estimated life of the operation is approximately 29 years. Since ultramafic rocks present in Ambatovy mine are highly unstable in a tropical weathering environment, the mine presents a deep weathering alteration, with a complete lateritic profile capped by a ferruginous duricrust. Thus, the ore deposit is a typical nickel laterite in which enrichment has occurred in the residual soils formed by tropical weathering of ultramafic bedrock. Prolonged weathering has produced a thick mature laterite profile in which the nickel grades have been enriched from the levels seen in the underlying bedrock.

The Ambatovy mine (Fig. 7.45) lies in a high-biodiversity area at the southern tip of a large section of remnant eastern rainforest corridor. From a reclamation viewpoint, it is essential to bear in mind that Madagascar is a global hotspot for biodiversity, with very high-degrees of endemism, and, at the same time, a high-level of threat. The most important impacts on biodiversity will carry out at the mine site and along the upper section of the pipeline.

Environmental management at the property is adaptive and consists of applying the mitigation hierarchy, which includes impact avoidance, minimization, and, where necessary, compensation or offsetting by regular monitoring of the physical and biological environment. Physical environmental monitoring includes water quality (total suspended solids and other parameters), air quality

Fig. 7.44 **a** North Shepard Waste Rock Dump in 2005 prior reclamation (Image courtesy of Kinross Gold Corporation); **b** North Shepard Waste Rock Dump after reclamation in 2013 (Image courtesy of Kinross Gold Corporation)

Fig. 7.45 Ambatovy mine and rainforest (Image courtesy of Sherritt International Corporation)

(dust and other parameters), and meteorological monitoring. Biological monitoring includes monitoring the populations and health of affected lemurs, small mammals, birds, reptiles, amphibians, and fish. Biological management actions of the mitigation hierarchy include defining clearly and minimizing the mine footprint, slow directional clearing of forest (accompanied by the salvage and relocation of plant species of concern and the less mobile vertebrate animals), and establishment and management of conservation zones or offsets. The offsets include about 3300 ha of forest surrounding the footprint, two set-aside parcels of azonal forest amounting to approximately 300 ha growing over part of the ore body and active support to regional conservation initiatives.

Mine Site

As a consequence of the estimated high residual impacts to biodiversity and the significance of azonal and transitional areas to supporting rare plants and fauna within the mine area, a comprehensive on- and off-site mitigation plan to preserve key habitat elements is proposed. At the mine site, sedimentation dams are constructed to prevent release of sediments from the mining area into local watercourses. A total of seven dams will be built, three of which have been completed. The dams are equipped with spillways as discharge structures.

The progressive mine site reclamation will be carried out through erosion monitoring, reforestation with certain species, and facilitated secondary successions. Several test plots have already been launched to establish the optimal floral species succession composition for the soil matrix once mining works are finished. The main goal is to generate a rehabilitation process for the mine site. It is necessary to comment that the process will incorporate specific ecological aspects such as the selection of the flora species that can favor species recolonization of the reclaimed pit zones. Throughout 2012, Ambatovy worked to conserve forests around the mine footprint and to prepare for reclamation of the footprint itself. Construction of a research and production nursery was completed, with a capacity to produce over 250,000 plants annually and equipped with a poly-tunnel and other experimental facilities to determine the optimal cultivation methods and conditions for successful plant production.

Fig. 7.46 Aerial view of slurry pipeline route in tavy zone (Image courtesy of Sherritt International Corporation)

Pipeline

The pipeline is mainly buried and the elected route made significant deviations, including tunneling, to prevent affecting forest fragments, cultural sites, and local habitations. The dominant vegetation type along the route is tavy (85%) (Fig. 7.46), areas disturbed by the traditional slash and burn technique used to clear brush and forest for crop production and comprising cleared forest and scattered shrubby vegetation or trees. The second most typical vegetation class is degraded primary forest (4%) comprising either heavily logged forest or very small forest patches that have been invaded by exotic (alien) plant species. For most of its length, the 220 km pipeline was buried using standard «cut and cover» construction at an average depth of 1,5 m. In areas of unspoiled forest and important rivers, Ambatovy drilled horizontally below the surface, leaving stretches of forest intact and allowing the pipeline to pass safely below the river courses.

Regarding the rehabilitation of the pipeline servitude, the implementation of erosion control structures commenced during 2008 with about one million linear meters of fascines (comprise scrub material collected selectively from surrounding areas, rolled into bundles, and tied with banana leaves) and vetiver grass hedgerows positioned on and below the fill embankment slopes of the pipeline servitude and right-of-way, as additional sediment control measures. This work was carried out over the full extent of the fill slopes of the servitude or right-of-way (ROW). In 2010, 550 ha of sparsely covered areas of the platform were hydroseeded and fill slope areas between the fascines and vetiver hedgerows. The seed was sourced from advance seed, and the seed mix was approved for use in the hydroseeding process which was done at 50 kg/ha along the servitude. The mix was selected to provide temporary cover until native species are able to establish over time. Lime and organics were added to the hydroseeding mixture.

Queen Copper Mine Reclamation (Bisbee, USA): Courtesy of Freeport-McMoRan

The porphyry copper deposits of Arizona are located in what is known as the «basin and range» physiographic province. This region is characterized by a series of fault bound blocks that have risen

Fig. 7.47 The former Crawford mill and diesel power plant area after reclamation (Image courtesy of FreePort-McMoRan)

and fallen creating a distinctive valley-mountain range topography. Critically as this landscape formed, they tilted exposing the lower crustal levels where porphyry copper deposits form. The deposits are all copper dominant with subsidiary molybdenum mineralization and unusually with very little precious metals. They are Late Cretaceous to Early Tertiary in age. Mineralization is high-grade copper sulfides (chalcopyrite and bornite) with minor lead and zinc carbonates in irregular replacement ore bodies. Ore control was nearby dykes and sills with associated brecciation. Alteration was gossan with Mn and Fe oxides induced by hydrothermal metamorphism.

At Bisbee, underground mining started in 1880 and kept to until all activities ceased in 1975. In the early 1900s, it was the most productive copper mine in Arizona. Once open-pit mining started in 1954, rock stockpiles were constructed, and tailings from diverse milling works were constituted. Since 2006, several restoration projects have been carried out to mitigate zones impacted by mining activities. These projects encompass approximately 500 ha. Part of this effort includes restoration studies at different stockpiles in the Bisbee area. These stockpiles were always sources of acid rock drainage during summer and winter storm events. The project included grading, capping, and replanting vegetation with the aim of enhancing visual impact, removing acid drainage, and creating wildlife habitat. About three millions of cubic meters of material were translated to recontour and cover the South Bisbee stockpile.

In 2011, restoration works started on the Bisbee area tailings dams and adjacent installations. The tailings program reclamation comprises the North and South tailings dams (Fig. 7.47), the Crawford mill concrete sub-structures and diesel power plant (Fig. 7.48), and the Horseshoe Basin. As part of that reclamation procedure, the company regraded the side and top surfaces of both dams and covered them with about 70 cm of clean material to efficiently control storm water and assure that it is discharged in a manner that originates replacement of the local watershed.

In this sense, fast liberation of these large storm water runoff flows is critical for restored tailings dams to decrease the volume of water that

Fig. 7.48 Reclamation of North (*right*) and South (*left*) tailings impoundments as of 2013 (Image courtesy of FreePort-MacMoRan)

can infiltrate into the tailings material becoming long-term seepage that must be gathered. In order to match runoff and infiltration objectives, past tailings restoration programs needed important quantities of new material to be placed with the aim of providing positive drainage from the top surface toward off-site conveyance.

The approach for the Bisbee tailings dam restoration plan was to prepare design ideas that would reduce regrading of the top surfaces with imported material while decreasing the necessity for conveyance structures needed to control peak storm water runoff flows. The Bisbee concept uses the present grading of the dam and the big top surface area to capture storm water runoff from certain areas of the dam and decrease the peak flow as it is conveyed off the top of the dam into an off-site conveyance. This new concept attenuated peak flows by nearly ten times. Moreover, basins are created to generate low net infiltration of precipitation. The basins are planned not only to decrease large flows but also to capture low flows. These attenuation basins work in essence as «engineered playas.»

Mina Fe Uranium Mine Reclamation (Salamanca, Spain): Courtesy of ENUSA INDUSTRIAS AVANZADAS S.A.

Uranium was discovered in Salamanca during the 1950s. Mine production started in 1974 at ENUSA's Mina Fe mine, an open-pit mine that increases to become the biggest uranium exploitation in Spain that produced over 4000 t of uranium. The mine closed in 2000 because of the low prices of the metal. A full decommissioning plan began in 2001, and the mining areas, including one large pit, three small ones, and four waste dumps, have since been restored. Also, a small uranium plant and heap leaching have been dismantled. The Mina Fe uranium-ore deposit is located about 10 km northeast of Ciudad Rodrigo (Salamanca, Spain). Regarding the geological setting, the rocks consist, mainly, of low metamorphosed carbonaceous pelitic and fine-grained psammitic rocks, in which sedimentary textures are commonly preserved, interlayered with carbonate metric beds. The igneous rocks (granodiorites) intrude the stratigraphic sequence generating a contact metamorphism. The Tertiary Alpine orogeny produced further fractures as well as the rejuvenation of older ones, forming some time important cataclastic breccia zones. Primary uranium deposits (uraninite + carbonates + pyrite + adularia) occur in fault-related rocks.

At Mina Fe, the Elefante plant was mainly a bacterial heap leach installation that was substituted by the Quercus mill in 1993. This plant utilized a combination of heap and dynamic leach until 2000. Quercus metallurgical process was based in a grading of the crushed mineral, in a humid atmosphere, to obtain three fractions of differing size and grade: the coarsest was classified as waste, intermediate was heap-leached (static lixiviation with sulfuric acid), and finest was leached in mixing tanks (dynamic lixiviation), also with sulfuric acid. After a back washing in thickener classifiers and a clarification of the fertile liquids obtained from previous stages, recuperation, concentration, and purification of the uranium contained were carried out. It was performed through a process of extraction with an organic dissolvent and re-extraction of pH controlled with ammonium sulfate. The following steps were precipitation of the uranium contained in the watery extract in ammoniac diuranate, drying the humid concentrate, and packaging the product in drums. The process terminated with the neutralization of the sterile effluents, sending these solutions and the neutralized pulps to the waste dam, and conditioning of effluents.

7

▪▪ Reclamation Process

ENUSA began in 2001 to reclaim the forming uranium mining operations and to dismantle the uranium plants. The objective of this restoration (one of the most important in Europe) was to recuperate the affected natural space with environmental and radiological conditions as similar as possible to those existing before mining works. Actually, these environmental reclamation activities are focused to control the dismantled radioactive installations and the restored mining works, and on chemical processing of polluted waters, which is required until the adequate quality for discharge to public waterways is carried out. The main criteria used to achieve the aforementioned objective were:

1. Ensuring the containment and stability of the contaminated structures for long term
2. Creating new structures without active maintenance, integrated in the environment
3. Protecting water resources (surficial and groundwater)
4. Limiting dust and radon emissions according to future land uses
5. Applying ALARA acronym for (As Low As Reasonably Achievable) criteria (a principle for radiological protection, minimizing radiation doses, and releases of radioactive materials by employing all reasonable methods)

The main works of reclamation of Mina Fe and ancillary installations were located in: (a) open pit mines, 15 Mm^3 (with about 2.7 Mm^3 of acid mine waters); (b) waste rock piles (schists), 35 Mm^3; (c) spent ore piles, > 4 Mm^3; (d) tailings dams, > 1 Mm^3; and (e) metallurgical plants: Elefante and Quercus plants.

The reclamation process was developed in different projects due to their different nature and structures involved.

▪▪ Uranium Plants (Elefante and Quercus) Decommissioning

The main activities in dismantling operations of Elefante plant were carried out between 2001 and 2004 and included:

1. In situ stabilization by leveling tops and slopes and extending beds of spent ore piles from heap leaching: 7.2 Mt (60 ha).
2. Dismantling of industrial plant: wastes were stored in a containment enclosure, built under reconfigured spent ore piles and capping beds.
3. Capping of a multilayer cover for land restoration (◘ Fig. 7.49), formed from bottom to top by (1) 0.9 m of clayey arkoses to minimize water infiltration and to attenuate radon gas emission, (2) 0.9 m of rip-rap (selected rock waste of low grade) to prevent erosion of the clayey layer, and (3) 0.5 m of top soil to allow planting of vegetation and reinforce the action of preceding layers.
4. Technical and radiological controls.

Concerning the evolution of the reclamation process, first the spent ore piles (more than 7 Mt, in the shape of a truncated pyramid with slopes near 75%) were reconfigured to a final structure having new slopes around 20%. The original surface 24 ha was converted to 56 ha of reclaimed terrain, being located the containment enclosure and the tailings dams, from the plant processing, under the restored ore piles. The whole set then was covered with the aforementioned 2.3 m multilayer cover, formed by almost 3 Mt of the

Fig. 7.49 Multilayer cover (Image courtesy of ENUSA INDUSTRIAS AVANZADAS S.A.)

cited materials. There is a monitoring and control program since 2006 to verify the compliance with limits for decommissioning.

Regarding Quercus processing plant, it is pending of decommissioning approval. Due to problems related to acid mine drainages (AMD), it is necessary to maintain some structures, as the tailings dam and big ponds, to collect acid waters as well as the plant for chemical treatment (neutralization process), working until the water quality allows its discharge directly to the river. For this reason, the process will be carried out in phases. Dismantling of the plant will be undertaken firstly, including the associated spent ore piles. The plan will include the building of a containment enclosure and a multilayer cover, as in the case of Elefante plant. At present, there is a maintenance and control program to the beginning of the dismantling process.

Open-Pit Mines and Waste Rock Pile Reclamation

Open-pit mines and associated waste rock dumps affected 250 ha. The main activities in open-pit mine reclamation from 2004 to 2008 were:

1. Geomorphological restoration by filling of open-pits with waste rock from dumps and/or in situ stabilization (Fig. 7.50).
2. Capping of multilayer cover for land restoration; it was formed from the bottom by (1) 0.3 m of clayey arkoses to minimize water infiltration and to attenuate radon gas emission and radiation, (2) 0.3 m of rip-rap (selected rock waste) to prevent erosion of the lower layer, and (3) 0.3 m of top soil to allow planting of vegetation and reinforce the action of preceding layers.
3. Land revegetation.
4. Water management plan, including collection, treatment, drainage, discharge, analytic and radiological controls, etc.
5. Technical and radiological controls. Since 2014, there is a monitoring and control program, including groundwater management and stability of created structures, to check the compliance of the restoration objectives.

The first activity was the most important from a visual impact viewpoint. Total amount of removed

Fig. 7.50 Open-pit at 2004 **a** and 2016 **b** (Images courtesy of ENUSA INDUSTRIAS AVANZADAS S.A.)

waste rock was about 20 Mm^3. Regarding the multilayer cover for environmental and radiological protection, it was prepared in a similar way for Elefante plant. The only difference was the total thickness, since the cover was globally 1 m less than in Elefante plant, because of the different radiological natures of the rocks to cover, mine waste rock instead of spent ore rock, and, therefore, different radiological activities. Revegetation process includes seeding and planting native species, such as herbaceous and

Fig. 7.51 Evaporation units (Image courtesy of ENUSA INDUSTRIAS AVANZADAS S.A.)

bush plants, but not trees to prevent their roots drill the clayey layer, covering more than 250 ha. Water management was carried out creating new channels for best drainage of waters as well as some minor dams for water temporary storage.

Acid Mine Drainage

To control acid mine drainage from the mine, it is necessary to collect approximately 500,000 m^3 of water per year for chemical neutralization process in two neutralization plants. This is in order to guarantee appropriate quality, according to required parameters, before the controlled discharge of the water to the river. In order to try to minimize this important problem, different actions were carried out, including (a) sugar beet carbonate foam amendments; (b) improvement of revegetation; (c) waterproof of filtering dams; (d) in situ stabilization actions, protecting gullies, repairing multilayer covers, etc.; and (e) incorporating new enhanced evaporation units (Fig. 7.51).

Their effectiveness has been only partial or temporary. This is the reason that a new plan for AMD remediation, based in artificial soils («tecnosoles») application technics, is being tested, including edaphic studies, chemical and radiological determinations, etc. They are obtained with inert residues, not toxic or hazardous, and are designed, made, and used à la carte. Artificial soils can solve or reduce the specific problems of affected mining exploitations and/or meet the needs for the restoration of contaminated soils. Previous successful results in the recovery of contaminated major sites were located in mining sites, such as the coal mine of As Pontes (La Coruña); waste dumps, open-pits, and waters in the sulfide mine of Touro (La Coruña); soils of the Guadiamar River Valley (Sevilla) contaminated by the failure of the Aznalcóllar sulfide tailings dam and the sludge discharge; and others. The artificial soils are spread in thin beds on the ground as surficial deposit or in areas with backwaters to create a reactive wetland.

7.9 Question

Short Questions

- Explain the final step in the operation of a mine.
- Define the concept of community used in minerals industry.
- Explain the concept of rehabilitation in mining reclamation.
- What is an Environmental Management System?

- Define sustainable development.
- What are the Equator Principles?
- List the main types of solid mine waste.
- What is biodiversity? Explain the relationship between mining and biodiversity.
- What are the main measures that can be implemented to control and minimize subsidence damage?
- List the potential contributors to visual impacts in mining.
- What are the main advantages of revegetation in reclaiming mined lands?
- What biosolids means?
- What is a social impact?
- Explain briefly the environmental impact assessment process.
- What is the main method for the identification of effects and impacts in an environmental impact assessment?

7

Long Questions

- Describe in detail the definition and importance of a «social license to operate.»
- Explain the acid mine drainage formation.

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