Mining
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Tools and criteria for the management of temporarily inoperative iron ore mines

Critérios e ferramentas de gestão das minas paralisadas de minério de Ferro

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Abstract

This paper presents a tool for managing inoperative mines under the responsibility of the Mine Closure and Projects Management/Ferrous Planning and Development Department - Vale S.A., Brazil. Inoperative mines are defined as mines where mining operations are temporarily suspended and there is no definitive strategy regarding their closure. The main management challenges are to: (i) act in a variety of environments and conditions based on action priorities; (ii) identify the main company's image risks; (iii) plan for maintenance and monitoring; (iv) take care of environmental conditions of the sites and follow up audit recommendations; (v) coordinate the field operations and site rehabilitation; (vi) re-evaluate the rehabilitation performance of the site over time, (vii) support the mine closure team. The tool is based on the consolidation of field information through qualitative and quantitative analyses of the environmental risks and quality of each mine. These analyses support the decision-making process and the prioritisation of action to be taken. The tool provides a performance evaluation of the sites, allowing evaluation over time of the maintenance and rehabilitation actions carried out. The input for the tool consists of primary and secondary data (geotechnical and environmental) collected during fieldwork, which is then processed in spreadsheets. These assign prioritisation values based on two main themes: environmental risk and quality. Each of these themes has specific groups of subjects. The prioritization spreadsheet generates thematic maps that present the classification of the mine areas and the action priorities. The tool output is an action plan that guides management, considering all the structures of each site under its responsibility.

Keywords: *Mine closure, risk analyses, inoperative mines.*

Resumo

Esse trabalho apresenta uma ferramenta para gerenciamento de minas inoperantes sob a responsabilidade da Gerência de Fechamento de Mina e Projetos de Ferrosos/Departamento de Planejamento e Desenvolvimento de Ferrosos – Vale SA, Brasil. Minas inoperantes são definidas como minas nas quais as operações de lavra estão, temporariamente, suspensas e não há nenhuma estratégia definitiva de encerramento. Os principais desafios de gestão são: (i) atuar em uma variedade de ambientes e condições com base nas prioridades de ação, (ii) identificar riscos à imagem da empresa, (iii) planejar atividades de manutenção e monitoramento, (iv) cuidar das condições ambientais dos locais e seguir as recomendações de auditoria, (v) coordenar as operações de campo e de reabilitação local, (vi) reavaliar o desempenho de reabilitação do sítio ao longo do tempo, (vii) apoiar a equipe local de fechamento de mina. A ferramenta é baseada na consolidação das informações de campo através de análises qualitativas e quantitativas dos riscos ambientais e da qualidade de cada mina e suas diversas estruturas, por exemplo, cava, barragens de rejeitos e pilhas de estéril. Essas análises apoiam o processo de tomada de decisão e priorização de ações. A ferramenta fornece uma avaliação de desempenho das diversas estruturas, permitindo a avaliação, ao longo do tempo, das ações de manutenção e reabilitação realizadas. A ferramenta é alimentada por dados primários e secundários (geotécnicos e ambientais) coletados durante os trabalhos de campo, para posterior tratamento em planilhas. Nessas planilhas, são atribuídos valores de prioridades com base em dois temas principais: risco e qualidade ambiental. Cada um desses temas inclui grupos específicos como vegetação, influência humana e aspectos geotécnicos, entre outros - e cada grupo é subdividido em itens com classificação específica. A planilha de priorização gera mapas temáticos que apresentam a classificação das áreas das minas, bem como as prioridades de ação. Resulta dessa ferramenta um plano de ação que orienta a gestão, considerando-se todas as estruturas de cada local sob sua responsabilidade. O desenvolvimento e utilização da ferramenta têm tornado possível a criação de planos de ação mais pormenorizados e eficazes, proporcionando uma maior precisão no tratamento de irregularidades, possibilitando uma avaliação do desempenho de cada área, minimizando o risco de exposição da empresa e fornecendo uma base de dados confiável, para a concepção, a implementação e o monitoramento de planos de fechamento.

Palavras-chave: *Fechamento de mina, avaliação de riscos, suspensão temporária de lavra.*

1. Introduction

For the context of this paper, inoperative mines are defined as mines where mining is undergoing care and maintenance suspension and there is no definitive strategy regarding their closure. There is a myriad of reasons for mine closure. Among these, weak market conditions followed by the low prices of mineral commodities can affect mine operations causing temporary mine closure (Laurence, 2006; 2010). Historically, closure is seen as an inevitable and problematic consequence of the nature of a mine, since the public image of mining is still one of abandoned sites and lasting environmental liabilities (Neil et al., 1992). Therefore, there is no controversy about the necessity and importance of planning for closure, since the lack of a mine closure plan results in severe environmental, socioeconomic and cultural consequences (see for example Keyes, 1992; Wolfe, 1992; CDPHE, 1998; Hoskin, 2002). Planning for closure should be integral to the whole of a mine's life cycle.

Planning for closure involves integrating the closure design for the entire mine area, identifying the timing of the planning process, considering issues which relate to stakeholder involvement and consultation, financial provision and guarantee, completion criteria and relinquishment in order to implement a comprehensive mine closure programme (ANZMEC, 2002). The timing of planning for closure is determined by a number of different factors and can influence the closure process itself. Design of a closure plan should start during the pre-feasibility study. As new projects move forward to the development stage, initial rehabilitation and closure plans as well as estimates are typically adjusted to respond to regulatory requirements for mining permits and bonds. Following mine development, the body of experience grows as well as the amount of baseline information for planning and estimation (ANZMEC, 2002; EPA, 2002). On-going reviews of the closure objectives and design are necessary to allow for changes in local physical or socio-economic conditions. If planning is delayed, it may affect which mine closure objectives can be met.

At least two types of closure plan are required through the life of a mine - the conceptual closure plan and the final closure plan. The conceptual plan is required to be submitted at the time of the mine permit process, and should be able to demonstrate and ensure that closure is technically, economically and socially feasible without incurring long-term liabilities (Anderson, 1995; Brodie, 1998). The final closure plan comprises a number of subsidiary plans with detailed design drawings and construction specifications. These typically include a rehabilitation plan, a decommissioning plan and maintenance and monitoring plans (Doran and McIntosh, 1995; Knol, 1999; ANZMEC, 2002; Lima & Wathern, 1999). In addition, it is recommended that closure plans should include contingency measures for temporary suspension (care and maintenance) of operations, not necessarily involving decommissioning and closure. When mining operations are long suspended, monitoring and maintenance procedures can be potentially burdensome for many companies. Though tools and guidelines for mine closure planning have been developed (Australia, 2011; Heikinnen, 2008; Sánchez, 2011; Bentel, 2009), since then there is a lack of literature about how to manage inoperative mines.

In Brazil, the regulation of mine closure is still far from completion (Castro et al., 2011, Flores & Lima, 2007; Lima et al., 2007) and Resende & Lima (2009) show that just in Minas Gerais, the most important Brazilian mining state, of the 1.739 mining rights, 234 are inoperative mines. The inoperative mines owned by Vale S.A., are dispersed among regions with different ecosystems, including various Brazilian States and, consequently, a tool is needed to evaluate the environmental condition and risks, to compare these mine sites and prioritise the necessary actions. Therefore the objective of this paper is to present the tools and criteria for the management of temporarily inoperative mines developed by the Mine Closure and Projects of the Ferrous Planning and Development Department (DIPF, Portuguese acronyms) of Vale S.A., Brazil.

2. The geotechnical and mine closure management group

The group is responsible for the management of inoperative mines. The group is composed of a multidisciplinary team in charge of actions addressing risk management, maintenance and monitoring programmes. Its main challenge is to identify the risks associated with these non-operating mines and decide upon priority actions. Another objective of the team is to renew environmental licenses, observing schedules and meeting conditions, as well as to audit tailings dams and waste rock dumps. This occurs annually and is reported to the environmental agency. The group also has mine closure coordination responsibility for the management, elaboration and implementation of mine closure plans of the iron ore mines. Mine closure team activities are supported by field data from the staff dealing with the inoperative mines.

3. The Tool's Development Steps

The next section shows the steps followed for development of the tool and demonstrates how the mine closure team is dealing with the planning for closure for the inoperative mines.

Performance evaluation methodology

A performance evaluation tool was developed for the management of inoperative mines, and helps the group to identify the risks associated with these non-operating mines and to decide upon priority actions. The input for the tool consists of primary and secondary analyses of data collected. The work procedure consists of collecting the data that feeds the spreadsheet system, data analysis and grade computing in order to rank the actions in accordance with the performance of each site/structure evaluated. Then an action plan is prepared with guiding schedules and an activity list. The indicated actions are implemented and the site/structure is re-evaluated after the actions are performed. Then the cycle is restarted with a new data collection phase.

Data collection

For data collecting, an inoperative mine site/structure is selected for pre-evaluation (Figure 1a). This pre-evaluation provides the base for a comprehensive data collection. Among the information necessary are maps, images, structural designs, histories (works, licensing, rehabilitations), boundaries of Conservation Units, Areas of Permanent Preservation (APP) and accesses (Figure 1b).

Once the data are collected, the evaluation process initiates. In most cases, the inoperative mines are on Vale's surface property since, in most cases, the company owns the land. However, in some situations, the influence of the mine extends beyond the borders of the Vale property that requires detailed evaluations, for example, when an erosive process affects watercourses or sites that go beyond the Vale property's borders. In this case all area of influence of erosion process needs to be considerate and evaluate. Once the borders are determined (whether the company's surface or that resulting from the range of influence), the entire site is divided into parcels in order to identify parcels/locations/structures that have similarities. Verification of the borders of the area and the parcels is done in the field (Figure 1d). This preliminary division requires use of a map with an aerial image to determine the borders to be created. Normally, the map scale used is 1:2,000 and the better the quality and details of the image, the less fieldwork required. The parcels created are then divided into two large groups. The first group consists of natural areas (Figure 1e) - those that did not suffer any direct modification due to the mining operations and show satisfactory conservation conditions (Picarelli et al., 2008). There is no need for maintenance in these areas, only monitoring. The second comprises modified areas (Figure 1f) - those that did suffer modifications due to the mine's operations and require rehabilitation, maintenance and monitoring programmes. This group includes tailings dams, waste rock dumps, pits, cut slopes, buildings and other impacted areas.

The natural areas (Figure 1e) and modified areas (Figure 1f) are assessed during field activities carried out to fill in eroded surfaces (Figure 1i), the dam (Figure 1j) and the structures tables of the mine (Figure 1l). The natural areas are examined for signs of erosion (Figure 1g). If there is an erosion process that requires specific action, the site is evaluated separately as a distinct one, using a specific spreadsheet (Figure 1h), creating a new structure to be prioritised. Natural areas without irregularities are included in a single group and identified with the same name (Natural Areas). Due to the particularities that tailings dams present regarding geotechnical issues (Minas Gerais, 2002), operation procedures and vegetation, a specific spreadsheet was developed for these structures. This allows a more consistent evaluation concerning the risk/state of maintenance of the tailings dams. In addition, the dam spreadsheet does not include items associated with environmental quality. Like dams, large scale erosion has specific spreadsheets. This is due to the fact that erosions with particular characteristics can be more effectively evaluated through an analysis focused on their specificities.

Analysis of the data

The spreadsheets help to evaluate and classify various items that influence management to deal with liabilities, in the sense of prioritising the most urgent demands in accordance with the risk they pose. The prioritisation spreadsheet is divided into two themes (Figure 2): (i) Environmental Risks and (ii) Environmental Quality. Three groups of risks are evaluated in the Environmental Risks theme (Figure 3) (i-a) geotechnical issues, (i-b) vegetation and (i-c) human influence. There are special items related to (i-d) structures for decommissioning and (i-e) the impact of water resources. Special items, when present, increase the complexity of the maintenance and mine closure activities. Two groups are evaluated in the Environmental Quality theme (ii): (ii-a) soil – subsurface and (ii-b) vegetation. Each group is subdivided into various items with different weights and degrees of complexity that receive a grade in accordance to their characteristics. The final result depends on the theme and, therefore, there are two different grades: one for the Environmental Risk and one for the Environmental Quality.

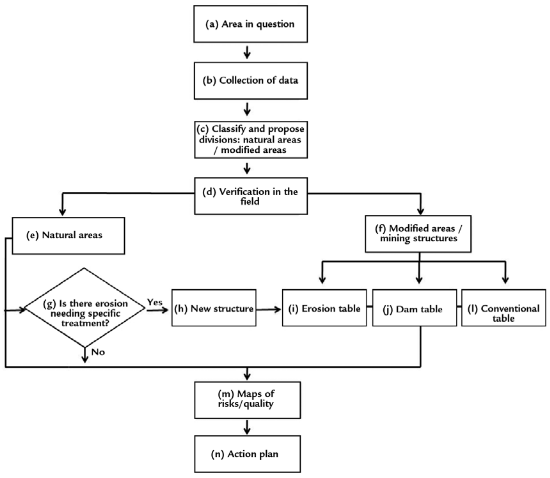

Figure 1
Tool flowchart.

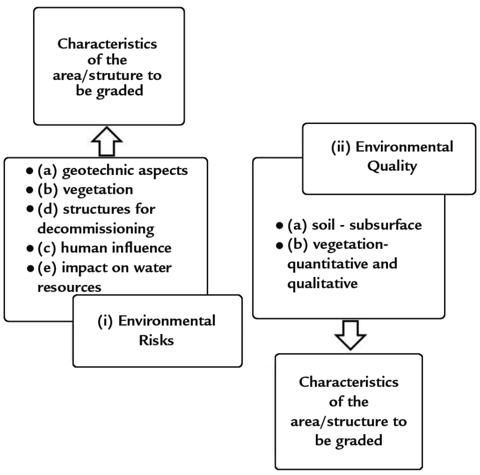

Figure 2
Prioritisation spreadsheet breakdown – groups and items evaluated.

Analysis of the data

The aspects of respective evaluated items in the tables and the prioritisation spreadsheet are used to build the ranking list. Each aspect has various factors responsible for determining different levels of severity/quality.

The prioritisation spreadsheet assigns grades to each item evaluated. The grades are generated by multiplying the characteristic of the structure examined during field work by the weight assigned to the item. Thus, the grade for each item is automatically calculated as the information is entered (Figure 3).

Groups	Items Evaluated				
THEME: Evaluation of Environmental Risks					
	1	Weight	Grade	Overal Critical Height	
		4	3	12	hc >= 100m
			2	8	50m < hc <= 100m
			1	4	25m < hc <= 50m
			0	0	hc <= 25m
	2			Visual Stability	
Geotechnic Aspects		5	5	25	Unstable
			3	15	Signs of instability
			2	10	Occasional instability
			1	5	With isolated indications of instability
			0	0	Stable
	3			Appearance	
			3	12	Visual movement of solids, Significant flow
			2	8	Dripping
		4	1	4	Presence of humidity

Figure 3
Example of the prioritisation table structure

The weight of each item receives ranges from 1 (one) to 5 (five), with the more significant ones receiving the higher value. The significance of each item is determined based on technical meetings of the multidisciplinary group responsible for the inoperative mines. The weights are assigned based on the risk criteria that each item represents in the context of the structure that is being evaluated.

For each item's characteristics, there are variations relative to severity/quality percentage that goes from 0 (zero) to 8 (eight). Some characteristics have equal value and this is due to the existence of natural conditions that, while being different, have similar severity/quality. The final grade is given by dividing the total score obtained in each group evaluated by the maximum possible, thereby generating an absolute percentage result.

The grades, in addition to serving as a base for describing the location, also indicate the degree of attention that should be given to the site. Thus, a site gets two grades – one for Environmental Risk and other for Environmental Quality. A higher grade obtained indicates the greater risk the site poses. Based on the score obtained for each area, colours are assigned to each structure of the area evaluated and thematic maps are generated that allow a quick and direct visualization of the overall characteristics of the context being evaluated. The colours vary from red to orange, yellow and green. Each colour is associated with a specific time frame for the action's plan, as showed in Table 1.

Once the data is collected and interpreted, a report is generated by means of a thematic map capable of facilitating visualisation and understanding of the situation. The updated images of the site with the respective parcels checked are used for preparation of the thematic maps. Each site in question is identified with the colour that relates to the prioritisation spreadsheet grade result (Table 1). In this way a mosaic is created, which is capable of, spatially, indicating the attention levels for each location. Figure 4 shows two thematic maps generated for a mine site – the Environmental Risk Map and the Environmental Quality Map.

Table 1
Classification of areas according to their grade.

Total Grade: 100	Colour	Environmental Risk Interpretation
More than 50 points	Red	Short-term actions: They will be re-evaluated by a multidisciplinary team with specialists in each theme to prepare a prioritised action plan.
From 36 to 50 points	Orange	Medium-term actions: A multidisciplinary team will prepare a plan for frequent monitoring of the points of concern. The objective is to monitor and create actions.
Up to 35 points	Yellow	Long-term actions: Assign teams suitable for monitoring the weak points.
15 points or less	Green	Monitoring actions: Occasional monitoring visits.


Environmental Risk Map


Environmental Quality Map

Figure 4
Thematic maps showing the classification of each parcel of a mine site.

Action plan

The operational planning for the Geotechnical and Mine Closure Management is based upon the organization of an action plan that covers the whole site and their respective parcels. In addition to the performance assessment of the inoperative mines and an environmental audit schedules for the dams and waste rock dumps are considered. The objective is to have a single document, which can evaluate the main characteristics of a mine site and the actions to be performed, considering primarily the schedules and risks.

A good coordination plan for the actions, especially in the case of inoperative mines, is essential for the success. The work actions, for example, require coordinated action between different teams - preparation of a plan, execution of the work, site rehabilitation and monitoring, making the logistic essential, primarily when the geographic distribution of the sites is considered. Thus, an action plan that allows quick and direct evaluation of the operational context ensures effective management. During the routine of the operation, re-evaluation of the initial schedule is always needed and inspections and monitoring provide new information that can modify the performance score of a mine site/structure, requiring the preparation of new actions.

Execution of actions and site re-evaluation

The sequence of the actions is internally coordinated by the staff in charge. The time to re-evaluate a site is previously established in the action plan. The re-evaluation is conducted in accordance with the risks identified and the actions planned are likely to cause a change in the characteristics evaluated in the field tables. Mostly, the re-evaluation is made after the end of the rainy season. Figure 5 summarises the methodology in its various execution steps.

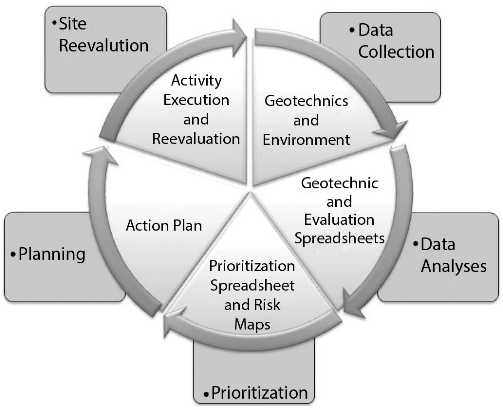

Figure 5
The management cycle for inoperative mines.

4. Conclusions

The tool for evaluating the performance of the inoperative mines was developed to help management and support decision-making by identifying and selecting actions using prioritization spreadsheets. The tool's objective is to reflect the current status of the mines, assigning weights to each mine characteristic /structure considered, resulting in a ranking that evaluates the complexity of the rehabilitation/monitoring actions, thereby facilitating preparation of plans and list of priorities. After implementation of rehabilitation actions, the classification ranking is re-evaluated, allowing comparison with the prior situation.

The performance evaluation tool for inoperative mines has met the proposed objectives, helped to guide actions and monitor changes in the environmental performance of the sites over time, allowed evaluation of the results of the actions implemented and assisted the development of mine closure plans. Use of the tool has facilitated the elaboration of more detailed and effective mine closure plans, since it provides greater accuracy for treating mine site liabilities, minimizes the risk of company exposure and creates a reliable database.

Appropriate management of inoperative mines prevents the build-up of environmental liabilities, in addition to keeping licenses up to date, which will facilitate putting these mines back into operation in the future or implementing a mine closure plan, when necessary.

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