# MINING PRIORITIZATION SYSTEM DEVELOPED FOR FORMER IMPORTANT BOLIVIAN MINING CENTERS

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## Abstract

Dirección de Medio Ambiente, a section of Corporación Minera de Bolivia, has developed a system to evaluate and prioritize their numerous mining centers. This system is based on physical, geochemical and social-economic characterization criteria of the sites and mine centers. Based on the characterization and the potential harmfulness of the constituents (mineralogy and element concentrations), a scoring of each site is calculated. This scoring will compared with scorings from other sites, and the sites are then prioritized based on the relative scoring. A cost-benefit analysis is then performed using the cost of score reduction relative to environmental improvement for the mine sites and mine centers in question. After this has been done, proper prioritization can be performed and selection (implementation) of the most cost efficient mitigation can be implemented.

## Introduction

In the early 1950's, the Bolivian Government nationalized privately owned mining companies. The management of these properties has since become the responsibility of the Corporación Minera de Bolivia COMIBOL). The management of the environmental issues at these COMIBOL mining sites is handled by the Dirección de Medio Ambiente, (DIMA). The Bolivian mining industry was once very important for the world's supply of metals, especially silver and tin. A few of these properties has recently been reopened by COMIBOL and there are many small co-operatives and private companies that are extracting ores from these earlier mined deposits, from underground and from old mine waste material.

COMIBOL administrates approximately 40 mining centers. Although COMIBOL does not operate any mining activities at these centers, there is evidence that many of the new operations together with COMIBOL's old mining operations are contaminating soil and waters over a great distance. The World Bank preformed a preliminary prioritization of these mine centers for mitigation work (Ayras et al., 1997). There is, however, little funding for mitigation work available and, therefore, a need of a reliable prioritization system to be able to perform cost-benefit analyses. The Bolivian prioritization and mitigation management consists of nine steps. This paper discusses Steps 2-3 and 6 (Table 1), the characterization for prioritization system and cost-benefit analysis (Walder, 2005).

*Table 1.Eight steps for Bolivian mine site prioritization and mitigation management.*

| | | | |
|---|---|---|---|
| 1 | First Screening | 5 | Cost-Benefit Analysis |
| 2 | Characterization for Prioritization | 6 | Design Mitigation Option |
| 3 | Risk Assessment (add. characterization) | 7 | Mitigation Construction |
| 4 | Remediation Option (add. characterization) | 8 | Maintenance and Monitoring |

## Prioritization System

The detailed prioritization work is based on a spread-sheet calculation system with 22 criteria divided into three different topics: Physical (Geotechnical), Geochemical and Social-Economics (Table 1). Each of the topics has been given approximately equal importance. Each of these criteria has been assigned an importance factor (weight factor).

*Site Prioritization Scoring*

To evaluate the present and future impact from the COMIBOL mining areas, a site condition from 0-5 is assigned for each of the criteria. These are based on given core ranges designed for the Bolivian mining conditions. The criterion condition multiplied with the weight factor gives the criterion score. The importance of each of the criteria listed in Table 2 is not the same for the receiving environment. It has, therefore, been necessary to develop weight factors based on the importance of each of the criteria. The sum of the criteria scores gives the site score. The site score gives the prioritization order. Thus higher score thus more environmental impact and higher on the prioritization list.

| **CRITERION** | | Score range | Weight factor |
|---|---|---|---|
| PHYSICAL CONDITIONS | | | |
| 1 | Size impacted area | 0-5 | 3 |
| 2 | Rainfall | 1-5 | 2 |
| 3 | Surface water use | 0-5 | 6 |
| 4 | Groundwater use | 0-5 | 6 |
| 5 | Wind erosion | 0-5 | 3 |
| 6 | Property Use | 1-5 | 3 |
| 7 | Water erosion | 0-5 | 4 |
| 8 | Terrain Angle | 0-5 | 3 |
| 9 | Adit drainage | 0-5 | 5 |
| GEOCHEMICAL CONDITIONS | | | |
| 10 | Mineralogy | -15-25 | 2 |
| 11 | Net Acid Neutralizing Potential | 0-5 | 3 |
| 12 | Metal Content Water Human | * | 6 |
| 13 | Metal Content Water Aquatic | * | 3 |
| 14 | Metal Content Solids | * | 3 |
| 15 | Tailings volume | 0-5 | 3 |
| 16 | Waste Rock volume | 0-5 | 4 |
| 17 | Paste pH | 1-5 | 2 |
| 18 | Iron Oxidation Products | 0-5 | 2 |
| 19 | Receiving Environ. mass load. | * | 6 |
| SOCIO-ECONOMICS CONDITIONS | | | |
| 20 | Population density | 0-5 | 15 |
| 21 | Agro-Ecology and Social Econ. | 1-5 | 10 |
| 22 | Poverty | 0-5 | 2 |

*Table 2. Prioritization criterion with the score range for each of the criterion and the weight factor.*

Physical Conditions

The physical conditions are divided into nine criteria. The physical conditions describe the size of the properties and problems, and how the water originating from the property and the property itself are used. The score ranges are between 0 or 1 and 5. The *surface water use of and groundwater use* are given scores based on how the water is used, human drinking water having the highest score to wild animal gracing with the lowest score. Water use is set to have the highest weight factors of the physical conditions. The score ranges of *size impacted area*, *rainfall*, *adit drainage* are based on conditions in Bolivia. The score ranges for erosions and angles are general conditions found in all countries.

Geochemical Conditions

There area 10 criteria under the geochemical conditions. These criteria are primarily based on observed and potential metal leaching from waste rocks, tailings and adits. *Metal content in water for human* consumption and *receiving environment mass loading* are given the highest weight factor under the geochemical conditions.

The *mineralogy* criterion has a score range from -15 to + 25. The score is based on sub weight factors for the reacting minerals: negative for neutralizing minerals and positive numbers for sulfide minerals. Neutralizing minerals have the potential to reducing the impact and are, therefore, given a negative score. Calcite has the highest negative factor due to the high neutralization reactivity, while, marcasite, arsenopyrite and, pyrrhotite has the highest positive factor, due to their high acid producing potential and/or high environmental impact. The weight factor is multiplied with the weight percent mineral content.

The score for the three metal content criteria and for receiving mass loading are given based on concentrations of 15 harmful elements multiplied with a sub weight factor for each of the elements. The concentration ranges are based on the harmfulness of each element taken from EPA hazardous ranking system (Tobin and Schatzow, 1984). Impact on human and aquatic systems differ, therefore, metal content was divided and given different sub weight factors. *Receiving mass loading* uses the same sub weight factors as for metal content in water for human consumption, multiplied with the amount of water.

*Volume of waste rocks* and *volume of tailings* are included in the geochemical section because this will give an indication on how much will potentially leach per year. This score range is based on the size distribution of waste material between the different mine centers of Bolivia.

*Paste pH* criteria are based on measurements that can easily be performed. The score range is based on data obtained. *Iron oxide* score range is based on observations of secondary iron minerals that are indicative of the acidity in which they are formed, hematite to jarosite.

The mass loading to the receiving environment is an important parameter in evaluating the effect of the mine center or the individual site. If there is a score calculation for the whole Center, this mass loading is based on the mass of constituents leaving the mining area or center per time unit. However, if the mine area or center has input from sources that are not due to mining, the mining based mass loading needs to be adjusted to account for those sources.

<u>Socio-Economic Conditions</u>

There are three criteria included under the social-economic conditions: *population density*; *agro-ecology and social economic*s; and *poverty*, discussed below.

*Population density* is the most important criteria within the social-economics conditions. The more the people are affected by contamination, the more important it is to perform mitigation. The score ranges are listed in the table below. The ranges for the scores are based on low density areas.

The criterion *agro-ecology and social economics* refers to economic importance of the area surrounding the mine property and the affected area. Mitigation in an area with high economic importance is expected to give a better economic feed back than in areas with low economic importance, and is, therefore, included as a criterion as listed in Table 2.

*Poverty* is included in the scoring system because high poverty areas are generally more exposed to factors such as poor water quality and soil contamination than less poverty area. However, the weight factor for the poverty condition is set low but is under discussion.

*Site Score / Center Score*

As mentioned above, there are about 40 mining centers administrated by COMIBOL. Many of these mining centers are complex with large amounts of waste dumps, several tailings piles and adits. These may be resulting from different ores giving very different geotechnical and geochemical characteristics. The different contaminant sources may eventually drain into the same river, the same receiving environment. It is, therefore, challenging to divide the center into meaningful units that belong to the center. However, it is necessary to make divisions into concise units in order to perform a fruitful cost-benefit analysis.

For the Bolivian prioritization system, it is suggested to divide the centers into distinct units that have their own possible environmental affect; however, the calculation of the receiving environment mass loading is not included in all the units' scores. The sum of each of the unit scores gives the score of the site.

**Cost Benefit Analysis**

The cost-benefit analysis utilizes the same spread sheet as the site score calculation. For each mitigation option suggested, the environmental improvement needs to be evaluated. That means evaluating improved water quality, dust reduction, improved geotechnical hazardous, etc., and recalculating the unit score(s) and center score based on the mitigation. The score difference for each of the mitigation options for the mine centers can then be plotted in a cost versus benefit diagram. From this diagram an Efficient Frontier line (Goodwin and Wright, 2003) may be drawn giving the most benefit for the cost for the plotted alternatives. Along this line there will be high cost high benefit and low cost low benefit. That means, increasing improvement of the environment usually is linked to increasing cost. Many small improvements at several sites may do more for a larger population, than a high level of mitigation on one site. However, this final decision is likely up to the politicians together with those controlling the funding source.

Theoretically, cost of mitigation versus benefit of mitigation follows a curve towards a maximum benefit; where each additional amount spent is giving less and less benefit (Fig. 1). In a practical setting, each alternative that can be applied to mining mitigation has a large cost, therefore, there will be steps instead of a smooth curve as seen for the theoretical setting. There are, in general, two different practical settings (Fig. 1): A, the second alternative builds upon the previous alternative, or you can go back and improve upon the previous chosen alternative; and B, the second alternative mitigation is not benefiting from the first alternative. These types of mitigation alternatives also need to be included in the cost-benefit analysis.

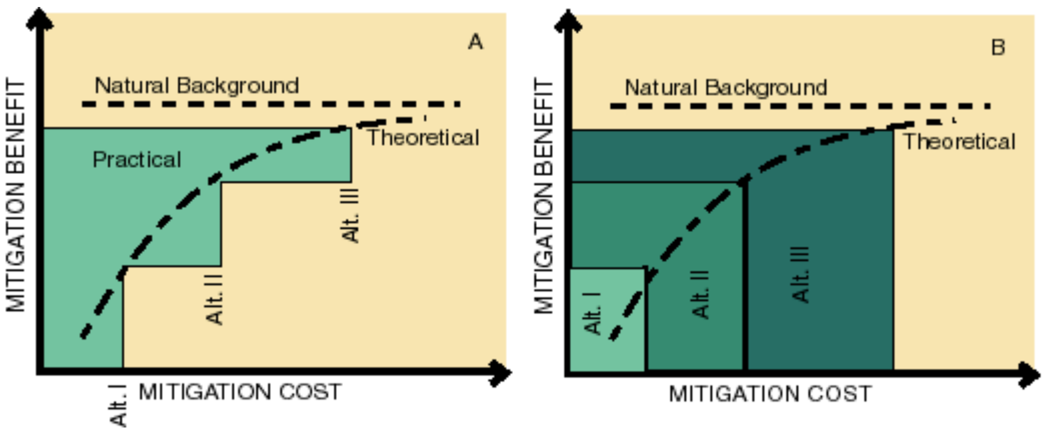


*Fig. 1. Mitigation cost versus mitigation benefit.*

**Prioritization Progress**

The prioritization system is currently being used; however, there is a considerable amount of characterization data that has to be collected in order to utilize the prioritization in step 2. The 40 plus mining centers have been evaluated through the first step, First Screening. Twelve mining centers have been short listed for second step at this point. Characterization data has been collected from three of the sites so far and the rest of these twelve centers will be completed by June 2009. The ranges for scoring of each of the conditions will be reevaluated based on the field data to make it the most applicable.

The development of the prioritization system has made it evident how importatnn it is to fully characterize the mining centers before mitigations are being performed. For example: At the Colquechaca Mining Center, located in the Altiplano, approximately 70 km north-east from Potosi, is has been found that only 25-50 % of the impact on the receiving environment is impacted by the original COMIBOL operation, a receiving environment that is producing salad, potatoes, and wheat.

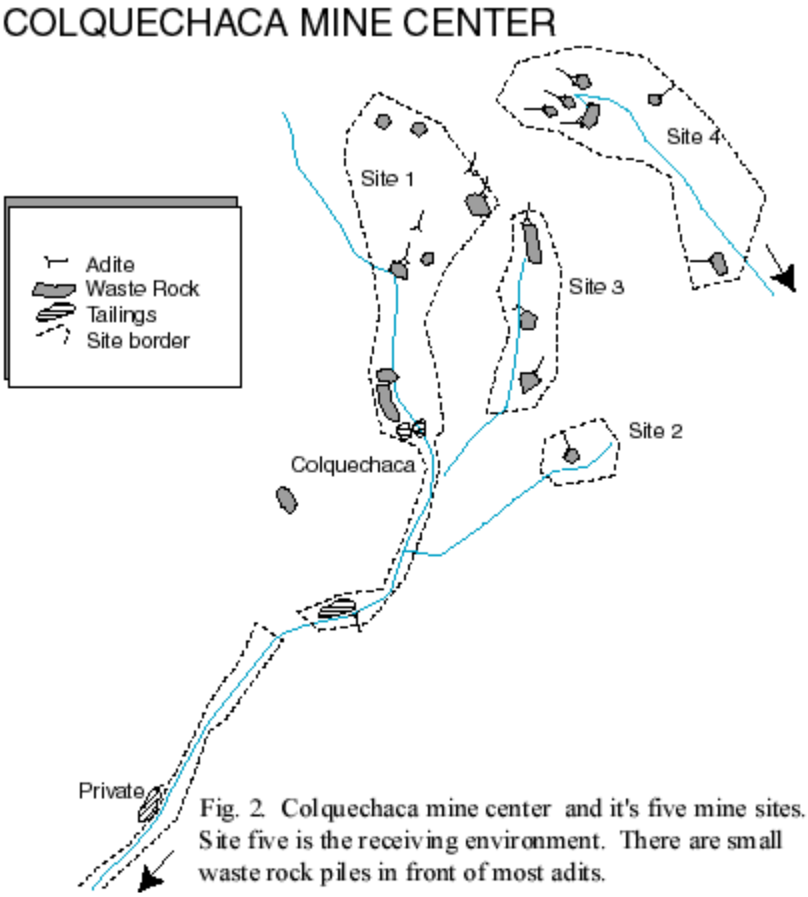


Fig. 2. Colquechaca mine center and it's five mine sites. Site five is the receiving environment. There are small waste rock piles in front of most adits.

The mining operation of Colquechaca dates from the pre-colonial time, after the colonial period the operation followed in regular form to 1900, time at which I arrive has to be the second producer of silver after Potosí; the main veins worked at that time were: Funnel and Discoverer.

Colquechaca is a hydrothermal a deposit of type with polimetálica vein mineralization (Zn, Pb, Sn, Ag), located to 4100 msnm. It was deposited in two stages were tin was introduced much earlier than the base and precious metals. The main minerals are, pyrite, marcacite, sphalerite, galena, arsenopyrite, pyrrhotite and chalcopyrite (and minor amounts of many other sulfide minerals)

With the nationalization of the mines, in 1952 COMIBOL reopened the workings and followed the operation until 1962, when due to the high losses, it rented the deposit to a cooperative which cept it open until 1965. In 1987 COMIBOL signed a contract renting the mine to Cooperativa Minera Colquechaca Ltda. Since then, Colquechaca has been producing tin minerals and mineral concentrates containing Pb - Zn – Ag. Both the cooperatives and another smaller private enterprise are producing tailings.

For the prioritization evaluation, the site was divided into five areas (Fig. 2): the receving environment which is along the river including irrigated areas; the main mining areas including mine adit and tailings and waste rocks outside the mine adit; A smaller area along a small tributary, and a a mining area that drains into another river basin.

The site is given a high score for the low water quality and high volume draining from the mine adit, and high sulfide content and strongly oxidizing tailings and was rocks outside the mine tunnel. The impact from mining on the receiving environment is considerable with low water quality for a very long distance from the mine (>20km). However, mass loading calculations indicate that a considerable amount of the contamination is currently coming from other sources than the COMIBOL mining areas. Mitigating all contamination from the COMIBOL mine site will not give a very high improvement on the receiving environment. Further evaluation of Colquechaca mine site together with comparison with the other 11 mining centers under investigation will indicate if it is worth mitigating the COMIBOL part of the contamination; if the other sources can be defined and be included in the mitigation; or finally if other sites are more cost efficient than the mitigation of Colquechaca.

## Conclusion

The detailed prioritization requires considerable characterization work: surface water groundwater sampling and analysis; mineralogical and geochemical analysis of waste material; prediction of long term pollution; and physical stability evaluation.

The prioritization work, which also includes cost-benefit analysis and health risk assessment, will give a substantial credence to the suggested and implemented mitigation work, thus increasing the possibility for obtaining *funding* for further mine site mitigation. This detailed site evaluation is certainly *necessary* where prioritization is *necessary*, but should also be performed where there is sufficient *funding* for mining mitigation. According to the EU Directive on Waste from the Extracting Industry all countries have to perform a similar characterization and evaluation as the Bolivian government is performing on their mine sites.

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