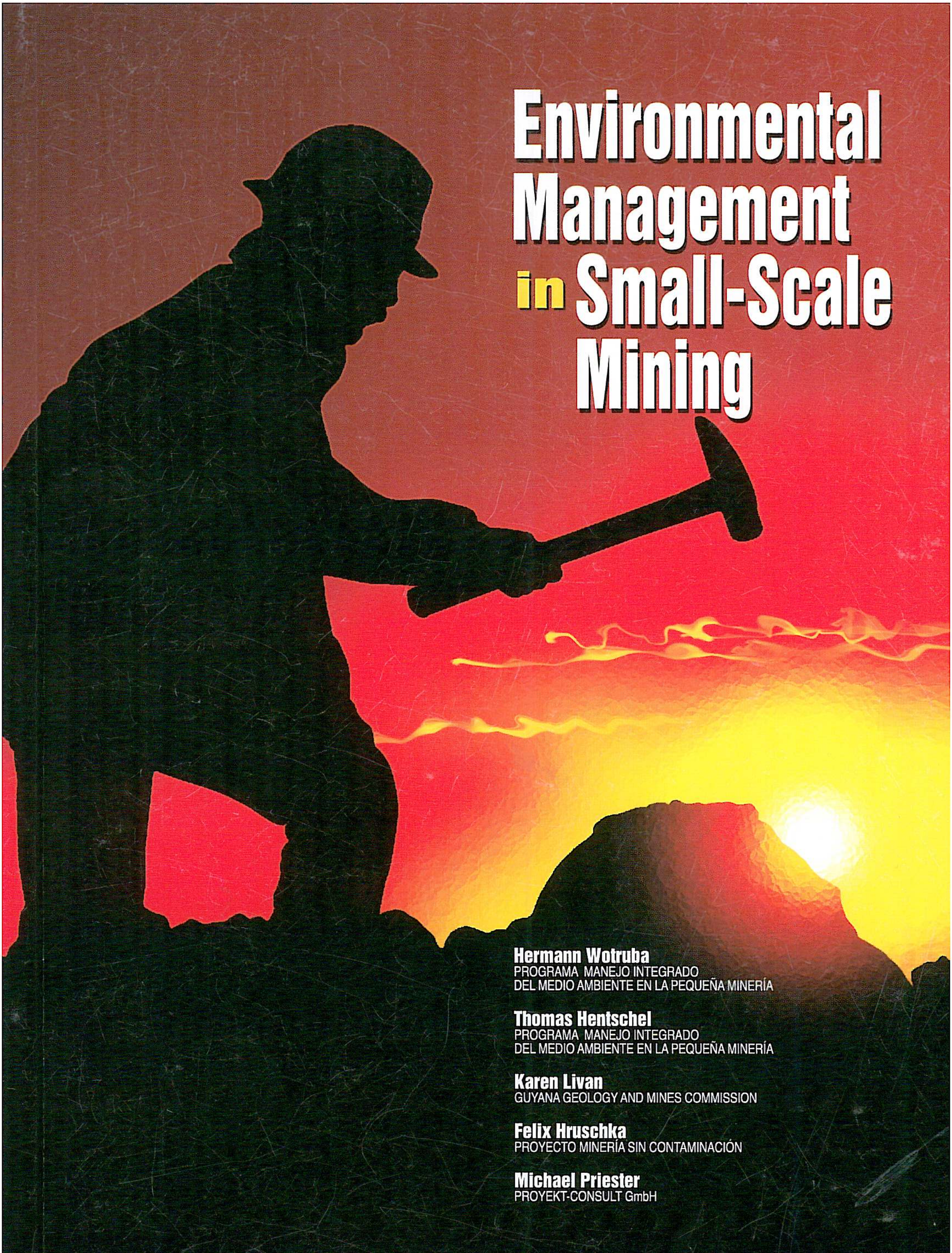
Environmental Management in Small-Scale Mining



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Presentation

The importance of environmental protection in the framework of development assistance is greater each day. The Swiss Agency for Development and Cooperation (COSUDE) has a broad program for protection of the environment for developing countries. The mentioned program has a special focus on environmental problems with global effects.

In general, the problem of small mining in developing countries is very complex; it includes legal, economic, social and particularly environmental aspects. At present, small gold mining is an economic activity of growing importance. A serious problem emanating from this activity are the mercury emissions. The non technical and indiscriminate use of mercury in artisan mining, constitutes a high risk for the environment. Due to it’s high toxic potential, mercury contamination has grave effects on the health of the mining population, and indirectly, due to it’s incorporation in the food chain, on the nearby and distant communities of the mining operations. The persistence of mercury in the ecosystem threatens the development possibilities of future generations.

At present, COSUDE is financing two programs that have the principle objective of mitigating mercury emissions produced by small gold mining: “ Mining without Contamination Project” in Ecuador, that has as counterparts, the non governmental organization Cenda Foundation, and the “ Integrated Environmental Management Program for Small Mining” in Bolivia, executed jointly with the Ministry of Sustainable Development and Planning.

The experience gained in the mentioned projects constitutes the knowledge base that has permitted the preparation of the present publication. The book shows the need of an integral focus that includes, legal, social-economic, technical and environmental aspects, for the successful application of environmental measures in small mining or other small industries. I hope that the content and the concepts of this publication contribute to a better quality of life and to sustainable development through the battle against environmental contamination.

Walter Fust
AMBASSADOR
DIRECTOR OF COSUDE

Foreword

The present publication is an English translation of the Spanish "Manejo Ambiental en la pequeña minería", published in 1998. Since its publication, there have been repeated calls from within the ASM community and at ASM events, requesting an English language version of the text, this edition therefore responds to those requests.

However, considering the accelerated pace of events today, information is outdated rapidly, so much thought has been given as to whether it makes sense in these times to issue an English version of a 1998 publication, and more so in view of the many changes that have taken place in the meantime within the framework of development policy, some of which have caused a considerable impact.

The concept of sustainable development serves as an example that has become a well established issue within the community of donors and the mining industry. Amongst the most relevant recent changes affecting ASM development policy, are:

- The formation of the Community and Small-Scale Mining (CASM) group as a coordination centre for dealing with ASM affairs. This group is co-financed by international donors, principally by DFID (United Kingdom) within the World Bank. CASM functions as a pivot for the exchange of information on small-scale mining, and to assist in coordinating donors for this sector.
- The Mining, Minerals, and Sustainable Development (MMSD) project, for which the international mining industry prepared a unified position for sustainable development of mining, presented it at the Rio+10 summit in Johannesburg in 2002. This paper is dedicated to scrutinizing the challenges confronting small-scale mining.
- The Extractive Industry Review (EIR) as an independent reviewer, has probed into the World Bank Group's support for extractive industry, and

has produced a set of recommendations for future intervention in mining in general, and small-scale mining in particular.

The latest themes to be introduced for consideration in small-scale mining are, “Poverty Reduction“, “Sustainable Livelihood” and “Local Economic Development”. The discussion on the rather sobering outcome of the traditional fiscal and normalising approach to small-scale mining, and on the alignment of some small mining projects and regional development programmes directed towards improving “sustainable livelihoods”, led to amplifying the small-scale mining approach by tying it to rural development, where it is used as an engine for progress in those regions.

This is encouraged by recognizing the fact that the indirect or secondary benefits of small-scale mining - even where production is informal, i.e. without legal title or payment of taxes and levies - its promotion is justified by the income it generates. Money is circulated in rural areas, new infrastructure is required, job skills and qualifications are produced, and the subsequent reduction in working over arable farmland. Additionally, there are the humanitarian goals, e.g., improvement of the traditional low standards of work-safety, elimination of child-labour practice, and the introduction of various other measures to improve the people’s welfare.

The basis for these new development policy changes can be further examined under:

- MMSD paper on ASM: http://www.iied.org/mmsd/mmsd_pdfs/asm_global_report_draft_jan02.pdf
- EIR website: http://www.eireview.org/eir/eirhome.nsf/englishmainpage/about?Opendocument
- IIED publication on ASM, which is currently being prepared.

Despite the backdrop of the environmental aspects of ASM, these development policy changes are important due to the fact that small-scale mining projects within the environmental management category, the same as those considered in this book, are as a rule tied into wide-range projects or programmes, and either refer to the small-scale mine in an integrated form, or are targeted at a mining-sector reform that contains small-scale mining components. Accordingly, this paradigm-change describes an evolving framework of activity in which environmental management comes into effect.

However, not only has the development policy framework undergone change; ASM itself has experienced many modifications in the past 6 years, some of which have ushered in a new boom, and others - a terrible necessity. Some of the causes for this have been:

- The strong fluctuation in gold prices, each rise and fall triggered a phase of new mining activities or mine closures.
- The tantalum price-hike (with tantalum mining partially substituting gold mining)
- The discovery of new gemstone deposits (e.g. in Madagascar), have triggered enormous waves of people migration and small-mine prospecting.

However, the reality is that in mining regions the picture remains grim. In gold-rush regions social conditions are horrifying, and the alarming rate of accidents that occur in the informal small-scale mines, have either become routine or are leading to drastic shut-downs. So, as before, for many of the mineros the small-scale mine represents nothing more than a bare subsistence level of existence within a "culture of poverty".

The welfare conditions have changed little in ASM, and equally as little have the technical conditions in small-scale mining changed, where many mines are still using technical standards reminiscent of the "status quo" at the time of the Industrial Revolution. As a consequence, the alternative solutions focused in the book remain unaltered by the changes indicated above, and the book's key-content remains valid. The technical-approach project is unchanged and is still valid today.

Therefore, the above considerations have led us to decide in favour of translating the text in its original form into English and make it more widely available. In this sense we hope that the book meets with a growing interest and contributes to the endeavour to help alleviate the environmental problems caused by small-scale mining operations.

Königstein, Aachen, Lima and La Paz, January 2004

1 Introduction

This manual presents in a condensed form, a compilation of the experiences obtained from several international cooperation projects in the area of environmental protection and management in small mining. Technical, organizational and strategic aspects are taken into consideration.

The publication is consciously focused on the managerial side of environmental protection because, amongst other reasons it is accepted that small mining is a sector very difficult to control by governmental institutions. The reasons for this will be dealt with further below. In order to achieve an increase in environmental response on the part of companies, strategies are required that focus on producers, in other words, on the originators of the environmental problems. Obviously, and at the same time, it will be necessary to adapt the legal-administrative processes, for example, simplify the issuance and legalization of the respective licenses. However, there will not be much success by limiting only to legal and administrative measures. This has been demonstrated by several intents in this regard that have failed (for example, prohibiting small mining or the use of mercury by small miners).

For this reason, the present text is directed principally to the planners and executors of projects that are related to environmental management in small mining. This will also be of interest to persons that work in the area of environmental protection, on company or small industry levels as the majority of the methods are transferable and applicable to other sectors.

This publication is based on experience acquired in several projects executed by the authors on behalf of international donor institutions: The Swiss Agency for Development and Cooperation (SCD) as also, the German institutions Deutsche Gesellshaft fur Technische Zusammenarbeit (GTZ), Bundesanstalt fur Geowissenschaften und Rohstoffe (BGR), the European

Community (EC) and other multilateral organizations. experiences to other countries is very viable, including the African and Asiatic areas.

1.1. Definition of the sector

Small mining plays a not insignificant role on a world wide basis, both in industrialized nations and in developing countries. Considering that the definitions of "small mining" are different in each country, the criteria used for its definition are: investment (e.g. less than US$1,000,000), labor force (e.g. up to 100 persons), crude ore production (e.g. less than 100,000 t/yr) annual sales, concession size, reserves situation, or combinations of these criteria. Discussions in this respect are being held and as yet, a limitation with objective criteria has not been established.

Consequently, small mining in developing countries is identified by subjective criteria that make it appear as an artisan activity:

- Non existent or scarce mechanization (use of operational machines and power); consequently, a large percentage of hard manual labor [a];
- low safety levels;
- low level of technical knowledge of the personnel;
- absence of technicians in the operation which consequently leads to deficient technical planning in mine production and processing;
- relatively deficient use of resources due to selectivity of high grade ore and consequent low level of recovery in processing;
- production of marginal resources;
- low salary levels;
- low labor yield;
- partially, mining is seasonal or when international prices are convenient
- insufficient consideration of the danger to the environment;
- chronic absence of capital

Parallel to these aspects that are particular to small mining, there is another of great importance:

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[a] However, some small mining operations are highly mechanized. A high level of mechanization together with informality is not necessarily excluded

- Workings in some cases are illegal due to the lack of mining rights or environmental licenses.

These factors make it necessary to include these companies in the informal sector, which acquires relevance in the aspect of environmental control: frequently these companies consciously avoid control by government organisms and at the same time possible government sanctions that are not high.

Frequently, small mining can be considered as an industrial sector that is particularly difficult to control and manage, the reason being the geologic reality of the deposits that create isolated and disperse nuclei in the rural areas. Clear examples of this are the mining companies in the Bolivian Andes, several of which are located over 5,000 meters above sea level and are only accessible by foot and several days journey (photo 52).

1. 2. Mining as an example of small industry

Small mining includes many aspects that are also typical of small industry and its companies:

- surrounding conditions do not permit development; there is a lack of interested groups and development institutions, they are inefficient or only represent the interests of a few persons (1);
- the buy/sell markets are fragmented, not transparent or inaccessible (1). Many products require high quality standards and quantities (although not valid for gold) in order to compete on the market;
- lack of qualified professional personnel. Insufficient qualified personnel with practical experience, reduces both quality and quantity (1)
- Installations and equipment are obsolete or inappropriate for local conditions; access to know how, technology and finance is made difficult or impeded (1). Many jobs stand out as being insecure and dangerous
- There is a great variety of companies: ranging from artisan level (that have no mechanization) to those that are semi-mechanized and some that are totally mechanized.
- Frequent instances of child and women labor in sub-human conditions.

With respect to environmental management, there is a clear similarity between small mining and small industry, particularly in the following:

- In many developing nations, artisan and industrial activities – particularly in the small company range – are highly toxic for the human being and the environment;
- The sources of contamination are widely dispersed;
- Difficult environmental control on the part of the government;
- Deficient legal regulations or not applicable in these sectors;
- Deficient occupational safety and hygiene at work;

In order to achieve a reduction of these negative effects on the environment and on those involved, and in order to achieve compliance with the usual and legal requirements, it is indispensable to achieve sensitivization, information and training of all actors at every level, and the adoption of technical environmental measures.

1.3. Present situation and significance of small mining

Small mining suffers from numerous ailments that make difficult and even inhibit development towards modernization and mechanization of the micro and small companies.

The present situation of small mining and miners, is defined by their interchange and connection with diverse areas and factors such as: nature, man and culture, technology and economy. Mining, due to the exploitation of resources and damage to the environment, affects nature by taking away raw materials and energy. Mining on the one hand and man and culture on the other, have had a mutual influence on each other since time immemorial. Mining contributes metals and precious stones that have a strong influence on culture. Mining is and has been an activity that opens roads for technical and rural development.

Despite these difficulties, small mining holds an important worldwide position and makes important contributions to world mining.

TABLE 1

PROPORTION OF SMALL MINING IN WORLD PRODUCTION OF SELECTED RAW MATERIALS, ACCORDING TO NOETSTALLER (2)

METAL				INDUSTRIAL MINERALS			
Beryl	100%	iron	12%	fluorite	90%	barite	60%
Mercury	90%	lead	11%	graphite	90%	sand/gravel	30%
Wolframite	80%	zinc	11%	talc	90%	bricks	30%
Chromium	50%	cobalt	10%	vermiculite	90%	salt	20%
Antimony	45%	gold	10%	pumice	90%	coal	20%
Manganese	18%	silver	10%	feldspar	80%	asbestos	10%
Tin	15%	copper	8%	clay	75%	phosphate	10%
				Gypsum	70%		

1.4. Global distribution of small mining

For a great number of developing countries in the world, small mining has become an important source of income and foreign currency:

TABLE 2

PRINCIPLE COUNTRIES WITH SMALL MINING, WITH RAW MATERIALS PRODUCED THROUGH SMALL INDUSTRIES, ACCORDING TO NOTSTALLER (2)

COUNTRY	RAW MATERIALS PRODUCED BY SMALL MINING
Latin America	
Argentine	antimony, asbestos, beryl, lithium, mercury, bismuth, wolfram
Bolivia	antimony, lead, gold, sulfur, silver, wolfram, zinc, tin
Brazil	beryl, chromite, gold, precious stones, titanium, tin
Chile	barites, lead, gold, copper, manganese, mercury, sulfur, coal
Dominican Republic	gold
Guatemala	antimony, lead, mica, manganese, tin, wolfram
Colombia	antimony, lead, chromite, precious stones, iron, gold, coal, platinum, mercury, zinc
Cuba	copper, manganese, pyrite
Mexico	fluorite, mercury, sulfur, uranium, tin
Peru	antimony, diatomite, gold, copper, manganese, molybdenum, silver, bismuth, zinc, tin lead
Venezuela	asbestos, diamonds, gold
Ecuador	gold
Asia	
Myanmar	antimony, manganese, tin, wolfram
China	antimony, iron, tin, wolfram
India	barites, borates, iron, mica, coal, manganese, tin
Iran	barites, lead, copper, zinc
Malaysia	gold, iron, manganese, zinc, tin, wolfram
Papua-N.G.	gold
Filipinas	chromite, gold, coal, copper, silver, zinc
Thailand	antimony, tin, wolfram
Turkey	lead, chromite, copper, manganese, mercury, zinc

COUNTRY	RAW MATERIALS PRODUCED BY SMALL MINING
Africa	
Algeria	antimony, barites, diatomite, mercury, zinc
Ethiopia	gold, manganese, platinum
Gabon	gold
Ghana	diamonds, gold
Kenya	beryl, precious stones, gold, copper, silver
Lesotho	diamonds
Liberia	diamonds, gold
Madagascar	gold, rare earths, bismuth
Morocco	antimony, barites, lead, manganese, zinc, tin
Nigeria	asbestos, barites, lead, gold, zinc, tin
Rwanda	beryl, gold, tin, wolfram
Sierra Leone	diamonds
Tunis	lead, mercury, zinc
Tanzania	diamonds, mica, gold, magnesite, precious stones, tin, wolfram
Uganda	beryl, bismuth, wolfram
Central African Republic	diamonds, gold
Zimbabwe	antimony, beryl, chromite, precious stones, gold, copper, lithium, manganese, silver

2 Costs and benefits In small mining.

Small mining in developing nations is frequently reproached for exploiting the national wealth and not contributing sufficiently to the national economy of the respective country. It is also stigmatized as the “social sore” of the nation. News of the misery after the gold fever in Acevedo do Peixoto, Brazil, seems to confirm this opinion. One of the consequences of this was that the government attempted to isolate this sector and impede its development. However, in a general form this was the only thing that occurred as the well known administrative deficiencies in developing nations do not permit the exercise of control over small mining.

Governments of the respective countries frequently tend to value small mining with different criteria than that proposed in this chapter. In many cases it is sustained that large multinational mining does not give the same problems as small mining. Large mining is easier to control; it contributes taxes and, has a strong lobbying position due to its economic and political strength. For this reason, many governments prefer large and medium mining (3).

At present, on a world scale, one is faced with a renaissance of small mining that obliges governments to recognize it as a social reality. For this reason, many countries have recently changed their attitude. Efforts have been increased to open new accesses to this informal sector and include it in the economic system. However, the discussion on costs and benefits in small mining activities is a very controversial subject. One of the reasons is, that there are very few existing analyses of the sector and that there are few indicators that can be examined on the subject.

In the majority of cases we have a positive balance if we take into account all the costs and benefits of small mining from a development policy point of view, although the direct monetary contribution of the sector, such as tax payments, is low. The direct and collateral benefits of small mining are frequently so important, that it is incomprehensible that developing nations do not **make greater efforts to accept this mining sector as a possible catalyst for the development of rural areas by adequately promoting it and assisting it to emerge from its informal status** and thereby include it in the formal economy. This is valid only when small mining includes adequate environmental protection and acceptable work conditions.

2.1. Generalized difficulties arising from the analysis of costs and benefits

In order to develop a wide base for analysis, it is necessary to include the classical aspects of a country's economy such as, social and environmental costs and benefits. Due to the deficiency of traditional analyses, in Europe also there is an effort to widen the bases for analyzing national and global economic processes. An example of this is the studies published by Ernst Ulrich von Weizsacker on this subject (4). However, for the benefit of a more integrated system of analysis, it is opposed by the fact that several of these non classic indicators cannot be quantified by a system of monetary values. Consequently, it is possible that analyses of the same situation may have divergent results because different methods are used to evaluate the subjective criterion.

Additionally, a factor that makes the transfer of criteria difficult and that normally can be quantified or valued, is the differences in the economies of the diverse nations. An example is the information that refers to the situation of the labor market: in the industrialized nations, the data on unemployment refers normally to open unemployment, whilst in the developing countries; there is practically no reliable information because it is not possible to gather quantitative data on the typical phenomena of hidden unemployment and of open or hidden underemployment.

Another aggravating factor is that in the developing countries the social aspects are regarded under other perspectives; some aspects have different priorities to those in industrialized countries, such as guaranteed full time employment, responsibilities of the educational area and environmental protection. On the other hand, as the government in many nations is deficient in the compliance of its social obligations, a parallel or informal economy has developed which includes small and specially artisan mining that has and can develop freely on the margin of the formal sector.

Although this informal sector is undesirable, in the majority of cases the government is not in a condition to offer alternatives.

2.2. Costs and benefits

In order to analyze costs and benefits it is important to take into account four major aspects:

- Geologic aspects
- The consequences for the environment
- Social aspects and,
- Economic aspects.

Table 3 shows a synopsis of these aspects and also the most important costs and benefits that can be obtained in these four fields.

As these basic local conditions vary in each case, the results of an evaluation of the effects of mine production also vary. The effects of production in the northern Chile desert will be evaluated differently from production located in a tropical forest.

It will not be necessary to explain all aspects of costs and benefits mentioned in Table 3. However, we wish to develop some of these in detail:

Exploitation of marginal resources: One of the particular advantages of small mining, is the possibility of beneficiating the dumps and tailings of larger operations or to exploit existing reserves in abandoned large mines. For example, a very important proportion of Bolivian small mine tin production comes from the tailings of large COMIBOL mines that have been transferred to several mining cooperatives. A similar situation exists in Ecuador with the tailings of the ex-SADCO company.

Table 3

VARIOUS ASPECTS OF COSTS AND BENEFITS OF SMALL MINING IN DEVELOPING COUNTRIES

COSTS	BENEFITS
Mining geological costs • Exploitation of a non renewable resource • Losses due to: - Irrational exploitation of high grade material - Incomplete exploitation - Treatment methods - Transport	**Mining geological benefits** • Possibility of exploiting smaller deposits • Small mining executes low cost successful prospecting • Exploitation of abandoned pillars, tailings etc. • Small mining discovers important deposits in abandoned areas
Consequences for the environment • Environmental risks, emissions and damage to: - The earth - The soil - The water (subterranean and surface) - The atmosphere - Flora and Fauna - Sources of energy - Ecosystems	
Social cost • Precarious working conditions • Negative health consequences (sickness, accidents) • Subhuman living conditions • Complicated dependency relations • Child labor • Unbalanced development between men and women (men dispose of economic resources) • Violation of the rights of resident communities and Indigenous communities. • Changes in systems of ethical values and the consequences. • Insufficient social security	**Social benefits** • Labor training • Source of income (cash) • Generation of jobs
Macro economic costs • Conflicts: - Due to variations in exploitation of land, water etc. - With the authorities (legal conflicts) - With large scale industrial mining - With the indigenous population - With the objectives of landscape preservation (national parks, nature etc.) • Contraband • Non legality (of products and profits) • No taxes generated • Cost of controlling the sector • Consecutive costs caused by social consequences (health, social conflicts, speculation etc.) • Uncontrolled development caused by lack of planning.	**Macro economic benefits** • Mobilization of natural resources • Tax collection • Activated effect on balance of payments • Buffer for the labor market in structural adaptation programs • Makes available labor reserves for industrial mining • Contributes to regional economic development: - Monetary circulation (social product) - Investments - Products demand and services - Vehicles - Structural consequences (alternative to agriculture) - Avoids rural migration • Development of infrastructure (road building, schools, energy) For small miners and neighboring settlements. • Comparative financial advantages (production with a high labor coefficient in countries with a high labor offer). • Offer of product is relatively stable even when there are market fluctuations • Contribute to product diversity and exports • Substitute imports

Selective exploitation: Easy selective exploitation is usually higher in small mining than in medium mining due to its low levels of mechanization; this is frequently called "high grading". This argument however, loses validity taking into account that this selectivity also permits working deposits that would not normally be profitable for large scale mining (veins of less than 1 meter width for example). It should be added that as far as "high grading" during the first years is concerned, this practice is common with medium and large scale mining under the concept of, maximization of net present value, and a fast return of investment.

Consequences for the environment: The environmental cost for a small mine is generally more than for a medium mine in proportion with the production [a]. However, a further problem lies with great number of contaminants and that in many cases are concentrated in determined regions, with two factors that cause an extremely high local impact. An example of this is the mercury contamination caused by gold mining in the San Simon (Bolivia) area of not more than 20 km x 5 km that reaches a level of 25 tons per year (64). Another grave effect is that of the discharge of slimes from concentrated alluvial mining into the large rivers.

According to Young 1993 (5), 40% of the national tropical parks are threatened by mining operations or projects. Strangely, there is no difference between small and large scale mining with regards to the danger to protected areas or to be protected.

Social consequences: There are very evident relations in small mining between very precarious working conditions – apart from very grueling work – characterized by serious safety deficiencies, and extremely negative health situations caused directly by intoxication, accidents, dust (silicosis) etc., but also indirectly by stagnant waters that in the tropics provide the conditions for the incubation of Anopheles and other pathogenic agents.

a Not only in the industrialized nations, but also in developing countries, large scale mining is generally well controlled and supervised. The majority of large mines belong to multi-national mining companies that have their own environmental rules and regulations. That in order to avoid problems with the population (and also with their own shareholders) is frequently more rigid than those of the host country. In relation to production (e.g. to produce 1 kg of gold), the environmental impact produced by a large modern mine "state of the art", is significantly lower than the impact produced by small miners.

The need to obtain quick production, the scarcity of means and the chronic lack of investment and operating capital, place the small miner in a condition of dependency with intermediaries, landowners, machinery owners or other groups that in a certain manner, pre-finance the operation.

One can predict criminality in those places where small miners live cramped together in isolated locations and where there is expectancy of great profits (see photo 51). Confrontation with resident and indigenous communities is common in regions where small mining is entering. As mining activities require technical knowledge and investment capital, the local communities are not in a condition to obtain an equitable participation. The massive or gradual <invasion> by mining, brings with it a change in the system of ethical values, that in certain extremes, ends in a loss of control on the part of the government (e.g. Serra Pelada/Brazil, Muzo/Colombia, Nambija/Ecuador, Mindanao/Philippines).

Social benefits: A very important aspect is the **employment of under qualified labor**. At this time, small mining generates employment for over 7 million people for the production and concentration of ore, divided into regions as follows (6):

China :	approx. 3.4 million small miners
Others Asia and Oceania:	approx. 1.5 million small miners
Latin America	approx. 1.3 million small miners
Africa:	approx. 0.9 million small miners

For the majority of these workers, small mining is attractive as the wages paid are higher than in other sectors (e.g. in agriculture). These employment figures in small mining do not include those sectors that depend on or benefit from mining activities such as, commerce, workshops, transport, etc. In addition to these figures, there are the families that depend on mining income. Thus, if we consider a factor of 2 for the infrastructure sectors and 4 for family dependents, it can be concluded that approximately 50 million persons depend directly or indirectly on small mining on a world level. This does not include the secondary effects from the generation of resources.

Economic effects: Both the contraband of goods and the monetary benefits produced by small mining produce negative effects on the national economy. The contraband of goods with a high value is particularly easy. For example, large quantities of gold pass in the form of contraband from Ghana to Togo and from Brazil to Uruguay, countries that do not have (or few) gold deposits of their own and yet register high sales values in their export statistics. At 400 million dollars per year, the gold and diamond production smuggled from Zaire surpasses by far the official exports of 300 million dollars. However, in many cases it is not possible to uncover the contraband as the gold production from small mining is used to launder the profits from drug traffic or as in Angola, diamonds are exchanged for armament. The contraband and illegality of many small mining companies, signifies a considerable loss in taxes. However, it must be pointed out that only a small part of these activities can be attributed to small miners. Their reduced production does not justify the contraband. This is organized, principally by groups of intermediaries that take advantage of the informal nature of their providers.

The informal nature of many small mining companies signifies a massive evasion **taxes**. On the other hand, there is **income from taxes** that are indirectly paid by informal small miners. Colombia for example, applies a royalty of 3% on gold production that at the time of sale is also paid by the illegal producers. Of this, 66% goes back to the community of origin in the form of an industrial tax. In Brazil, the companies in the mining sector, pay taxes on sales and a financial compensation for the exploitation of resources, and as in Colombia, a large part of these funds go back to the community of origin. Many communities in Latin America cover their budgets with the taxes generated from small mining. Additionally, the income from indirect taxes such as IVA (Added Value Tax), etc., generated by mining activities, must be taken into account; government income generated as a secondary instance from circulating capital produced by small mining. This indirect and renewable government income over a period, is more significant for the national budget than direct non renewable taxes from royalties, patents, concessions, etc.

The reason that the **activation effect for the balance of payments** is produced is due to investment and production costs payable in national currency on products and national services. As there is no foreign participation, there is no flow of capital overseas. Production is sold directly in the international market generating foreign income, or substituting imports thus reducing the transfer of funds to the exterior. All of this can be of great importance to countries with small mining activities as is demonstrated in Ecuador, where, according to information from the World Bank, small mining, legal and illegal, produce over 90% of the national gold production, that is, approximately 15 tons per annum according to official sources and 30 tons per annum according to unofficial sources.

An essentially beneficial function of small mining is as an **employment buffer in situations of structural adjustments.** A typical case is Bolivia, where after the collapse of the international tin cartel, the government corporation COMIBOL closed its tin mines. Small mining absorbed more than 20,000 miners that had lost their jobs.

A further benefit is **very low production costs** that consequently **offer relatively stable productions** even when there are price fluctuations. For example, the Colombian small coal mining activity can produce first class coal at between US$8 to US$10, despite its low production capacity. However, this economic benefit has a high social cost (child labor, subhuman working and living conditions) that is unacceptable. The very low production costs are also a result of negligence in environmental aspects.

Finally, it is necessary to also to consider the aspect of **import substitutes** that is of special importance with regards to some materials that are produced in quantity for the local market. Indonesia with about 77,000 companies and more than 350,000 miners, produces principally stones and earths with a value of 60 million US$ per annum. In India, more than 3,000 small companies with more than 250,000 miners, produce more than a half of the national mine production.

Origin of the problem: The majority of the negative effects of small mining in developing nations have their origin in problems related to informality and illegality or, insufficient control of the sector. If the government were to make an effort to legalize the small companies, it would gain on the one hand the possibility of controlling them, and on the other, sanctions for lack of titles or for their environmental impacts. Unfortunately, in many countries the publication of laws and regulations for the protection of the environment, desirable per se, is also the cause of new hazards for the small mining sector. In many cases, small mining does not have sufficient technical or administrative capacity to comply with norms, and is continually forced into illegality by those in charge of environmental protection.

Illustration 1

GENERALIZED COMPARISON OF THE DIFFERENT BRANCHES OF MINING WITH RESPECT TO COSTS AND BENEFITS

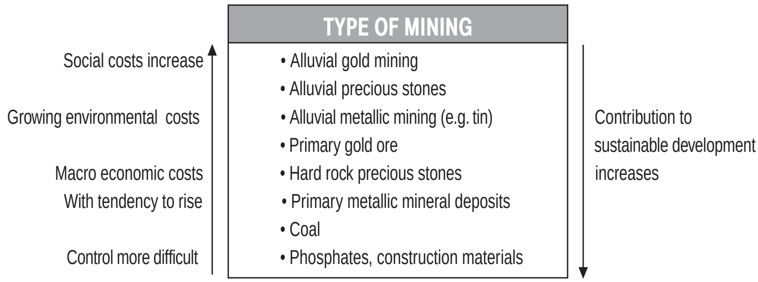


Illustration 1 shows a generalized comparison of the different branches of small mining with respect to costs and benefits. The extremes contrast the exploitation of earths and rocks on the one hand and on the other, the highly speculative area of mining such as, alluvial mining and precious stones placers.

2.3. Results of a comparative study in Ecuador on small and medium mining

In a study carried out in Ecuador (7), a comparison is made of three different branches of mining: small informal artisan mining; small formal mining; and medium mechanized formal mining. The gross contribution to the national economy and the environmental debt was determined for these three branches of mining[a]. The results are shown in Illustration 2.

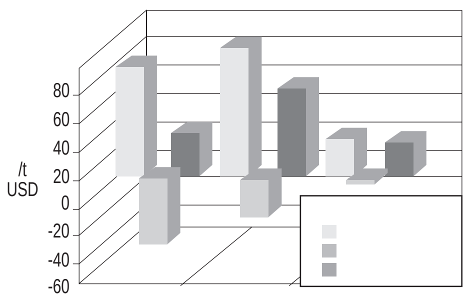
This shows that for companies with comparable ore production, the gross contribution to the national economy of the two sub-sectors of small

a This investigation includes a series of monetary values and factors that, in part, are the results of case studies in Ecuador, and that were also complemented by data on international mining activities in developing countries. The investigation for the comparison of several mining companies with defined parameters (installed capacity, availability, annual production, productive life, rate of exchange, ore grade, price of gold, recovery and cost distribution of personnel, transport, energy, administration and materials) contained investment cost, operating costs divided into national and international costs, income, taxes and royalties, profits, environmental cost with impacts on the hydrological system and agriculture, factors for other impacts and time factors.

mining is clearly above that of medium mining. These positive figures are partially neutralized by the high environmental cost generated by these two groups: those generated by the informal sector are the highest; those by the medium miners are the lower. Due to this, the major net contribution to the national economy is made by the formal small miners. It would be interesting to prepare similar analyses for other mining areas, and in the same manner for other work alternatives in rural areas. Surely these kind of studies would quantify and document the economic advantages of orderly and organized small mining, and would place emphasis on the fact that advisory projects for small mining would be profitable (8,9).

Illustration 2

GROSS MACRO-ECONOMIC CONTRIBUTION, ENVIRONMENTAL DEBT AND NET MACRO-ECONOMIC CONTRIBUTION OF INFORMAL SMALL MINING, FORMAL SMALL MINING AND MEDIUM MINING IN US$ PER TON OF ORE PRODUCTION; GOLD MINING IN ECUADOR (7)



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3 Environmental problems of small mining

The environmental problem of small mining has many facets, and its origin lies in the inherent mining risks, in the general conditions of small mining, in the mentality of the miners and in the notorious ignorance of environmental criteria.

3.1. Environmental risks

Mining in general produces various impacts on the physical and social surroundings in all of its stages, during geological reconnaissance, prospection, exploration, as also in the production, beneficiation and closure of the mines.

For mining in general, the multi and bilateral organizations have developed and published several compendiums on the risks to the environment, which can be consulted.

Unfortunately, these compendiums refer to large scale mining and have very limited validity for small mining (10, 11, 12, 13, 14, 15, and 16).

As an example, environmental impacts caused by alluvial gold mining (Illustration 3) and by the concentration of gold bearing materials (Illustration 4).

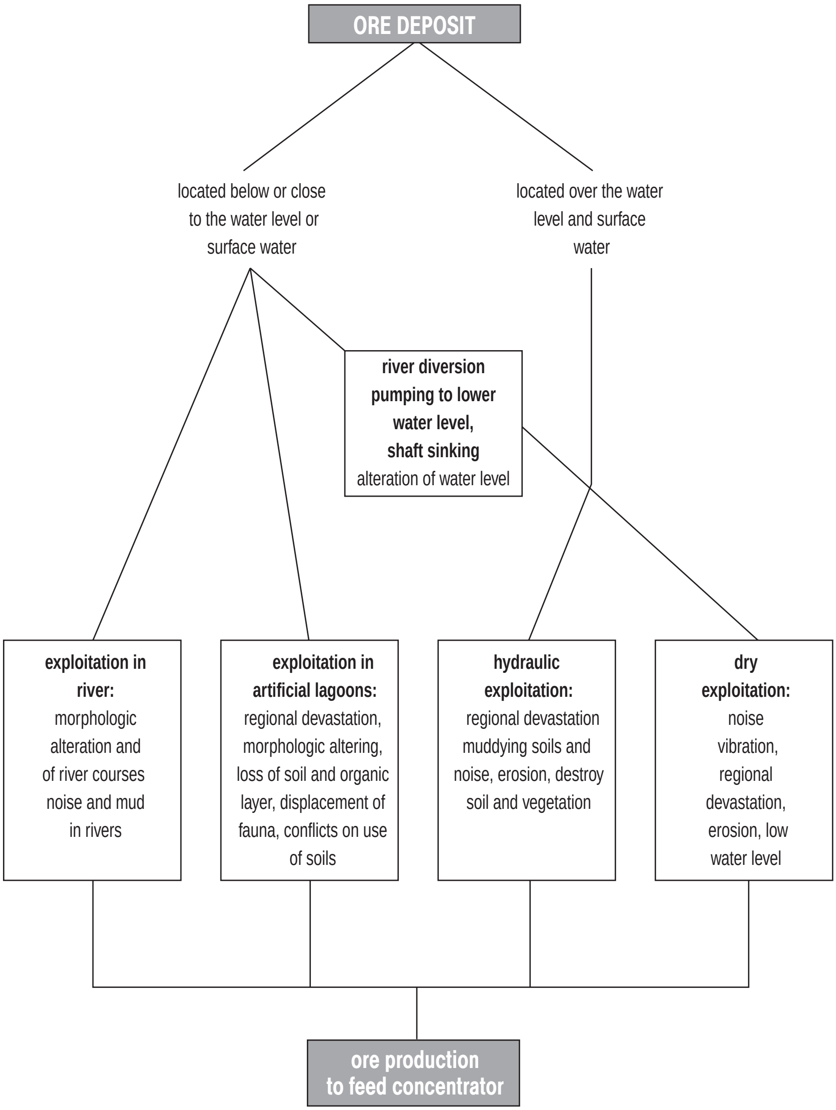
In addition to these risks directly related to exploitation, there are a series of indirect environmental effects equally grave, such as:

- Production of garbage and waste
- Colonization of remote places is induced due to the development of infrastructure
- Propagation of tropical diseases originating from stagnant water

Illustration 3

POSSIBLE ENVIRONMENTAL IMPACTS GENERATED BY THE DIFFERENT ALLUVIAL GOLD PRODUCTION METHODS

(Without considering the impacts caused by concentration)



The following illustration shows a general summary of the possible environmental impacts caused by small mining.

Illustration 4

ENVIRONMENTAL IMPACTS CAUSED BY THE CONCENTRATION OF GOLD BEARING MATERIALS (33)

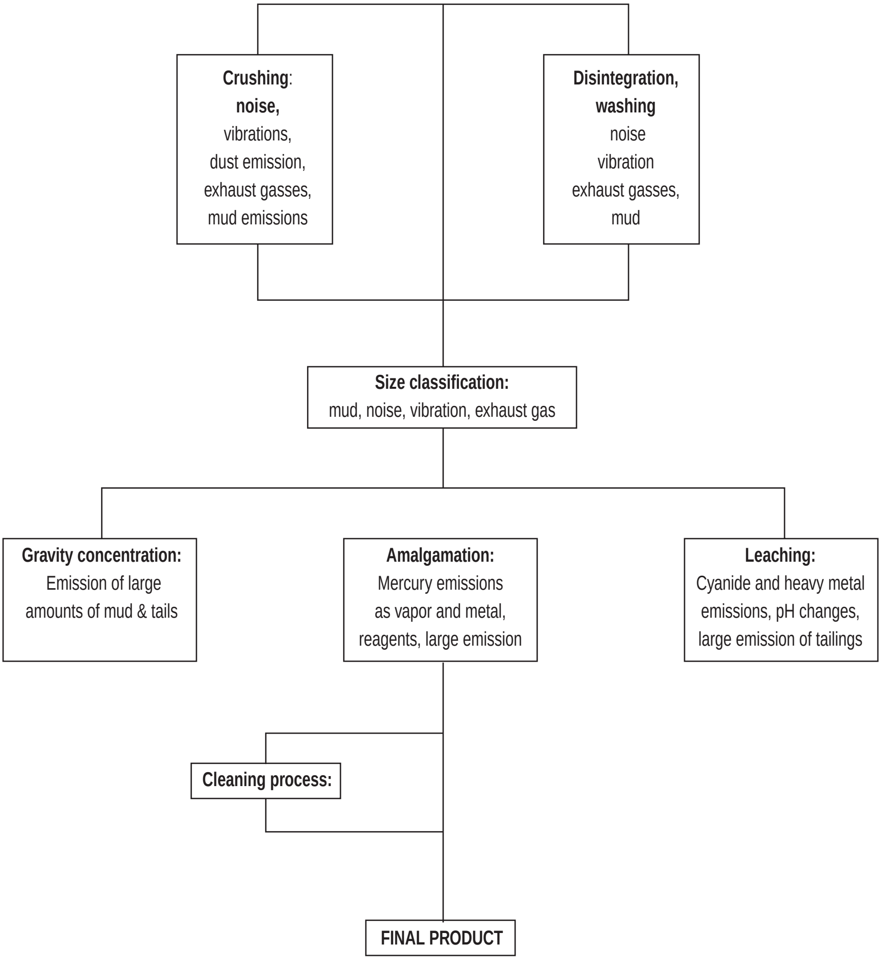


TABLE 4

ENVIRONMENTAL IMPACTS CAUSED BY SMALL MINING

MEDIUM IMPACTED (129)			EFFECTS ON THE MEDIUM (IMPACTS)
Physical medium	**Inert medium**	**Air**	**Deterioration of air quality:** Contamination by mercury, nitrous gas, sulfur oxides from exhausts, gas from calcining, roasting and smelting etc. **Dust generation:** Production drilling, transport, beneficiacion, etc. **Noise:** Machines, blasting etc.
		Soil	**Contamination:** Coarse solids, tailings, rubble, sulfides, mercury, lubricants, heavy metals etc. **Erosion:** Dumps, tailings, effects of deforestation, etc. **Agricultural capacity:** Removal of vegatable top soil, covering fertile soil with tailings and dumps, destruction of agricultural soil for open pit mining, erosion etc. **Geologic values:** Low valuable mineral recovery, loss of tailings, "high grading" etc. **Vibration:** Machinery and equipment, crushers, heavy transport etc.
		Water	**Alteration of water resources:** Unecessary filling of ravines with tailings, change of river courses, etc. **Deterioration of water quality:** Mercury contamination, heavy metals, cyanide, fine solids, acid waters, lubricants, sewer waters, etc.
	Biological medium	**Flora**	**Herbaceous species**: Forest clearing, burning of vegetatopn, etc. **Forest species:** Forest clearing, etc.
		Fauna	**Terrestrial fauna:** Disturbance and extinction of fauna due to hunting, contamination, forest clearing, noise etc. **Aquatic fauna:** Disturbance and extinction due to fishing, contamination, course alteration etc.
	Visual	**Landscape**	**Alteration of landscape value:** Destruction of landscape, fertile soil, terraces, beaches etc.
Social-economic,cultural.	**Social medium**	**Use of land**	**Change of use:** Abandon of traditional activities such as agriculture etc. **Resting and recreation:** Destruction of beaches, river and lake contamination, forest clearing, etc. **Tourism:** **Green areas:** Forest clearing, conversion to industrial areas, vegetation loss, etc. **Commercial zones:** Industrial areas, mining centers, accumulation of gold buyers, etc.

MEDIUM IMPACTED (129)			EFFECTS ON THE MEDIUM (IMPACTS)
		Cultural	**Education:** (Abandon schools for premature work in mines etc.) **Monuments:** (Destruction of remnants of ancient mine workings, colonial period etc.) **Archeological remains:** (Mining in pre-colonial areas.) Architectural style: ("Mining architecture"). **Style of living:** (Migration, cultural interchange, loss of traditional values, conflicts with indigenous groups and residents etc.)
		Infrastructure	**Communications:** (Pioneer role of mining in colonization of remote areas.) **Equipping:** (Creation of workshops, mechanics, building materials etc.) **Supply chain:** (Building airstrips, access roads etc.) **Sanitation:** (Garbage, sewage waters etc.)
		Human	**Sensations** **Quality of life** (Contamination, illness, change to "industrial culture" in remote areas, availability financial resources etc.) **Traffic congestion:** (Transport of materials, ore etc.) **Citizen security:** (Crime, public order, creation of vigilance committees, body guards etc.) **Catastrophe risks:** (Landslides etc.) **Health and Hygiene:** (Occupational health problems, venereal diseases, malaria, other tropical.)
	Economic media.	**Population**	**Population density:** (Mining settlements, "gold rush" effects; e.g. Sierra Pelada, Nambija etc.) **Employment level:** (Requirement of qualified and non qualified labor.) **Social relations:** (Conflicts with local communities, conflicts between formal and informal miners, invasions of territory etc.)
		Economy	**Level of consumption:** (Acceleration of economic development processes) **Change of prices:** (Price increases, scarcity of certain products, increase in demand etc.) **Change in land values:** (Informal mining: Landowner "allows" exploitation, mill construction etc.) **Purchase and sale of land:** (For construction, infrastructure, road building etc.) **Introduction of administration:** (Municipal taxes, municipal participation in royalties, funds for public works etc.) **Income for local economy:** (Increase buying capacity, commerce, bars, stores, infrastructure etc.)

3.2. Lack of control/supervision

The government has great difficulty in controlling the small mining sub-sector, due to:

- Location of numerous small companies
- Lack of laws and norms applicable to the sub-sector
- Lack of qualified personnel
- Lack of necessary infrastructure (vehicles, equipment, laboratories etc.)
- Access denial on the part of companies/mines, partly due to the lack of will on the part of the government to recognize the reality of the sub-sector.

Mining is an activity that produces multiple serious impacts on the environment. For this reason, public interest has focused on it. During the present decade, the preoccupation for environmental problems has reached political levels in developed and developing nations. As a result, laws have been passed and government environmental institutions formed. Application of these laws has generally been easy by large and medium companies; however, many nations have been unable to include small and artisan mining in their formal legal systems or in their national environmental policies. Small mining today is stuck even more in its informal status. In some countries small miners suffer from:

- Negation for their operating permits
- Retarded process for approval of their applications
- Extremely complicated administrative requirements

In some countries, it is almost impossible for small mining to obtain legal status from the government, even though this is contrary to fundamental legalities. Even so, these small mining companies continue to work without the required legal backing. On the one hand, this policy brings as a consequence, the conscious evasion of government control and, on the other, they do not feel obligated to comply with existing laws and commit acts against the law, the environmental regulations and industrial security. Some companies have a disastrous social and environmental behavior. This situation makes development work by government and non government organizations very difficult with these companies as they have created an atmosphere of a lack of confidence that can only be surmounted by applying costly and time consuming measures. These measures cannot be directed immediately towards environmental improvements in the companies and will only be accepted if the advisory work offers greater production, lower costs, or other advantages. Only on this basis will it be possible to introduce changes with respect to the environment.

3.3. Deficient occupational health situation

Whilst considering the environmental situation of small mining, it is of major importance to take into account not only the impacts on the physical surroundings, but also those on the social level. Work activities and other aspects in the life of the miners develop in conditions in such a manner, that the impact on their health is extremely complex and in many cases threatens their life.

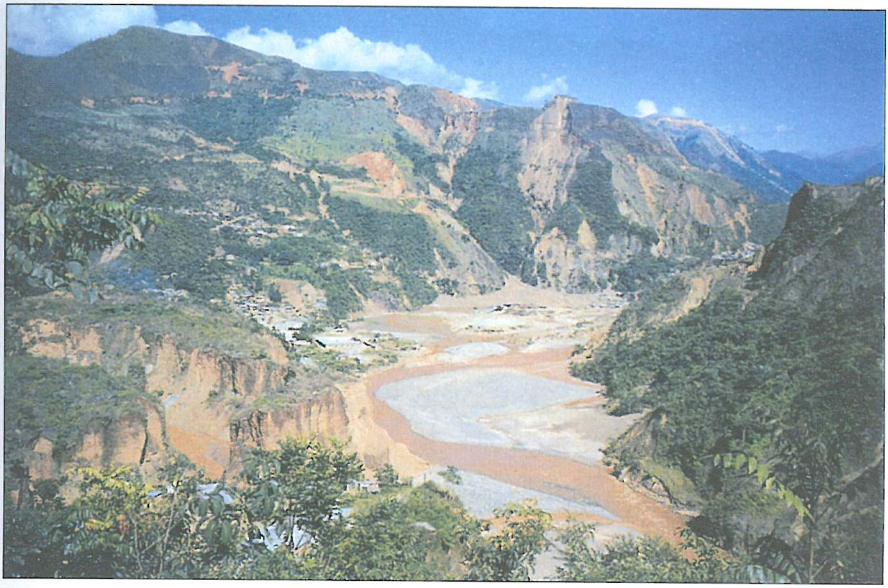
The situations related to mercury are only a small part of the problem, others are: the general sanitary conditions, the characteristic illnesses of mining activities that range from death by work accidents to acute and chronic intoxication of different types; additionally, pneumopathy, otopathy from intense noise, the effects of fatigue from long journeys, mental disorders, etc. Added to these, risk of landslides, explosions, fires, floods, careless tools and machinery handling from dragging and transporting material; the risk of falls and the multiple problems arising from inadequate use of electricity. It is frequently not possible to separate work conditions from other living conditions that affect the health of the miners. Parasites, malaria, anemia and tuberculosis are maladies that affect the miners and their families.

It cannot be ignored that the miner's health problems are closely related to the existence or not of occupational health programs and the availability of sufficient and adequate health services, housing characteristics, basic sanitation, education, relaxation and recreation, with the government and private company policies in the mining field, with the organization and conscience of the mine workers. Unfortunately, in the majority of developing nations there are no reliable and complete registers on the epidemic profile of workers involved in this activity (17, 18, 19, 20, and 53).

3.4. Causes of the problems

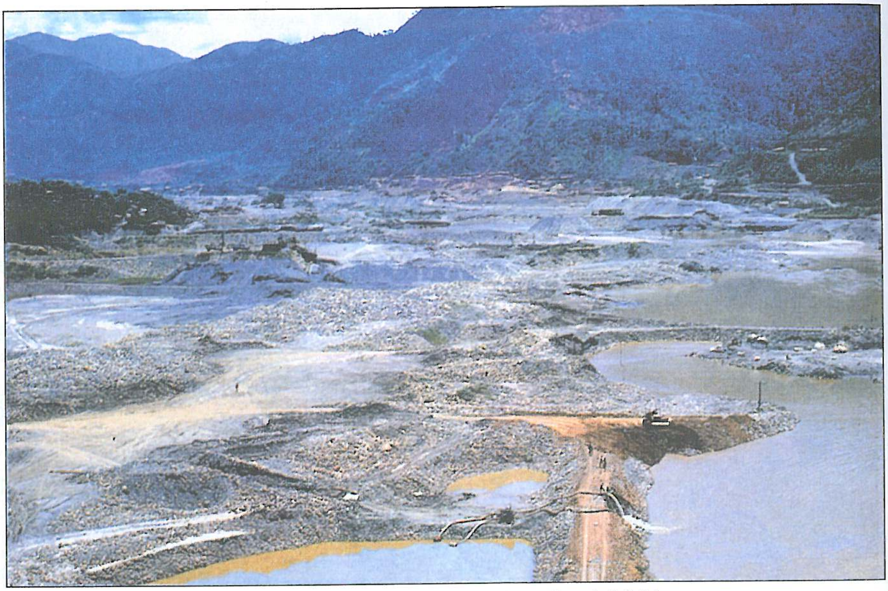
There are many and varied causes for the environmental impact in small mining. The following list enumerates the principle reasons:

- Lack of knowledge, education and training (technical and environmental)
- Inefficient technology/technical limitations
- Inefficient administrative management
- Errors in human control
- Economic limitations
- Lack of access to technology
- Lack of information on better practices
- Lack of control and sanctions/reinforcement.



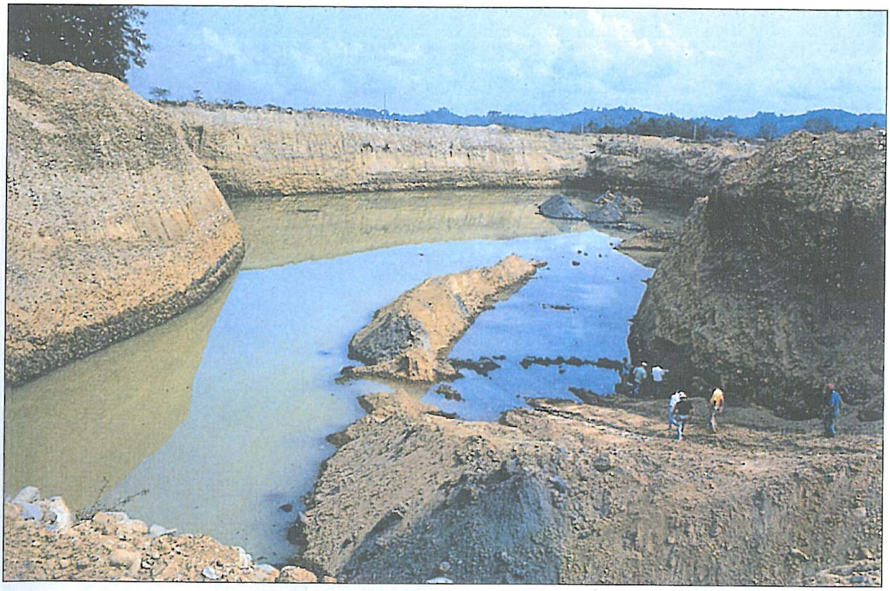
1. Aluvial Mining: erosion (Tipuani river valley, Bolivia)

2. Alluvial Mining: Destruction of landscape (Huaypetue, Peru)



3. Alluvial Mining: alteration of river course (river Tipuani, Bolivia)

4. Alluvial Mining: River muddying (confluence of river Consata with mining and river Camata without mining, Bolivia).



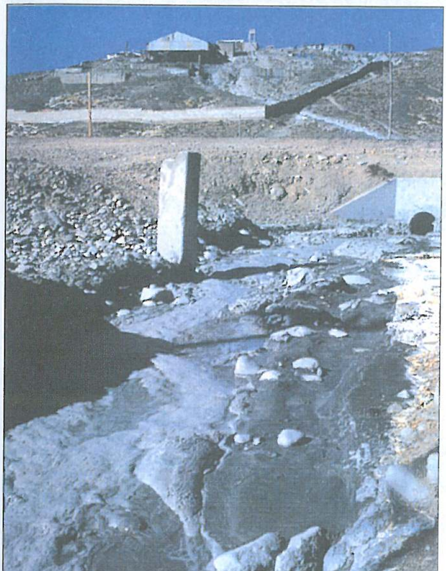
5. Alluvial mining: Residual lagoons (Tupara coop., Bolivia)

6. Alluvial mining: Discharge of tailings to river (Kabaketa, Colombia)

7. Primary mining: inappropriate tailings dump (Concepcion mine, Bolivia)

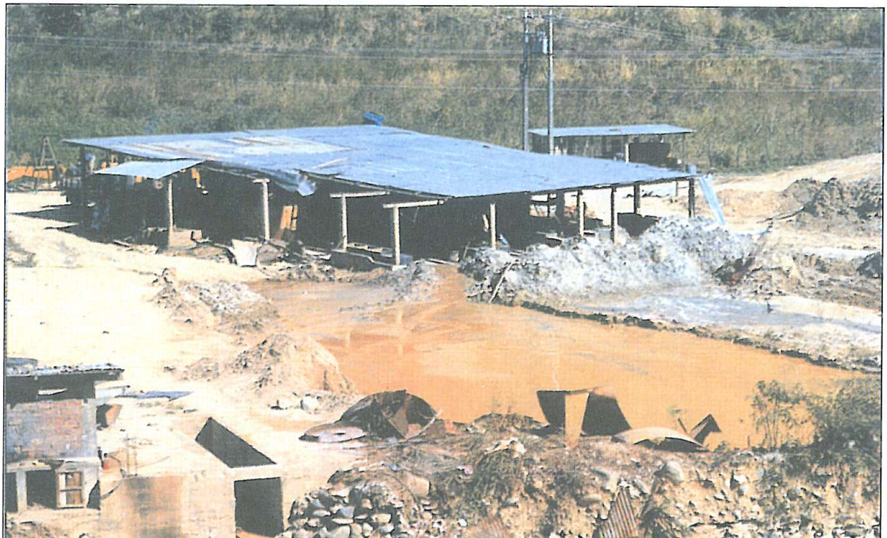
8. Primary mining: mine acid waters (San Francisco mine, Poopo, Bolivia)

9. Discharge of fine solids (ground material) to river (Potosi, Bolivia)



10. Primary mining: flotation plant, discharge to river (river La Ribera, Potosi, Bolivia)

11. Primary mining: tailings discharge to surroundings (Huayna Potosi Coop. Potosi, Bolivia)



12. Primary mining: percolation plant (cyanide leaching) (Portovelo, Ecuador)

4 Environmental management for small sustainable mining.

It is obvious that the precarious situation of small mining is accompanied by the absolute necessity to solve, mining, environmental, social, legal and technical problems. From the end of the decade of the ‘70s, when donation institutions began to take ever increasing interest in small mining as a potential sector for international cooperation, it has been possible to carry out many and diverse experiences focused on this area. From these, it has been concluded that one-dimensional focuses do not achieve the goal nor those actions with social motives.

4.1. Sustainability of mining

4.1.1 The concept of ore reserves

Mining is one of the oldest economic activities of humanity. It is not in vain that the pre-historic epochs of humanity are classified according to the materials used (stone age, bronze age, iron age).

From when the study “The limits to growth” was published in the ‘70s (21), there is much confusion with regards to mining sustainability. The mentioned study forecasts in the year 1972, that world reserves of various mineral resources were on the road to depletion in the near future (examples: gold in 9 years, tin in 15 years, petroleum in 20 years etc.). Present day reality shows clearly that this is not the case. However, based on this principle, the concept was born that mining was not sustainable.

To better understand mining sustainability it is necessary to define certain terms (22,23):

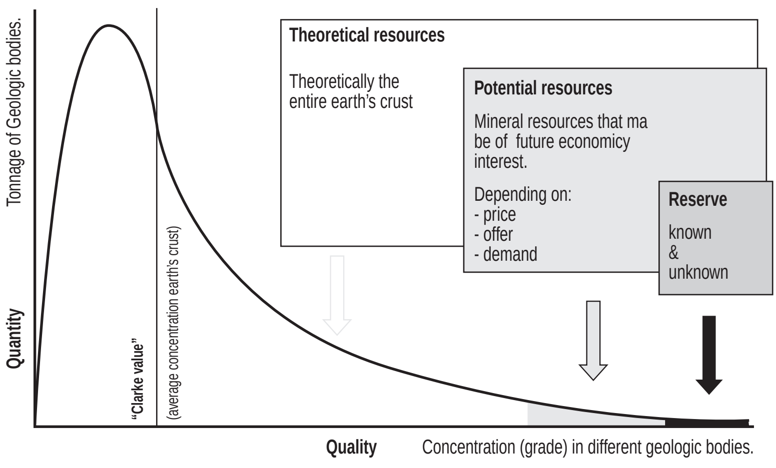
- **Raw material:** Raw material is defined as any organic or inorganic material that is transformed or that is introduced directly or indirectly in a productive process. Depending on the production phase, raw material may be composed of natural resources or of previous production phases.

- **Mineral resources:** Mineral resources are defined as all metals, minerals, rocks and hydrocarbons that can be utilized by man, and that exist on the surface and subsurface.
- **Mineral deposits** are geologic bodies that contain mineral resources in a higher concentration than in the earth's crust in general and therefore of economic interest.
- Those mineral resources found in deposits, are considered as being **mineral reserves**.

Illustration 5 shows the commonly accepted hypothesis on the distribution of mineral resources within the earth's crust. This illustration shows, that although a quantity of a resource on a global scale may be large or enormous, there is a limit that can be considered as a reserve (productive resource). There exists a large quantity of rocks with minimum contents of a given mineral, and in comparison, there are very limited quantities with high content.

ILLUSTRATION 5

CONCEPT OF RESERVES, POTENTIAL RESOURCES AND HYPOTHETICAL RESOURCES



If we analyze the gold situation, it can be said: practically all tocks contain traces of gold (average grade: “Clarke value” = 0.0035 gm/ton)(24), but it is understood that a deposit is a body with above a certain grade (critical grade). This quantity –the reserves- however, is subject to changes during the course of time according to: new geologic discoveries, advances in processing techniques, variations in market prices, etc. Thus, potential resources, little by little may be converted into reserves in the measure that mining or metallurgical technology advances, or if the economic situation and demand make these resources profitable that were not so previously.

4.1.2. Raw material and the term “not renewable”.

In order to better understand the term “not renewable” with regards to mineral resources, there must be a clear distinction between (25):

- **Deposits of mineral resources** form part of the “raw material” for mining activities that in turn process the mineral and converts it into raw material for subsequent production phases that are generally industrial. For example, in the case of gold, its major…………
- **Mining products** normally considered as “raw material” for industrial processes.

Both are normally considered as “Mineral Resources”, the gold deposit as also the gold itself. The important difference that exists can be explained easily, for example in Spanish there is a clear distinction between “pez” and “pescado” (fish), even though they are the same animal. In this sense mineral resources in the ground (deposits) correspond to pez the fish in the water, whilst mineral resources produced by mining correspond to pescado the fish sold in the market.

Thus, mining in its production phase consumes the raw material “gold deposit”, and produces the raw material “gold”. The raw material “gold” is not consumed but is subjected to a process of concentration by different mineral beneficiation processes.

The term “deposit” on the other hand is related directly to economic conditions: the deposit contains mineral reserves of economic interest. The quantity of mineral reserves as we have seen in Chapter 4.1.1. however, is not fixed but depends on external conditions (principally price). Thus, what occurs is, as the richer reserves are depleted world wide, lower grade deposits become more attractive and which, as gold prices increase, they become converted to potential reserves resources. In this manner, neither can we talk about deposits as not-renewable resources if we consider that the entire earth's crust is made up of minerals.

4.1.3. Aspects regarding mining sustainability

- Gold mining converts gold deposits into metallic gold. During the process, gold is not consumed, it is concentrated. Gold is a chemical element it is not a not-renewable resource.
- Mining always exploits the most attractive deposits (higher grade), which individually are not-renewable. However, in a parallel form, the quantity of reserves (and deposits) increase due to the increase in prices, potential resources are converted to new reserves. Whilst there is a demand for a mineral or metal, neither are its reserves not-renewable.
- Mining has always been a nomadic activity: it is carried out where there is a deposit, and when the deposit is exhausted, it moves on to other places. Consequently, its sustainability must be evaluated not on a local basis, but rather regionally. Human history (with thousands of years of mine exploitation), leaves no doubt that mining is a sustainable activity. Who can doubt that future generations will continue to exploit metals such as iron, copper, zinc, gold, silver, stone materials for construction, or non-metallic minerals for different uses ? Maybe they will exploit lower grade deposits at a higher cost; they will probably do it with other deposits; but it is sure that they will.
- Gold produced contributes to the buying power of society and consequently to development.
- Mining like any other economic activity, should be reconsidered and guided under the criterion of sustainable development, amply expressed as the result of the United Nations conference in Rio de Janeiro in 1992 (see chapter 4.2.1.).

Sustainable development is a new paradigm to be achieved. It is understood as being a process that intends to transform productivity to improve the quality of life by making rational use of human capital, natural, physical, financial and cultural, without putting at risk the satisfaction of future generations, within the framework of social equality (26,27,28).

The above considerations make it clear that present mine exploitation does not risk the satisfaction of future generations with regards to mineral resources. From this viewpoint, mining can be considered as being absolutely sustainable. The risks are to be found at another level, environmental management of several mining sub-sectors, and the consequent conflicts related to land use and end environmental contamination.

Degradation of the environment is not sustainable. A clear example related to the central theme of this book is “Carson River” in the United States, which 150 years after mining activities were terminated, has been declared an “EPA superfund site”, as a result of the mercury contamination and that is being rehabilitated with an investment of several million dollars (28).

From the above description, mine exploitation is not a problem of depletion of mineral resources, but rather a social and environmental problem. And, due to economic interests, it frequently becomes a political problem.

By adopting a global and multiple perspective instead of a local and uni-sectorial viewpoint, it can be affirmed that mining is a sustainable activity providing it is adequately practiced by applying suitable technology and recycling the benefits in regional and national development.

If mining benefits are effectively invested in the development of society, this activity can guarantee an improved quality of life from taking advantage of geologic resources. Profits from mining can improve education and increase development opportunities in different areas. Unfortunately, history teaches us that it is not always so (e.g. silver mining during the colony and tin mining by the “Tin Barons” in Bolivia).

The following Table 5 presents some conditions for the sustainability for the exploitation of mineral raw materials:

TABLE 5

ASPECTS OF SUSTAINABLE MINING AT DIFFERENT LEVELS

Level	Economic Aspects	Social Aspects	Relevant to the	Political Aspects
Macro State level	• Tax & Royalty collection	•Fair distribution of micro/macro mining economy	• Minimize or eliminate potential conflict in the case of competition for resources (water, land, air, minerals etc.)	• Existence & apply mining and liberal policies. • Existence of clear legal system (taxes, economic, mining, environmental etc.) • Existence of positive investment climate, (stability, free economy judicial security, free access to market, investment and capital assets etc.). • Inclusion of mining in regional planning and development.
Intermediate Level	• Offers of relevant services for companies • Contribution by mines to local economy (local royalty)	•Include the population in mine work and consideration for local interests and planning	• Offers of environment services	• Fluid dialog between company and State. • Existence of tools and institutions to execute political directives.
Micro company level.	• Company competition + economic • Knowledge of reserves for solid planning • Capitalization of company • Economic functioning without free subsidies from other parties • Continuous long term mine exploitation	•Qualified and motivated labor •Skill + training program in the the company •High grade of labor safety •Social security •Include mining in current legal legal system in the country	• Rational + careful use of not-renewable mineral resources (where possible, total exhaustion of deposit with high recovery; extraction of 2ndary products; avoid abusive extraction etc. • Extraction + treatment with minimum environmental costs	• Planning basis for the use of mineral, financial, material and human resources • Concept regarding the situation on mine close.

4.2. Conceptual framework of Environmental Management

Environmental Management is a group of actions directed towards achieving maximum rationality in decision processes related to the conservation, defense, protection and improvement of the Environment, based on coordinated multi-disciplinary information and citizens participation (129).

The legal framework for environmental management is defined by the environmental legislation established in each country on a Constitution level, laws, regulations, proceedings, permits, customs etc. Although legislation varies from country to country, there is similitude, and above all, there are current ratified international norms and agreements on a world level.

Amongst these, we can mention:

- Agenda 21 of the United Nations (27).
- ISO norm 14000 (29).

4.2.1. Agenda 21

The United Nations conference held in 1992 in Rio de Janeiro propounded to establish how sustainable development should be defined and how to apply it. The final document, the so called Agenda 21, summarizes these themes.

Transfer of Environmentally Sound Technology as defined in Agenda 21.

Article 34.3
The environmentally sound technologies are not simple individual technologies, but are complete packages that include "know-how", procedures, assets and services and equipment, and also organization and management processes.
This implies, that when discussing technology transfer, aspects of the development of human resources and local formation and training should be considered that seek alternative technologies, including the relevant gender aspects.
The sound environmental technologies should be compatible, on a social economic, cultural and environmental level with established national priorities.

4.2.2. Environmental Management according to ISO 14.000 and following

This current world wide system addressed to the corporate areas is structurally based on the norm ISO 9000 for quality control management. Its fundamentals can be resumed as:

Definition of an environmental policy for company surroundings

↓

Planning

- Environmental aspects
- Legal and other requirements
- General and specific objectives
- Environmental management programs

↓

Execution

- Organization structure and responsibilities
- Training, consciousness and suitability
- Communication
- Document preparation for environmental management
- Channel documents
- Direct the development
- Forecast emergencies and plan measures

↓

Control and corrective measures

- Control and evaluation
- Discrepancies, correction and prevention measures
- Registration
- Environmental management system

↓

Evaluation by General Manager's office

↓

Permanent improvement of the environmental management system

The ISO norm provides for periodic evaluation of the environmental management system and certification of the company by official entities. As in a great measure this system is compatible with the quality control management system according to norms ISO 9000 (30), those familiar with the subject, count on the management system being widely applied in the future, although with great difficulty in small mining.

4.3. Environmental Management: interaction of environmental requirements; demands and compliance.

In all countries, there are legal environmental norms. Environmental legislation is the basis for environmental management, however, experience has shown that the mere existence of environmental laws in no way guarantees an improvement of the environmental system or public health. Compliance with environmental norms – as with any law – does not happen on its own, but through demand and control mechanisms. This demand can be applied by the State or by non-government organizations or the community itself (31).

To search for, propose and apply solutions to the environmental problems, there are different approaches:

Voluntary strategies: These look to voluntary compliance with environmental requirements through technical assistance, environmental education, awareness, sensitivity, incentives etc. These strategies are applied mainly through non-government organizations (environmental ONGs), or by the individual sectors themselves (chambers etc.).

Regulation strategies: Non-government organizations generally tend to demand compliance with environmental regulations by means of their authority and power of legal demand.

Mixed strategies: Demand changes and at the same time offer assistance for their application.

4.3.1. Environmental requirements

Environmental legislation and certain cultural and ethical factors form the basis for any environmental management. The requirements can be formal or informal; in any case, they are not static but are dynamic. What twenty years ago seemed to be alright, today we consider them to be errors of the past, and what today we consider as being right, maybe in twenty years will be considered as an error.

Environmental management is only possible if the requirements are clearly defined and realistic. The objective of being abler to comply with the requirements however, is only feasible when the requirements are demandable. Non-demandable requirements are inefficient, they have high demandable costs and the results are unsatisfactory.

In many countries, environmental laws and norms abound and which are not duly respected. In many cases this is a problem of demandable requirements. In order that environmental requirements (be they laws, regulations or environmental standards) be demandable, they must be:

- Clear, precise, consistent and without contradictions
- Attainable with available technology, reliable and economic.
- Easy to control with previously established procedures.

- Compatible with complementary regulations (e.g. health, natural resources, etc.).
- With clearly defined responsibilities
- Foreseeable with respect to the consequences in the case of non-compliance

The requirements should be strict in the sense that they can achieve an environmental improvement sufficiently fast and significant. In practice however, too ambitious environmental standards are frequently established, that can produce the opposite: too ambitious requirements are frequently barely demandable due to, the lack of available technology, lack of operator's knowledge and lack of education[a], and consequently the requirements lose credibility.

The execution of environmental programs requires time and resources. For the application of requirements, it is necessary to establish the respective schedule, differentiated into short, medium and long term goals. Environmental requirements can be general (in the form of laws and regulations) or individual (permits and licenses). The general requirements form a framework for the preparation of individual requirements. For this purpose, in addition from being demandable in the sense mentioned above, they must have a certain amount of flexibility in order to adapt to different local conditions of the installations being regulated. Additionally, where possible, they should indicate the possible causes for exceptions in order to avoid as much as possible, subsequent interpretations.

In general, monitoring and follow up of general requirements is easier, as the personnel in charge of control can apply the same pattern for all installations. However, the majority of individual requirements have a greater probability of compliance.

4.3.2. Factors that influence compliance

The principle objective for achieving sustainability in an environmental program, is to influence human behavior towards a habit of complying with

[a] The limit values for mercury emissions proposed by OMS for example, do not have major demand problems in industrialized countries. For small mining operations in developing nations however, it should be considered as a great achievement to have reduced the percentage of emissions, despite the fact that the quantitative values are still above those permissible.

environmental requirements, that is, to create an atmosphere of compliance. To achieve this objective means motivating the community to comply, remove barriers that impede compliance and overcome motives that induce non-compliance.

There are several factors that influence compliance with environmental norms.

Economic factors: Economic considerations can motivate or demotivate making changes in the environmental attitude. However, when the cost is high it is less probable that compliance will be achieved. The major probability of voluntary compliance, are those environmental measures with "win-win" options where everybody gains (see chap. 4.3.4.). On the other hand, the cost of fines and sanctions are considered which can provide a motive for compliance, where the cost is at least equal to that of compliance.

Institutional factors: Each country and each culture has its customs with regards to compliance with the law. Institutional credibility is the product of traditional seriousness of the government and its officials. The strategies to create credibility can vary: in some cultures, an aggressive demand can create credibility, in others it requires an initial period of for the creation of confidence in order to create a subsequent atmosphere of cooperation.

Social-cultural and psychological factors: Any "target group" is always composed of individuals that always give three different answers to the required norms, and consequently also to environmental requirements:

- Individuals that voluntarily comply with the requirements
- Individuals that resist compliance with requirements and,
- Individuals that only comply when they see that there are sanctions for those that do not comply.

In order to achieve compliance with environmental requirements, it is important that:

- A high probability exists that non-compliance will be detected
- The reply to non-compliance is immediate and foreseeable
- The reply to non-compliance includes a sanction, and
- The presence of the above three factors is felt.

The personal prestige of being linked to being a "responsible citizen" varies with different cultures, and also within the same culture depending on the grade of maturity. Its value can be minimum recent informal mining settlements, but can reach higher levels in regions with an old mining tradition.

There are leaders in each community whose attitude towards requirements of compliance with laws and norms is extremely important. According to the characteristics of the community, in some cases there are “good leaders” and in others “bad leaders” that can contribute to an atmosphere of compliance.

Technological factors: Compliance should be technically feasible. It is necessary that those involved know exactly what they have to do and have access to the necessary technology and the knowledge required to correctly apply and operate the technology.

4.3.3. Promotion of compliance

Promotion of compliance is any action that achieves voluntary compliance with the environmental requirements.

Promotion of compliance itself is frequently not sufficient to achieve changes in environmental attitudes. Frequently it requires certain demands in order to create an atmosphere whereby every member of the regulated community has clear incentives to make use of the opportunities and resources offered by the promotion. On the other hand, experience has demonstrated , that demand by itself is not so efficient as when it is combined with promotion.

This last applies particularly when:

- The target group is large and dispersed; as is frequently the case in small mining where there are a large quantity of contamination sources.
- The target group has a certain predisposition towards voluntary compliance.
- When there is cultural resistance towards the demands which is typical of the informal sector.

Promotion is an important element in many environmental programs. Possible forms of compliance promotion are:

Education and technical assistance for the target group: Education, awareness and sensibility form the basis for voluntary compliance and are necessary to break the ignorance barrier that is an obstacle for compliance, and important especially in the initial phase for applying changes.

In very few cases, these changes are self employed by the target group solely on the basis of consciousness and education. It is necessary to provide technical assistance and follow-up over a long period in order to apply these changes and assure their sustainability.

Community participation: The affected population is a powerful ally for the promotion of compliance. The affected population can be an important watchman if it is instructed on the causes and effects of environmental contamination over a short and long period. This is where the women play an important role, particularly in those cultures where the home and family welfare are considered as part of the woman's responsibility. Because of this community role, many companies, cooperatives and mining partnerships, voluntarily look for a harmonic cohabitation with the surrounding population. There are too many examples where the community, after having been affected by the environmental impacts of mining, has taken an active part in the defense of the environment, impeding future mining development[a] causing millionaire losses.

Publication of positive examples: For many companies, positive publication resulting from compliance with environmental standards is considered of great importance.

Innovative forms of financing: A barrier for the implementation of environmental measures is the cost. The government can create different models to finance environmental investment with financial and/or tax systems. But also, non-government organizations can create these facilities[b].

Economic incentives: In the same manner as innovative forms of financing environmental investments, the government has various forms of intervention. The range of measures goes from subsidizing environmental costs, tax exemptions to taxation on contaminants (as is common in several industrialized nations). On an NGO level, it is possible to offer incentives

a In May 1997 an international seminar was held on the theme "Mining and Community", in Quito, organized by the World Bank.

b One example is the plan ECO+ of the project, Mining without Contamination in Ecuador that offers miners a low cost affiliation to, A Collective Study of Environmental Impact, with the condition that they invest the money that an individual study would have cost in environmental measures (see Subtitle 7.3). In Bolivia, the MEDMIN Project is organizing a "common environmental manifest" for the almost 40 lead-silver-zinc flotation plants in the city of Potosi. An environmental manifest – necessary to legalize plants – costs each plant, much less collectively than individually (see subtitle 7.1) within the area of technical advice that can be considered as "win-win" options (see Chap. 4.3.4.).

Legal incentives: In many cases, the informal status of small mining is the major obstacle for development. The prospect of being legalized in exchange for voluntary environmental compliance can represent an important incentive for informal mining[a].

4.3.4. "Win-win" options for environmental compliance

As part of the technical assistance, the transmission of information on "win-win" options is of primordial importance. These options are technical or technical-organizational solutions that provide positive technical-economic results and, a reduction of environmental impact at the same time. These solutions already include economic incentives for their application, that at the same time go together with technical innovations. From the point of view of environmental policies, these solutions have much more value than the intents to achieve environmental goals through directive mechanisms of a legal nature, for example: through royalties, taxes and sanctions.

Small mines frequently operate with very low profit margins. For this reason, and due to the absence of environmental consciousness, for these the technical measures that would improve the environmental situation are only successful if they coincide with the idea of improved production. The fusion between economy and ecology must be carried out in a way that there is assurance that the miners apply these measures. It is possible to distinguisIn the case of retorts for example, we have a direct relation. By using the mercury recycling technology, the miner can save himself the expense of purchasing new mercury, this not only has direct financial advantages, but it also helps to preserve the environment from increased contamination.

a This occurs in the execution of the ECO+ of the Mining Project without Contamination Plan in Ecuador, where the Ministry of Energy and Mines committed itself to legalize those mineral beneficiation plants that voluntarily affiliated themselves to the Environmental Management Collective Plan (se subtitle 7.3). In the MEDMIN Project in Bolivia, the technological changes (e.g. avoid mercury use in the grinding mills, construction of tailings ponds, etc.), are the basis to obtain legal environmental permits (see subtitle 7.1).

An indirect relationship can be achieved through technical advice to the processing plants and their operators. By applying advice, plant production is optimized, and as a result the miners can spend part of their increased income in measures for the conservation of the environment. At the same time, miners can count on increased income thanks to the use of this technology.

Apart from the financial advantages for the miners as mentioned above, advise on health and safety can also be of considerable help for them, as these three aspects; environment, health and safety are interconnected and frequently deficient in small mining. In general, the miners worry about their health and safety at work and are grateful for this type of advice.

The following Table 6 shows some simple examples of win-win options for miners and smelters:

Table 6

EMPLOYMENT OF WIN-WIN OPTIONS IN MINING AND SMELTING

AREA	WIN-WIN OPTION	ECONOMIC BENEFIT	ENVIRONMENTAL BENEFIT
MINING	Use mill tailings for Underground Fill.	Filling reduces loss of reserves in pillars Reduces costs of buying or producing fill material	Reduces amount of sterile material to be stacked on surface and the area required; stabilizes the mine increasing mine safety etc.
ORE BENEFICIATION.	Introduce retorts for mercury recovery in “burning” amalgam.	Mercury costs reduced	Eliminates operator intoxication and emissions to atmosphere.
	Recover gold pyrites from tailings	Low cost by-products to be sold increasing income	Reduces sulfide content in tails, and less acid water from sulfide oxidation in tails, less heavy metal materials in rivers etc.
SMELTING	Slag treatment to obtain road building material	Income generated from sale of additional products.	Reduces slag to be stored

4.3.5. Demand: reply to incompliance

Experience shows that in general, to demand is essential to achieve compliance with environmental requirements. At the same time, demanding demonstrates requirement seriousness and the seriousness of the institution promoting changes in environmental management. If there is not a clear and if possible, immediate answer in the form of consequences and sanctions for a possible incompliance with environmental requirements, any voluntary compliance terminates quickly.

Demand on the part of government entities, has the objective of correcting violations of the law and creates an atmosphere wherein compliance is encouraged, as the authorities demonstrate their intention to enforce respect of the norms and to take action in the case of incompliance.

On the other hand also, the private sector can exercise “pressure”. This can be done through vigilance and denouncement mechanisms [a], through contractual commitments [b], and/or other forms to create a commitment. In other economic sectors and particularly in industrialized nations, the public frequently responds to violations of environmental norms, by blocking the purchase of the products.

The reply to an environmental violation can come from different levels depending on the gravity of the case of non compliance with legal dispositions:

a The gold buyers in Portovelo, Ecuador, found themselves obliged to relocate themselves and adopt environmental measures – due to repeated protests on the part of the neighboring population - when the competent authorities closed their locales.

b An example of are the agreements between the owners of ore beneficiation plants affiliated to Plan ECO + (Mining without Contamination Project), and the counterpart of the project (CENDA Foundation), where the owners gave performance guarantees to be made effective in the case of non-compliance with environmental measures. The MEDMIN project in Bolivia includes not only environmental measures, but also production improvement. In the cases of non compliance or neglect of environmental measures, the Project withdraws its technical assistance. To this moment, no mine that received cooperation from MEDMIN has run the risk of losing its technical assistance for not complying with its environmental obligations.

Table 7

REPLIES AND SANCTIONS FOR INCOMPLIANCE OF ENVIRONMENTAL REQUIREMENTS

INFORMAL	FORMAL		
	CIVIL		CRIMINAL
	ADMINISTRATIVE	JUDICIAL	
Conversation to mMediate in conflict Technical visit Phone calls to Manager or Directors Involve communication mMedia. Strikes, block access rRoads etc. Denounce to press Denounce with competent authorities.	Administrative sanctions imposed on guilty party to demand compliance For first offence against environmental norms, a warning is issued. For repeated offences, mMore drastic sanctions. In case of incompliance with administrative sanctions, recur to civil judicial procedures.	Sanctions imposed by Judge in case of repeated incompliance or grave damage.	Applicable or not according to local legislation More drastic Sanction if somebody or something has suffered damage and can prove intentional incompliance. Last recourse, but Generally, most drastic/ efficient.

WORK OF GOVERNMENT AUTHORITIES →

← WORK OF PRIVATE SECTOR (AFFECTED POPULATION)

In all cases, it should always be born in mind, that any measure of demand has the only final objective of achieving compliance with the requirements. Parallel to the evaluation of applicable and appropriate sanctions, a re-evaluation should be made to see if the requirements comply with the entire criterion to be demanded seriously.

Extra-judicial ways to solve environmental conflicts:

Negotiation between the parties involved can frequently clear up misunderstandings and avoid obstacles in the compliance and demand mechanism. The affected community should actively participate in the early phases of the conflicts. It is important that all parties involved show major comprehension for the problems and viewpoints of others.

The participation of a third independent party (arbiter, conflict mediator) can avoid the growth of a conflict and overcome a deadlock. An arbiter can be proposed by either of the conflicting parties. A third party or experienced institution can introduce new dynamics, change perspectives and propose possible unconventional solutions. Specialized mediators are necessary to solve highly complex technical or social problems, as a lawyer or a judge do not normally have the specialized knowledge for a satisfactory solution.

4. 4. Environmental management at a corporate level

4. 4.1. Sound management practice

There are several basic principles for corporate environmental policies that can be called <sound management practice>. These are general recommendations for environmental management directed towards a permanent improvement of corporate environmental protection. Some of these recommendations are guides ("lean and clean", Environmental Quality Program 5S"), others, for example the decree for Environmental Audit by the European Community (32), are for the moment voluntary norms. At this time, practically all of these recommendations can be considered as being in the "promotion of compliance" stage (see chap. 4.3.3.).

The "sound management practices" of the European Community for example, establish:

- The level of environmental consciousness and responsibility shall be practiced amongst employees of every level.
- Environmental impacts will be evaluated in advance of any new activity, product or process.
- Impacts on the local environment by present activities will be monitored and examined, and all impacts of these activities on the environment in general will be evaluated.
- All necessary measures will be taken to avoid and eliminate the environmental impacts, and where this is not feasible, emissions and garbage production will be minimized and the resources will be conserved; sound environmental techniques will be taken into account for all of these.
- The necessary measures will be taken to avoid emissions of substances and energy resulting from accidents.

- Procedures will be established and applied to monitor coincidence with environmental policy, and where these procedures require medication and analysis, registration and updating of the results will be carried out.
- Updated procedures and measures will be established for those cases where it is determined that the company does not comply with its environmental policy or environmental goals.
- Special procedures will be prepared and updated, to minimize as far as possible, the impacts from eventual spills due to accidents, in cooperation with Government entities.
- The community will receive all information necessary to enable it to understand the environmental impacts of the company; additionally, an open dialog with the community will be sought.
- The clients will be adequately advised on all environmental aspects related to the handling, use and final disposal of the company's products.
- Measures will be taken to guarantee that all contractual counterparts that work in the company's installations apply the same environmental norms as the company.

The objective of this system is to promote the continuous improvement of environmental protection on the part of the company within the framework of its manufacturing activity:

• Establish and implement systems of environmental policy, environmental programs and management on the part of the companies.

• Systematically evaluate objectively, and regulate the effectiveness of these instruments, and

• Place at the disposal of public opinion, the pertinent information on the environmental protection measures on the part of the company.

In order to improve the effectiveness of environmental protection in s**mall mining companies**, a suitable and simple environmental management system is required, as the traditional systems do not achieve the objectives and are not applicable. These should include the following minimum components:

- Strategic and political aspects:
- Consideration of the environment and environmental protection and of the costs derived from these in all company decisions (includes creating reserves to cover shut-down costs and/or stabilization measures, personnel formation and training, etc.).

- Determine explicitly within the company, the responsibilities with respect to the environment, risk avoidance, industrial safety etc.
- Apply an internal monitoring system
- Emergency plans
- Long term company development plans, including shut-down plan.

• Legal aspects:

- Compliance with current legal norms

• Production aspects:

- Utilization of raw and production materials compatible with the environment
- Application of clean technology and processes
- Introduction of innovations with the objective of improving environmental protection effectiveness by means of integrated measures in the production process.
- Adequate cleansing of residual material and discards (recycle before dumping etc.).

The assistance that a project for the improvement of environmental management for small mines can offer, is detailed in chapter 5; an example is the case of mercury contamination.

4.4.2. Environmental obligations in the different phases of a mining project

Mining activities are carried out in phases: prospecting, planning, production and shut down. Each of these phases has its environmental impacts, and the corresponding environmental measures should be foreseen in order to prevent, mitigate, repair or compensate the same.

The table below compiles the diverse phases of a mining project and visualizes the problematic areas in each of the phases. Analogous considerations are also valid for beneficiation plants and smelters.

TABLE 8

DIVERSE PHASES OF A MINING PROJECT AND THEIR RELATION WITH ENVIRONMENTAL PROTECTION OBLIGATIONS

PHASE	OBLIGATIONS OF THE COMPANY	COSTS OF THE ENVIRONMENTAL MEASURES	PROBLEM AREAS
Exploration	• Focus the project towards the option with most compatibility with environment considering economic and profit aspects. • Minimize environmental impact in this phase, particularly thru organizational measures.	• approx. 5% of exploration costs are preliminary costs	• Pressure to reduce time and prelim. costs.
Planning	• Take into reflection all the relevant legal bases. • Carry out a base study. • Evaluate impact of planned operation in all phases and, • Meditate between technical alternatives and option of abandoning the project. • Plan the application of compatible environmental • technologies.	• Absolute costs comparatively low, but(-) of up to 20% of planning costs, but (+) with high savings potential in the following phases.	• Pressure to reduce time and prelim. costs.
Production	• Minimize environmental impact and health risks taking advantage of all the technical and administrative solutions as appropriate and constantly improve protection measures.	• Approx. 5% of production cost	• The high cost of investment for environmental protection, some times seems prohibitive, even in those cases with higher profit.
Shut down and environmental liability	• Minimize environmental effects produced by mining, (tailings, dumps, mine buildings etc.).	• Generally unplanned costs, that in this phase, are no obstacle to entry.	• In many cases the responsible party cannot be be surely established • High specific costs. • In many cases no funds held to rehabilitate land. • Almost never able to justify this economically.

It is possible to pressure companies to apply the so called "sound management practice" especially during the planning, exploration and production phases of mining projects.

4.5. Environmental management in small mining

Environmental management on a small mining company level is based on the three pillars shown in table 9

Table 9

THE THREE PILLARS OF ENVIRONMENTAL MANAGEMENT FOR SMALL MINING

ENVIRONMENTAL MANAGEMENT ON COMPANY LEVEL	ENVIRONMENTAL MANAGEMENT ON REGIONAL LEVEL	POLITICAL/ENVIRONMENTAL CONTEXT
Detailed in Table 10	Amongst other aspects composed of: • Mediate in dialog between mining companies and local community. • Include and strengthen local official bodies so they may start their work for environment protection • Inform population and consciousness on their part. • Environmental analysis with specific objectives on a regional level.	Amongst other aspects composed of: • Consider specific demands of small mining within environment legislation. • Commence and expand dialog between government and mining companies. • Advise entities with power of decision in the creation of adequate possibilities for legalization and creation of production incentives in accord with demand for environmental protection.

Environmental management on a corporate level focused on small mining is differentiated from other productive sectors in as much as:

- Mining is a productive sector with high financial risk, and as such, miners look to minimizing their investment. As a result, many installations are of a "provisional" nature.
- Frequently, small mining is informal and it is difficult to apply formal mechanisms demanding compliance.
- Due to the geologic characteristics of the deposits, mine activities are frequently in regions with difficult access making control difficult.

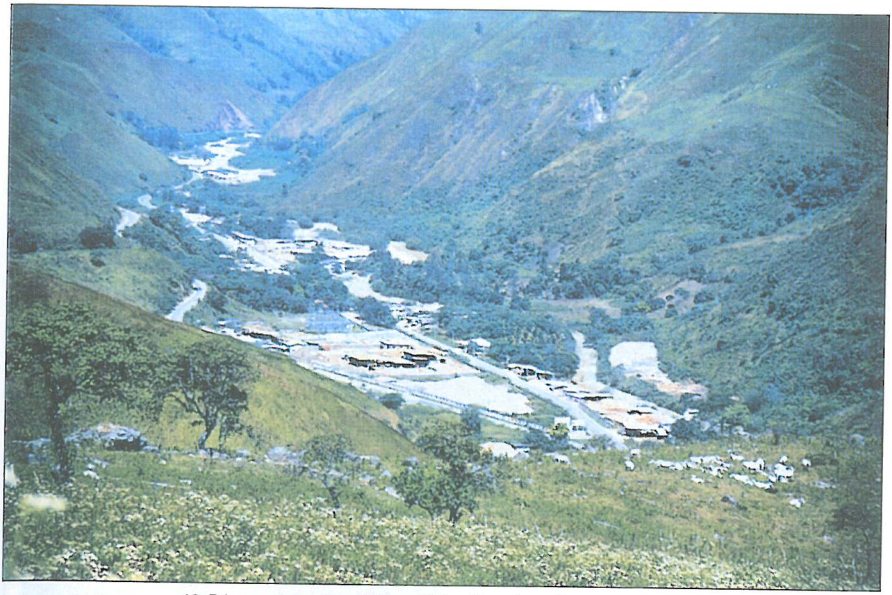
- Due to the limited life of the deposits with small reserves, mining is a transitory activity on a local level. From its initiation, to a certain degree, the termination of an operation is predictable.
- The closure of a mine signifies abandoning substantial investment (tunnels or access routes) and the transport of equipment to another deposit is costly, contrary to the closure of other economic activities where assets may be sold generating an income.
- Mining is a migratory “nomadic” activity; this means that only in few cases is it exercised by the resident population who “worry” about their environment.
- This last aspect is reinforced by mining legislations which generally differentiate clearly between the surface landowner and rights of mineral exploitation on the surface and sub-surface.

Table 10 mentions some of the particular aspects of the possibilities of environmental management on a corporate level in small mining. These are principally strategic, political, legal and production aspects. The technical aspects – with special emphasis on gold mining and mercury contamination – are the central theme of chapter 5.

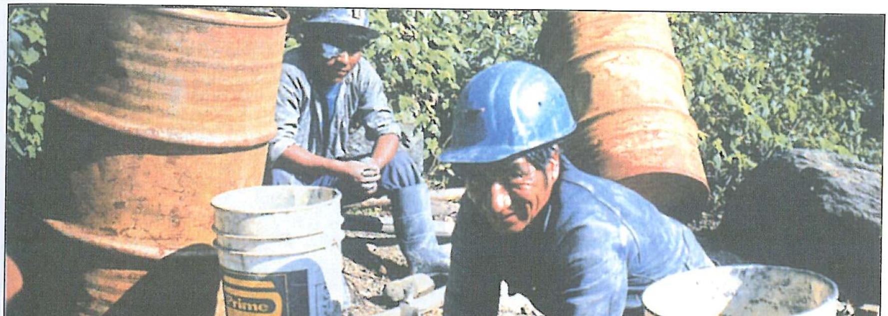
Table 10

ENVIRONMENTAL MANAGEMENT AT CORPORATE LEVEL IN SMALL MINING

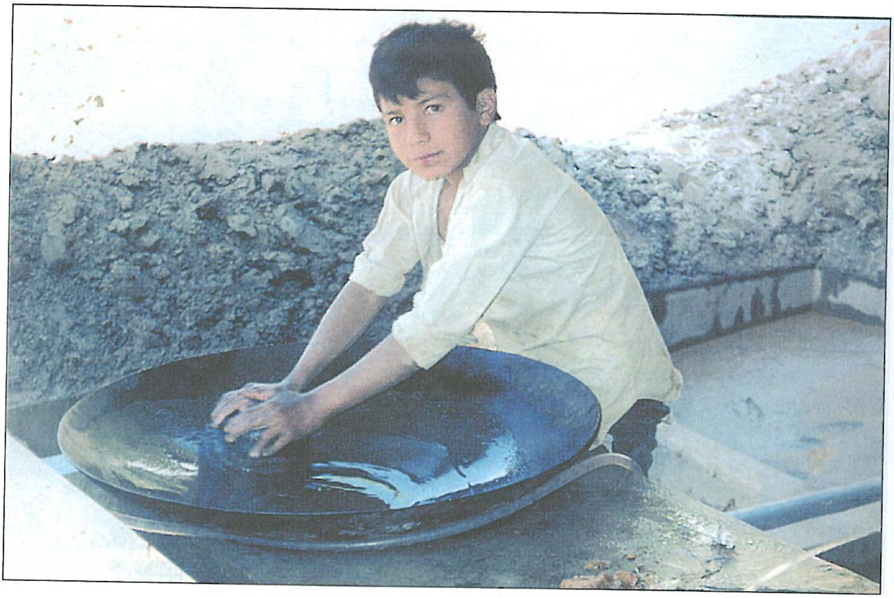
ASPECTS OF ENVIRONMENTAL MANAGEMENT	CONTRIBUTIONS OF DEVELOPMENT PROJECTS
STRATEGIC AND POLITICAL ASPECTS	
• Take environmental surroundings into account, the protection of same and costs generated in all company decisions.	• Formation and training of company personnel • Create conscious (sensitivity) • Initiate external experience interchange. • Introduce participation methods for identifying and solving problems and their implementation
• Determine and define responsibilities within the company with regards to environment, risk prevention, industrial safety etc.	• Propagate need to create the position of "environmental head" within the company. • Training and technical support from the environmental promoters in the company.
• Apply an internal monitoring system	• Introduction simple analysis system parallel to the process. • Train workers in the application of these techniques • Documentation of the results.
• Have available emergency plans and safety iInstructions. • Have available company long term development plans.	• Development & application of safety systems. • Support companies in application of preventative measures. • Strategic assistance.
LEGAL ASPECTS	
• Compliance with current legal norms.	• Divulge laws, decrees etc. • Courses on current legal norms. • Assistance for legalization. • Support studies of environmental impact. • Introduction of collective systems to study environmental impacts, license approval, and environmental management. • Support companies for compliance with demands stipulated for the protection of the environment.
PRODUCTION ASPECTS	
• Use of raw materials, accessories for production compatible with the environment. • Application of technologies and clean processes • Introduction of innovations with the objective of improving environmental protection affectivityperformance by use of measures integrated into production processes. • Application of "good housekeeping" measures • Adequate curing of residual material and discards (recycle before disposing, etc.)	• Analyze the weak points. • Initiate technology transfer and its application as in Agenda 21. • Technical assistance. • Formation and training.



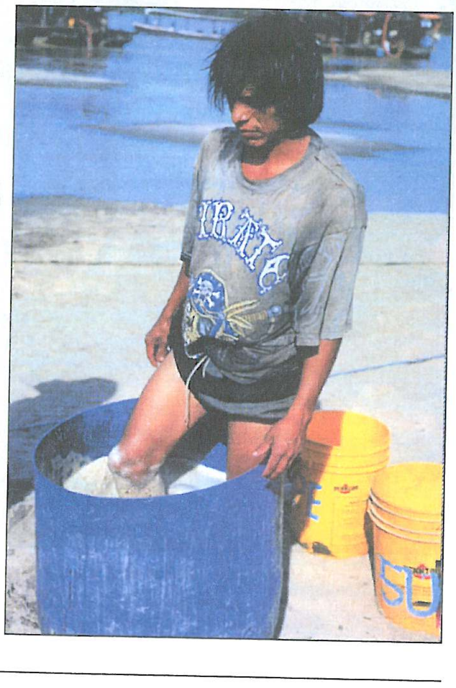
13. Primary mining: river Calera with leaching plants (Portovelo, Ecuador)



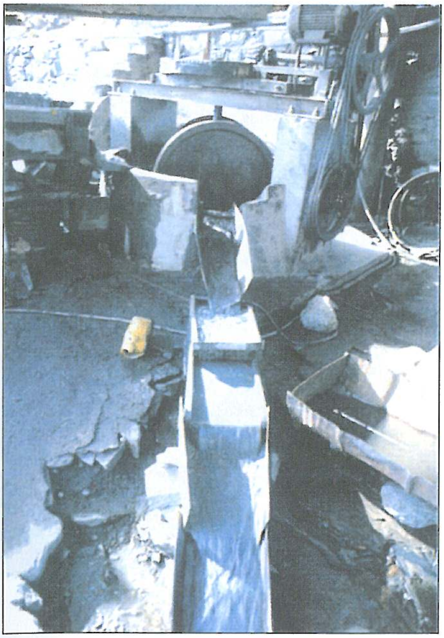
14. Manual amalgamation (small stone in large one, the large stone had already been used for this purpose in Colonial times. (Kantuta Coop. Bolivia)



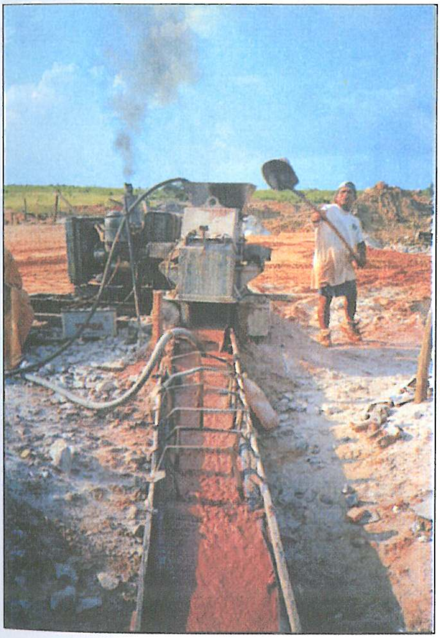
15.Manual amalgamation (in large metal pan) (Zaruma, Ecuador)



16. "Foot" amalgamation (river Madre de Dios, Bolivia)

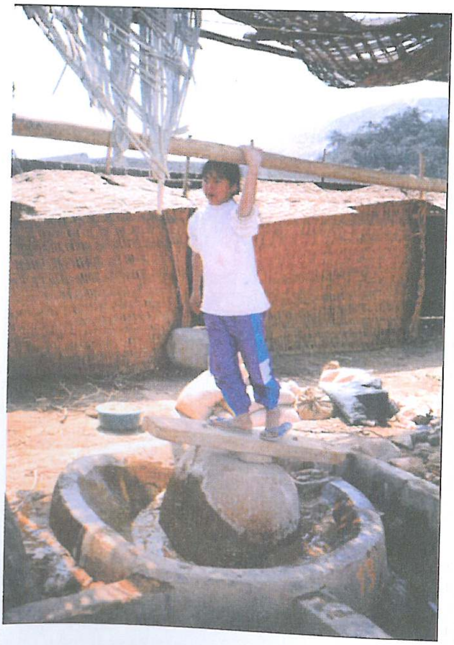


17. Chilean Mill with amalgam sheets
(La Suerte Coop., Bolivia)

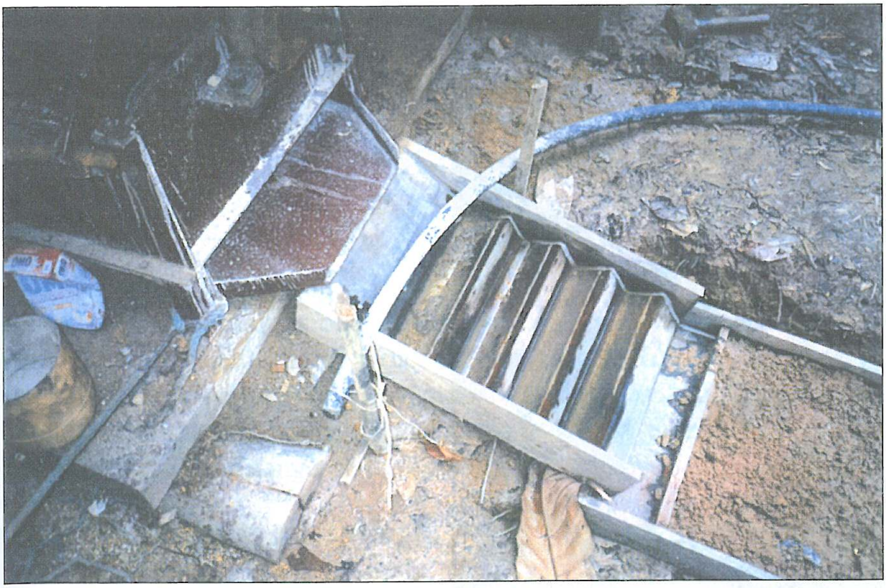


18. Hammer mill with
amalgam sheets
(San Simon, Bolivia)

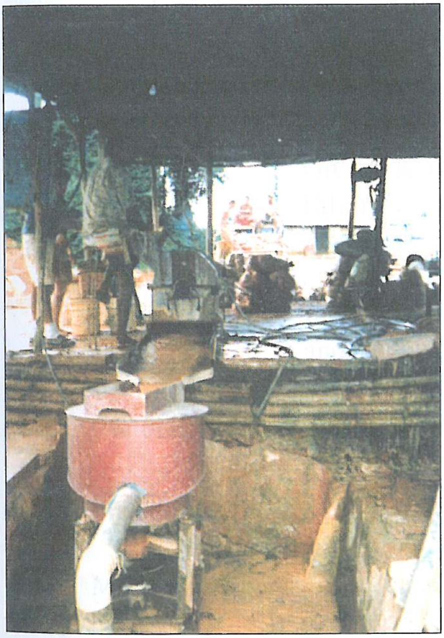
19. Stamp mill with amalgam sheets (Los Guavos mine, Nariño, Colombia)



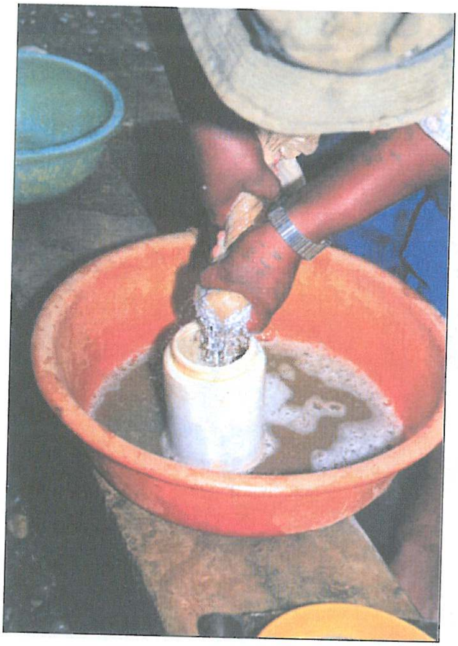
20. Stone amalgamating mill (typical child or woman labor, Nazca-Peru)



21. "Jackpot" type amalgamator, following Hammer Mill (Cerro Azul, Tapajos, Brazil)



22. Amalgamation in centrifugal concentrators. (Km. 88, Venezuela)



23. Squeezing liquid mercury from amalgam through a rag (Tupara Coop., Bolivia)

24. "Burning" amalgam in the open air. (river Madre de Dios, Peru)

5 Amalgamation in small gold mining and, possibilities of improvement

Amalgamation is one of the most important processes in gold production by small mining in developing nations. The simplicity of this technique and its effectiveness in gold recovery makes it one of the favorite processes of the small miners. However, they do not take into account the health risks and the danger to the environment.

5.1. Regional distribution of small gold mining

The indiscriminate use of mercury in small mining operations in the world is generalized, both in alluvial and primary mining. The majority of small scale gold mining operations are located in (33):

Latin America: Honduras, Nicaragua, Colombia, Ecuador, Peru, Bolivia, Chile, Brazil, Surinam, Venezuela and the Dominican Republic.

Africa: Ghana, Kenya, Tanzania, Zambia, Zimbabwe, Ethiopía, Guinea, Liberia, Nigeria, Gabon, Central African Republic, Burundi and Madagascar.

Asia: India, China, Philippines, New Guinea, Indonesia and Malaysia.

5.2. General characteristics of mercury and its environmental impact

5.2.1. Physical-chemical properties

Mercury is a bright silver colored metal that is liquid at room temperature; its point of fusion is -38.9 º C and its boiling point is 357.3 º C.

Its specific weight is 13.6 g/cm_ (0º C). Metallic mercury, due to its high vapor pressure (163 x 10^{-3} Pa), evaporates easily at room temperature: at 20º C its concentration in the air can reach up to 0.014 gm. /mt.^{3} and at 100º C, up to 2.4 gm./mt.^{3}. In general, mercury vapor is referred to when elemental mercury is present in the atmosphere and metallic mercury when it is in liquid form.

A great number of metals, mainly gold and silver, form alloys with metallic mercury and are called amalgams. This property makes it attractive for gold recovery in small gold mining.

The solubility of mercury in water depends mainly on the temperature:

60 µg/l	(20 ºC)
250 µg/l	(50 º C)
1100 µg/l	(90 ºC)

The Lipid solubility (in oil and greases) oscillates between 5 and 50µ/l (34).

Inorganic compounds of mercury.

Metallic mercury dissolves easily in nitric acid, and aqua regia; and to a lesser degree, and only at high temperatures, in sulfuric acid and hydrochloric acid, forming mercury salts. Apart from metallic mercury Hg^0, other forms such as Hg^{1+} and Hg^{2+} can exist.

The inorganic compounds of mercury can be classified into the following groups:

Sulfides:	HgS
Oxides:	HgO
Compounds with Halogens	Hg_2Cl_2, HgF_2, $HgBr_2$,etc.
Cyanides and thiocyanates	Hg (SCN) $_2$, etc.
Nitrates, Sulfates:	Hg_2 $(NO3)_2$, Hg_2SO_4, $HgSO_4$, etc.

Mercury organic compounds

Metallic mercury also dissolves in organic acids, and the inorganic compounds of mercury (especially those with halogens) can react with organic substances to form organic mercury compounds. Organic mercury compounds can generally form covalent links with carbon. For practical purposes, these compounds are classified into:

- Mercurous alkaloids (methyl mercury, ethyl mercury etc.)
- Mercurous ariloids (phenyl mercury, etc.)
- Mercury diuretics.

Organic mercury cathions react easily with important biological compounds, especially with the hydro sulfate groups. These compounds pass readily through biological membranes.

The high toxic grade of some organic mercury compounds (e.g. methyl mercury) and their uncontrollable behavior in the ecosystem has attracted the attention of health and ecology professionals.

5.2.2. Origins, extraction, production and use

The earth's crust contains an average of approximately 0.02 ppm of mercury. Air contains and average of 0.005 – 0.06 ng/mt.3, fresh water 0.1 µg/l, and sea water: 0.03µg/l of mercury (35). There are more than 20 different minerals that contain mercury. Of these, only the sulfide (cinnabar) and sometimes metallic mercury are of importance for its production. As a trace element, mercury is present in practically all types of volcanic rock and probably massive quantities of this element were introduced into the early atmosphere of the planet due to volcanic activity. The most important mercury deposits are in volcanic rock or black shale (bituminous). Soils typically contain 20-150 ppb of mercury. Some deposits are worked exclusively for mercury (such as Almaden, Spain, where over 250,000 tons of mercury have been produced over centuries, and at present there are known reserves of over 75,000 tons) (38). However, a great part of the mercury produced comes from byproducts from the production of other metallic sulfides, whilst another part is produced from the recycling of secondary materials (36, 37).

Due to its low boiling point, mercury is distilled directly from its minerals. In some cases, not even a pre concentrate is used (e.g. flotation), the crushed material is heated directly in various types of furnaces and the gasses are cooled to recover metallic mercury by condensation.

The following table shows the latest statistics on the production of elemental mercury world wide (Table 11).

TABLE 11

WORLD MERCURY PRODUCTION (BY COUNTRY) IN TONS (1,/2/) (38)

COUNTRY	1992	1993	1994	1995	1996
Algeria	476	459	414	292	300
China e/	580	520	470	780 r/	240
Czechoslovakia 3/4/	60	xx	xx	xx	xx
Finland	75r/	101 r/	90 r/	90 e/	90
Krghiztan	350 r/e/	350 r/e/	379 r/	380 r/	580
Mexico	21	12	10 e/	15 e/	15
Moroco e/5/	20	20	20	20	20
Russia e/	70	60	50	50	50
Slovakia e/4/	xx	50	50	50	20
Slovenia e/	7	-	-	-	-
Spain	36	64 r/	393	1,497	1,500
Tajkistan	100	80	55	50	45
Turkey	5	-	-	-	-
Ukrain	100	80	50	40	30
United Status	64	W	W	W	W
Total	**1,960 r/**	**1,800 r/**	**1,980 r/**	**3,160 r/**	**2,890**

e/	estímate
r/	revised
W	not revealed to avoid use of company data, excluded from the total.
1/	Table includes information to April 29, 1997
2/	“Total” and estimated data are rounded off (sum may differ from total shown)
3/	Disintegrated Dec. 31, 1992
4/	All production Czechoslovakia 1992 is from Slovakia
5/º	Mercury production as a sub-product from silver mining
6/	Mercury production as sub-product from gold mining.

To these primary production figures, secondary recycled mercury production should be added:

- Obsolete chloral-soda plants
- Electrical and electronic industry (thermostats, batteries, lamps, switches etc.).
- Chemical industry (catalysts)
- Barometers and thermometers.

At the same time, due to the high toxic nature of mercury, there is a tendency to replace it where possible in the above mentioned uses by other less dangerous substances, and especially in the following applications:

- Use as a pigment (Cinnabar)
- Use in metallic form (for amalgamation)[a]
- Insecticides, fungicides
- Dental amalgam

5.2.3. Emissions

Industrial activities in the world are responsible for the emission of a great variety of organic and inorganic forms of mercury. The electrical industry, the chlorinating industry and the burning of fossil fuels (coal, petroleum etc.) release elemental mercury into the atmosphere. Metallic mercury is released directly to fresh water for chlorinating plants; compounds of methyl and phenyl mercury are discarded into both fresh and salt water – phenyl mercury by the wood pulp paper industry and methyl mercury by the chemical industry – (36).

There exists a source of natural mercury independent of the actions of man. This is a cycle whereby mercury is transported to superficial water as a result of soil erosion which then passes to the atmosphere by means of the natural degasification of the earth's crust (volcanoes, wind erosion, and degasification of the soil) and of the seas. There are different figures regarding the quantities of natural emissions: whilst some authors mention quantities of up to 150,000 tons per year, others affirm that natural emissions do not surpass 3,000 tons per year (39).

The second source of mercury is the direct or indirect result of human activity (use of mercury plus emissions from wood burning (40), coal and petroleum). The anthropogenic emissions at this time are diminishing. For example, in the German Federal Republic, between 1983 and 1985, mercury emissions to water dropped from 1.1 to 0.2 tons and emissions to the atmosphere diminished from 5.5 to 4.2 tons (41).

From the point of view of environmental exposure, the methyl mercuric compounds cause the most concern as the main route for human exposure to this danger is through food. Occupational contact with mercury is generally

a Amalgamation has lost much of its previous importance . In the past centuries it was one of the most used processes (also on a large scale) for the extraction of precious metals. At the present time, with some exceptions, it is restricted only to informal and artisan mining due to the diffusion of techniques such as flotation and cyanide leaching (37,38).

exposure to metallic mercury vapor. There is also exposure, although to a lesser degree, to a large variety of mercury compounds, depending on the circumstances of every individual (occupational, medicinal, accidental or environmental).

5.2.4 The food chain and man

Mercury emitted by small mining, accumulates in the river sediments and soils principally in the form of metallic mercury (or in some inorganic compounds), such as mercury nitrate (see sub title 5.3.2.3). Due to bacterial action, mercury converts to organic mercury (42). This form of mercury (micro-organisms – aquatic invertebrates – fish) concentrates and accumulates in fish, especially carnivorous fish. The concentration factor of water: fish can reach values of up to 1:5000 for metallic mercury and up to 1:100,000 of organic mercury. There is still a lack of exact information on the conversion of metallic mercury to methyl mercury in different environmental conditions. It is estimated that no more than 1% of the metallic mercury in sediments is converted into methyl mercury (36).

The concentration of methyl mercury in fish is generally related to its size and ecologic niche. Concentrations as high as 1 mg/kg have been reported in open sea predators such as, sword fish and tuna. However, contaminated industrial waters can reach levels of methyl mercury exceeding 10 mg/kg in the mucous membrane of fish. The accumulation of mercury in fish is also related to age and position in the food chain. Terrestrial animals very rarely have mercury levels exceeding 50 µ/kg (50 ppb) (36).

The most serious known accident occurred in the ’60s in Minamata, Japan at a vinyl chloride factory that discharged waters contaminated with mercury that eventually reached the Minamata bay. The accumulation of methyl mercury in the fish and seafood in the bay, and the subsequent consumption by humans and animals resulted in massive methyl mercury poisoning (43).

5.2.5. Danger evaluation and concentration limits

The following table shows the suggested limits for occupational exposure and limits for water, soil and food.

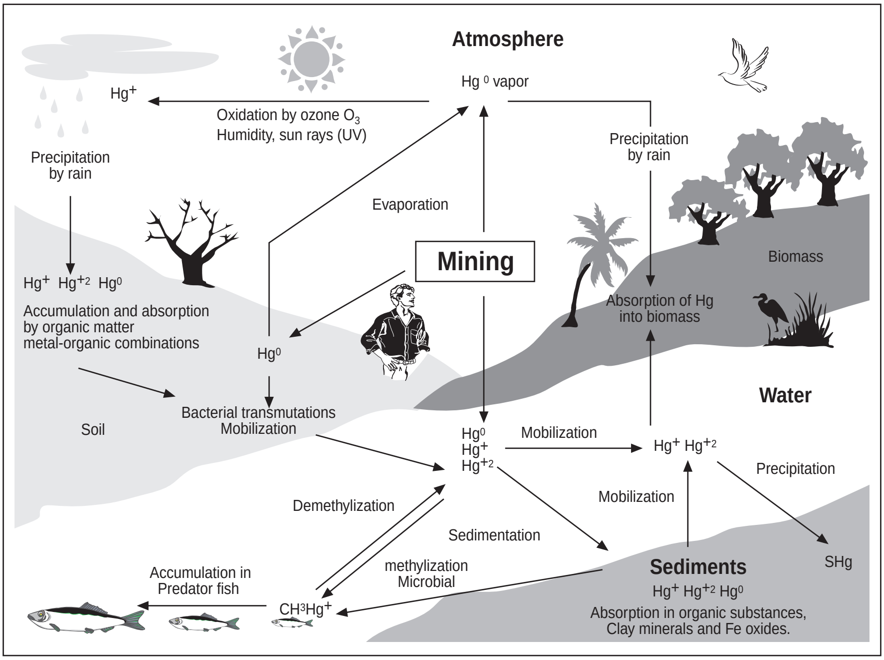
TABLE 12

VALUES OF MERCURY LIMITS (44, 45)

MEDIA		VALUE	ORGANIZATION/ COUNTRY	SOURCE
Water	Potable water	0.001 mg/l	OMS	LAU-BW, 1989 in GTZ
		0.001 mg/l	European com., Canada, Germany	DVGW, 1985 in GTZ
		0.001 mg/l	Japan	MERIAN 1984 in GTZ
		0.002 mg/l	USA/EPA Safe drinking water act PL93-523 40 CFR 302 4	DVGW 1985 in GTZ
		0.003 mg/l	Switzerland	Merian 1984 in GTZ
		0.005 mg/l	ex-USSR	Merian 1984 in GTZ
	Surface water	0.0005 mg/l	European Com. Germany [Limit for natural treatment]	DVGW 1985 in GTZ
		0.001 mg/l	European Com. Germany [Limit for physical & chem. treat]	DVGW 1985 in GTZ
	Irrigation	0.002 mg/l	Germany	DVGW 1985 in GTZ
Air	Work place	0.01 mg/m3	ACGIH/USA [TWA value for Organic compounds]	ACGIH 1984 in GTZ
		0.01 mg/m3	Germany [MAK value for organic compounds]	DFG 1994 in GTZ
		0.025 mg/m3	ACGIH/USA [TLV value]	ACGIH Threshold limit Value (1994) in TEE
		0.03 mg/m3	USA [STEL value for organic compounds]	Merian 1994 in GTZ
		0.05 mg/m3	Japan, Netherlands, Sweden, Finland.	Merian 1984 in GTZ
		0.1 mg/m3	Germany [MAK value for metallic mercury]	DFG 1994 in GTZ
		0.1 mg/m3	OSHA/USA ["Acceptable Ceiling concentration"]	OSHA: 29 CFR 1910 1000 (1993) in TEE
Soil		0.3 mg/kg	Netherlands	Terra Tech 6/94 in GTZ
		0.8 mg/kg	Switzerland	BAFUB 1987 in GTZ
		1.0 mg/kg	UK [Farms]	Sauerbeck 1986 in GTZ
		1.5 mg/kg	UK [Private gardens]	Sauerbeck 1986 in GTZ
Foods	Limits for human consum.	0.2 mg/week	OMS [max.consum. organic Hg]	Clark. 1992 in EDF
		0.3 mg/week	OMS [max.consum. total Hg]	Clark 1992 in EDF
		0.021 mg/day	USA/US exposure limit	Eisler 1987 in EDF
	Milk, Cheese	0.01 mg/kg	Germany	Grossklaus 1989 in GTZ
	Eggs, meat	0.03 mg/kg	Germany	Grossklaus 1989 in GTZ
	Cold cuts	0.05 mg/kg	Germany	Grossklaus 1989 in GTZ
	Liver, kidneys	0.10 mg/kg	Germany	Grossklaus 1989 in GTZ
	Fish/seafood	0.30 mg/kg	European community	CE 1986 in EDF

ILLUSTRATION 6

ENTRANCE AND CIRCUIT OF MERCURY IN THE ECOSYSTEM DUE TO GOLD MINING (46)



5.2.6. The environmental impacts of mercury

Normal mercury concentrations in the environment are not toxic for plants. However, high concentrations inhibit cell development and affect permeability. Some plants (potatoes, carrots, aquatic plants and mushrooms) can absorb mercury. Fish accumulate mercury (see Table 14) but does not normally cause their death. As a result, fish consumers (e.g. fishing communities down stream from small gold mining operations) cannot detect that their fish are contaminated and they eat them without knowing the danger that exists.

Monitoring the environment includes: air, water and sediment analysis for the detection of mercury. High mercury values have been detected in several samples taken at the Bolivia, Brazil, Ecuador and Colombia projects.

However, in any case it is true that mercury contamination is difficult to detect through environmental monitoring, as the specific analysis techniques are extremely difficult and costly and can only be handled by specialized and experienced laboratories, and the analysis carried out in laboratories of developing nations are only partially correct. The following table shows some average values of mercury in rivers where there is small mining in Bolivia (47) [a], Ecuador (48) and Colombia (49) (Table 13). The values of mercury found in fish are shown in Table 14.

TABLE 13

AVERAGE VALUES OF MERCURY IN RIVERS (47, 48, 49)

SAMPLE	LOCATION	MERCURY (µg/g dry weight)
Sediment	Huarinilla river, 2 km down from confluence w/ river Chairo Bolivia	284.7
Sediment	River Chairo, 20 m up from Esperanza mine, Bolivia	407.0
Sediment	River Chairo, 30 m down from Esperanza mine, Bolivia	578.1
Sediment	River Chairo, 100 m down from Ideal Union mine, Bolivia	11490.0
Sediment	River Chairo, platform of Cotapata mine, Bolivia	2237.3
Sediment	River Amarillo, Ecuador	0.33-3.56
Sediment	River Pindo, Ecuador	0.27-1.44
Sediment	Chachajal gorge, Colombia	3.4--5.1
Sediment	Piscoyaco gorge, Colombia	0.38 – 4.1

TABLE 14

AVERAGE VALUES OF MERCURY IN FISH

LOCATION	SPECIES	MERCURY µg/g
Huarinilla River, Bolivia (47)	Chiracidae	121.8 [b]
Huarinilla River, Bolivia (47)	Trichonycteridae	187.1
Araras-Madeira River (Bolivia)	Characidae	213.2
Madeira River, Brazil (51)	Dourada	2.1

a The sediment samples in Bolivia were taken in rivers where primary small gold mining uses mercury in an open circuit (ball mills).

b Value recommended by OMS : 0.2µg/g

5.2.7 Impacts of mercury on health

The toxicity of mercury and its effects on human health depends strongly on the type of combination and its grade of oxidation. Contact with the skin causes dermatitis although little is absorbed by this route. Inhalation of vapors and dust from mercury compounds is the most frequent form of labor intoxication.

Metabolism:

- Approximately 80% of mercury inhaled is absorbed by the lungs and it reduces to about 50% in about 50 days (this reduction to a half is produced every 50 days).
- The major concentration is found in the kidneys.
- It is excreted with the urine and the faeces as a combination of mercury and albumin.

The toxic effect is due to the Hg^{2+} ions.

Symptoms of acute poisoning due to mercury vapor inhalation are:

- Chest pain
- Difficulty in breathing
- Cough
- Metallic taste
- Nausea
- Diarrhea
- Abdominal pain
- Vomiting
- Head ache and occasional albuminoidal
- Acute intense Gastroenteritis, with a latency time of 24 hours.
- After 3 or 4 days, gingivitis and nephrites may appear, that is to say, renal insufficiency with an increase of extra renal uremia due to the mercury albumin ate. Recover possible in two weeks.
- In severe cases, psychopathological and muscular tremor appears.

In cases of prolonged vapor inhalation, **chronic poisoning (Mercurial Isis)** occurs. The symptoms are:

- In cases of intense exposure, oral, renal, respiratory and gastrointestinal symptoms appear.

- Neurological symptoms are frequent in prolonged exposures
- Mouth: gingivitis, alveolar destruction, pigmentation of the gums, salivation, trembling of the tongue, speech difficulty, alteration of tongue sensitivity (taste) and smell.
- Nose: epitasis, nasal irritation.
- Loss of appetite, anemia.
- Neurological: the most common is trembling, first of the eyelids, lips and then the extremities, in grave cases rigidity (chronic spasms), additionally; neuralgia, parasitism, ataxia and increase of sole reflexes.
- Eyes: diminished visual sharpness, crystalline opaqueness.
- Psychological: irritability, insomnia, reduced concentration capacity, melancholia, depression, timidity, fatigue, memory alterations.
- Kidney deposits, liver, brain, transmitted to maternal milk. Eliminated through urine. In some cases nephritic syndrome develops (52)

The inorganic combinations of Hg^{2+} show similar toxic effects.

The organic combinations of mercury, particularly methyl mercury (CH3Hg+), are highly toxic for humans. These are introduced through food. Methyl mercury dissolves easily in fats and passes the blood-brain and placenta barriers; it has mutagenic and teratogenic potential. The typical symptoms of intoxication are recognizable after a few weeks (except for pathological trembling):

- Restricted visual field
- Pronunciation and writing unclear
- Abnormal hyper sensibility
- Skin irritation
- Nasal hemorrhage
- Depression
- Irritation of nervous system (53,54, 55, 56, 57, 58)

In addition to chemical analysis of hair, nails, urine or blood to detect mercury in the organism, medical-clinical examinations to detect mercury intoxication or contamination should be carried out. Within the project scope of Bolivia, Brazil, and Ecuador, the health of the miners, their families, gold buyers and inhabitants of the mining region in general..... (falta texto)

5.3. Amalgamation as a processing technique. Present situation.

5.3.1. History and technical background

Amalgamation is a process used to recover gold and native silver from gold or silver bearing materials. Gold, silver and several other metals and their compounds are able to form an alloy with mercury. These alloys are known as amalgams. Amalgamation in gold mining serves to recover gold in the form of amalgam and thus separate it from other accompanying minerals. The amalgam is formed by the contact between mercury and gold in a pulp with water. Mercury can be present in the form of "pearls" dispersed in the pulp or extended over a surface (amalgam plates). The first use of amalgamation for gold production, probably dates back to mining in Bosnia

a. An inquest taken on school age children (3000 inquested) in the region of Portovelo/ Zaruma (Ecuador), concluded that about 53% of the children had seen and observed the burning of amalgam in or close to their homes. Furthermore, a medical study with clinical examinations with blood and urine samples from the miners, families, neighbors and children (50 each group) in the same region, gave as a result, that half the miners showed mercury impregnation, whilst the other population groups (with minimal exceptions), could be considered as not affected (61).

during Nero's time (54-68 BC). To the present time, small gold mining uses this technique in a generalized form.

Free gold (native) between particle sizes of 20-50µm and 1-2 mm, is appropriate for amalgamation. Coarse gold is easily recoverable by gravity methods. In the amalgamation process, gold is dissolved in mercury to a minimum degree. The amalgam generally contains particles of gold that are allied superficially with mercury and are joined to each other.

In principle, all free clean gold (e.g. not covered with iron oxides) amalgamates. However, the coarse material may contain certain accompanying minerals and/or impurities that have negative effects on the amalgamation process. Some of these problems are described as follows:

- The sulfides of arsenic antimony and bismuth react with mercury producing a significant loss of the precious metal and mercury. In an oxidizing environment (e.g. acid mine waters), also pyrrhotite and to a lesser degree pyrite and chalcopyrite can have a negative effect on amalgamation.
- Barites, talc, steatite and other hydrated silicates of magnesium and aluminum can also interrupt the process and increase losses in gold and mercury.
- Lubricants and grease are a great problem as they adhere to mercury and tend to trap sulfides, talc, clay and other minerals. As a result, mercury is covered by a solid film of fine particles. Additionally, the presence of oil and grease cause gold to float and move away from mercury. These factors naturally reduce recovery of gold in the amalgamation process. Preventative measures to avoid these negative factors include, adding cleaning agents such as a strong detergent or the sap ("juice") of plants such as sisal (fique or pita), the leaves of which are frequently used in Colombia; the objective is to saponify the oil and grease. Other frequently used agents to improve amalgamation are: panela (sugar cane concentrate), lemon, traces of cyanide, gasoline, detergents, etc.
- Aluminum or metallic copper from detonators or electric cable, and metallic lead (in the form of small spheres or shot from cartridges in alluvial mining), metallic zinc from batteries can amalgamate, consume and soil mercury. The amalgams of these metals frequently disperse as very fine particles under oxidizing conditions.
- Mine acid waters, frequently used as process water, also have damaging effects on amalgamation (due to sulfide oxidation, see above). A measured dose of lime partially neutralizes these effects.

Detailed information on the effects of other minerals and chemical substances can be found in the corresponding literature (62).

5.3.2. Application of amalgamation in small gold mining

There are small mining operations where amalgamation is not employed. These are mainly mines that work alluvial deposits with coarse gold where amalgamation is not necessary (e.g. some mines in the river Consata, Bolivia). Apart from these operations, the use of amalgamation in small gold mining is generalized.

5.3.2.1. Applied amalgamation processes

Amalgamation is used both in small primary mining (veins) and in small alluvial mining. There are two principle techniques:

1) "Open circuit" amalgamation

All the feed material (gold bearing) is put into contact with mercury by a continuous pulp flow[a]. It is not possible to recover all the mercury in the form of amalgam, a part in the form of free metallic mercury (droplets or very fine particles) or in the form of amalgam (fine particles or floccules) escapes with the tailings, contaminating a great quantity of material.

2) Amalgamation of concentrates
(or "closed circuit" amalgamation [b])

This means that only a small part of the material treated (a "concentrate") generally produced by gravity methods, is exposed to mercury in a partially or totally enclosed environment and where amalgamation is effected without any pulp emissions (e.g. amalgamating drums)

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a In alluvial mining, frequently a part of the material (coarse and sterile) is eliminated by classification before being concentrated.

b However, the tailings from amalgamation concentrates still contain mercury in variable quantities (depending on the type of material and amalgamation process used). Amalgamation, for example in an amalgamating drum is carried out in a "closed environment"; manual amalgamation is in a "semi-closed environment". It should be noted that a process cannot be considered as an entirely "closed circuit" if the contaminated tailings are released to the environment or if there are mercury leaks, e.g. by evaporation during the process.

In order to complete the amalgamation process, the following steps should be followed:

- Separation of accompanying amalgam-minerals
- Separation of free mercury – amalgam
- Separation of gold-mercury

Table 15 shows the application of different amalgamation techniques in small primary and alluvial gold mining:

TABLE 15

PRINCIPLE AMALGAMATION PROCESSES USED IN SMALL GOLD MINING

Amalgamation process	In small primary Mining.	In small alluvial Mining.	Used mainly in open circuit.
In situ	no	yes	yes
In sluice boxes	yes	yes	yes[a]
In grinding mills (Chilean, Ball, stamps, manual)	yes	no	yes
In centrifuges (Knelson type)	yes	yes	yes
In Jackpot	yes	yes	yes
Amalgam plates c)	yes	yes[c]	yes
Manual	yes	yes	no
Amalgamation drums	yes	yes	no

a In the small alluvial mines in the Brazilian Amazon region where they work almost exclusively with the system, monitor-gravel pump-sluice box, sluice boxes are also used to amalgamate gravity concentrates. On the clean-up day (washing carpets etc.), the exit of the sluice box is blocked by a wooden strip. When shaking and washing the upper surface of the carpet, mercury is

5.3.2.1.1. Amalgamation in situ

Amalgamation in situ is applied only in alluvial mining. Mercury is thrown into the excavated pit and subsequently, with the movement and transport of the material the free gold is partially amalgam. This technique is used frequently in alluvial mines with the monitor-gravel pump-sluice box system. Amalgamation takes place both in the pit and during the passing of the pulp through the pump and pipe towards the sluice box. As a result of the violent agitation of the pulp during transport, a good part of the mercury is pulverized and is lost in the tailings together with the flocculated amalgam. Neither the pulverized mercury not the flocculated amalgam can be recovered efficiently in the sluice box. **Mercury losses are extremely high and fine gold recovery is low.**

5.3.2.1.2 Amalgamation in sluice boxes

Apart from amalgamating apparatus designed specifically for the process, amalgamation can also be executed in other artifacts normally used for gravity separation with water; the most common of these is the sluice box. Amalgamation in sluice boxes is frequently practiced both in alluvial and primary gold mining.

Mercury is placed between the riffles of a sluice box or in depressions in the floor. The sluice box is then operated in much the same manner as in normal gravity separation. When fine gold has a clean surface, it amalgamates rather than carried out of the sluice box. However, in many cases gold passes

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added to the sluice box. Simultaneously, as two men shake the carpets, two others agitate the pulp by hand. The pump works at low revolutions feeding a reduced amount of water to the sluice box. Amalgamation is effected by agitating, and simultaneously the sand and quartz is eliminated from the concentrate. Finally, when there is no more visible gold, the wooden strip is removed, the concentrate with the amalgam is placed into a bucket and the amalgam is separated in a gold pan. This process can also be an open circuit amalgamation, as the water together with the discarded quartz, passes first through the bucket to retain leaks and then is thrown out to the environment. Contrary to other open circuit processes, the quantity processed (as it is a gravity concentrate) is relatively small (50 – 100 kg.). The losses depend on the amount of care taken in the work and is normally less than 2% of the mercury used, but can be a little less or more.

c. The use of amalgam plates is not frequent in alluvial mining.

through the sluice box without amalgamating and gets lost in the tailings (because the gold surface or the mercury is dirty). This process – aside from resulting in low recovery – emits large quantities of mercury. Many times, the pulp passes through a mixing barrel before entering the sluice box, in which mercury is placed for a prior amalgamation. With this additional artifact, mercury losses are even higher due to strong turbulence in the barrel.

5.3.2.1.3. Amalgamation in grinding mills

In primary mining, gold must first be liberated by crushing and grinding. Frequently, advantage is taken of this milling stage to simultaneously carry out the amalgamation process, that is, a combination of grinding and amalgamation. In this stage, mercury is poured into the grinding mill and gold amalgamation is effected in the following types of mills (see Photos. 17, 18, 19, 20):

- Ball mills
- Stamp mills
- Chilean (trapiche)
- Manual (toloca)
- Hammer mill

In this process, part of the amalgam remains in the recipient of the mill (drum, bowl etc.). The other part leaves the mill and is partially recovered by gravity methods (sluice boxes, traps etc.) or amalgam plates. However, the mercury losses in the tails, particularly in the form of mercury flour ("floured mercury") are very high.

5.3.2.1.4. Amalgamation in centrifugal concentrators

The "original" centrifugal concentrators such as, Knelson or Falcon manufactured in Canada, are rarely found in Latin-American small mining for different reasons (see sub-title 5.4.2.1.6). However, copies of these exist made by local workshops. These copies of the centrifuges do not generally have the same efficiency as the originals. For this reason, these "home made" machines are frequently converted into amalgamators in an open circuit (e.g. "Km 88" Venezuela; Tapajos, Brazil; San Simon, Bolivia; see Photo. 22). The operation with this equipment consists in placing mercury at the bottom of the conical recipient and in the annular spaces of the same, then, through the effect of centrifugal force, the gold-mercury contact is achieved thus producing amalgamation. Due to the high speed flow with circular velocity within the centrifuge, a high loss of finely dispersed mercury into the tailings is produced.

5.3.2.1.5. Amalgamation in “jackpot” type amalgamators

Gold is also amalgamated in apparatus of the “jackpot” type, these are traps full with mercury, generally installed at the exit of the mills or just in front of the sluice boxes (see photo 21) These amalgamators should be avoided for their high mercury losses, especially with coarse material.

5.3.2.1.6. Amalgamation with amalgam plates

Amalgamation plates are used in primary mining to recover fine (ground) gold; for this purpose they are installed at the exit of the mill. The pulp (mixture of ore with water) flows over slightly inclined plates made from copper or Muntz metal (60% copper 40% zinc) electrolytically plated with silver. A coat of mercury or amalgam (of silver or gold) is applied to the sheet. As the gold sinks in the pulp, it contacts the mercury and is retained in the form of amalgam. To keep the plates operational, they must be “activated” from time to time, that is, they need a new application of mercury to continue trapping the gold and the amalgam maintains a favorable consistency (a plastic like mass). When the coat of amalgam is appreciable, this is removed by a rubber spatula.

When mercury is used in the mill, the amalgamation plates serve to partially retain the amalgam that does not remain inside. In some types of mills (stamp mills, Chilean mills), the plates are placed on the walls of the mill.

The plates need to be cleaned several times a day and be reconditioned for reuse. These operations require considerable time and imply – due to the high value of the product – a high theft risk. Some solutions have been developed locally for the problem of preparing and cleaning plates, such as scrubbing with urine, Sisal sap (fique or pita), detergents, etc. Sooner or later however, the plates require new electro-plating.

As a general rule, the efficiency of amalgam plates is not very high (especially with sulfurous material), for several reasons:

- In many cases, gold leaves the mill (especially ball mill) with a coat of iron or iron oxide and passes over the sheet without amalgamating.
- Mechanical drag of amalgam by coarse particles in the gangue
- The mercury on the sheet gets contaminated by various substances that prevent or inhibit contact. (”Sickening”), (see sub-title 5.3.1.) (62).

Amalgam plates are also used in some instances in alluvial mining. For this, the larger stones must be eliminated to avoid mechanical drag.

There is a high health risk for the workers that handle amalgam plates as mercury evaporates at a relatively low temperature (see sub-title 5.2.1.). Evaporation during the application of mercury on the plates is so strong, that intoxication of workers is significant (see Photo. 25).

Amalgam, gold and mercury losses using amalgamated plates in an open circuit can be high. Additionally, the risk of intoxication of the operators from mercury evaporation during plate preparation is high. For this reason, this process is not considered recommendable and should be avoided.

5.3.2.1.7. Manual amalgamation

In both primary and alluvial mining, manual amalgamation is generally done on gravity concentrates. It is sometimes done with the feet (see Photo 16). There are concentrates, especially from alluvial deposits, that are easily and quickly amalgamated using a simple bucket and a wooden pole, as the gold is clean and the accompanying minerals are innocuous (black sands) there is good gold recovery and little mercury loss in the tailings (e.g. Tapajos, Brazil and River Madera, Bolivia).

Normally, the sulfurous concentrates require much more effort and time (several hours) for amalgamation to take place, sometimes a stone mortar or a large pan is used (Photos 14 and 15). Although in this case the mercury is in the pulp, **the health risks for the workers** can be high due to the long exposure time and mercury vapor inhalation (48).

5.3.2.1.8. Amalgamation in amalgamating drums

Amalgamating drums are used with frequency both in primary and alluvial mining to amalgamate gravity concentrates. Different models exist and also cement mixers are used. **In some cases, the amalgamating drums are used simultaneously to grind and amalgamate concentrates, with significant losses in the form of ground mercury** that goes to the amalgamation tailings. Amalgamation drums are useful for carrying out controlled amalgamation in a closed circuit, but most important, the process can be very well optimized (see sub-title 5.5.1.4).

There is other equipment for mechanical amalgamation in closed circuit such as “amalgamation cones” where the pulp is agitated by a propeller agitator. This machine is used principally in Venezuela (River Caroni). Similar to this is amalgamation in buckets using a propeller agitator driven by an electrical motor (Huepetue, Perú) Other known machines used such as the “Berdan Pan” are not frequently used in Latin America.

5.3.2.2. Processes used to separate amalgam and accompanying minerals

Only with amalgam plates can an amalgam almost free of accompanying minerals be obtained. In all the other processes described above, a mixture of amalgam, liquid mercury and some heavy minerals are obtained. The amalgam, as a “heavy mass” is separated from the other minerals by gravity methods. Normally using:

- Sluice boxes
- Manual pans
- Mechanical pans
- Hydraulic separators
- Amalgamation plates
- Centrifuges

Losses of amalgam and mercury to the tailings using these methods and equipment can be high. A great part of the ground mercury (floured mercury) is lost. For this reason, it is indispensable to amalgamate in such a manner as to eliminate or reduce mercury flouring and amalgam floccules (see sub-title 5.5.).

5.3.2.3 Processes applied for the separation of free mercury and amalgam

Depending on the mercury/gold relation used in the amalgamation process, the amalgam comes out "dry" with a high gold content, or "liquid" if the gold content is low. In order to reduce the quantity of ground mercury, it is preferable to obtain a "dry" amalgam (see sub-title 5.5). Generally, in the following step the free mercury (not alloyed with gold), should be separated from the amalgam, and in the last step, gold should be separated from mercury.

The separation of free mercury from amalgam is carried out by squeezing through a fine cloth (generally a miner's shirt) or leather, into a suitable recipient and the amalgam stays in the cloth as a compact mass (see Photo 23). However, with these manual separation methods, as the miner is in direct contact with mercury he runs the risk of intoxication and, as the squeezing is with low pressure, this operation has low separation efficiency. For these reasons, it is recommended that rubber gloves be used or even better, employ mechanical methods (presses, centrifuges etc.).

5.3.2.3.1. Amalgam press.

In order to improve free mercury-amalgam separation, some operations use amalgam presses that permit the application of higher pressure than manual methods. Amalgam presses, at least in the simpler models, can be manufactured locally at low cost. Any good metal-mechanical workshop can easily make the amalgam press using commercial thread unions (33).

Generally, if the mixture is introduced into hot water before manual or mechanical squeezing, mercury-amalgam separation is easier and more efficient. By raising the temperature, the viscosity of the contents is lowered and produces improved separation of mercury and amalgam in a cloth or press.

5.3.2.3.2. Centrifuges

In some cases, centrifugal force is used to separate free mercury from amalgam more efficiently. The hand squeezed amalgam is placed in a tube with fine metallic mesh lids. The tube is placed in a centrifuge (e.g. Knelson concentrator) and the high revolutions of the device generates a centrifugal force that assists more free mercury to exit the tube and is recovered in the external recipient. In this manner, a very dry amalgam is obtained, that facilitates the subsequent gold-mercury separation.

5.3.2.4. Processes used for gold and mercury separation

Separation of gold and mercury in amalgam can be done by thermal or chemical means. In general, small mining prefers thermal separation.

5.3.2.4.1. Thermal separation

Mercury evaporates at a temperature of around 360º C; consequently, amalgam must be heated in order to evaporate the mercury. Gold remains in the heating vessel as a final product. **Unfortunately, this thermal separation is frequently practiced in a direct and elementary manner by "open crucible" or "open burning", releasing the highly toxic mercury vapor into the atmosphere, contaminating the environment, putting at risk the worker's health and that of the surrounding inhabitants.** Generally, gas heaters or blow torches of different types are used for this purpose. The majority of the vaporized mercury settles in the area surrounding the site of the "burning" (normally the mining camp), contaminating the soil, food and living beings of the location (see Photo 24.) With time and rain, the settled mercury on the surface is transported to the nearby rivers. In many cases, the amalgam is "burnt" in the miner's home or kitchen.

There are various forms considered as being "advanced" to burn in a semi enclosed environment, that include the following a):

- Device with a recipient and plate (63).
- Covered system: depending on the region, sometimes with a banana leaf, potatoes or a pumpkin, placed over the amalgam in the "burning" vessel,

that help to recover part of the mercury vapor by condensation on their surfaces.

Unfortunately gold-mercury separation in a closed circuit using retorts is still exceptional. However there are some mines that use industrially manufactured (see Photo 39) or home-made retorts (see Photo. 40). A more detailed description on the use of retorts is to be found in sub-title 5.5.5.1.

5.3.2.4.2. Chemical separation

There are also chemical methods for separating gold-mercury from the amalgam. We can cite the method of dissolving mercury of the amalgam with nitric acid. This method is used only in some gold mines. Although separation is efficient, the environmental impacts caused by the emission of vapors and residual solutions are grave. Even more, the operators of the process are dangerously exposed to the strong nitrous gasses produced. A more ample description of the process is given in sub-title 5.5.5.2.

5.3.3. Mercury losses in traditional processes

It has been observed that mercury emissions into the environment are produced in the following phases:

- Mercury emissions in open circuits when amalgamation is carried out earlier, together with and after grinding and/or during the pre-concentration phase (use of mercury “in situ” in sluice boxes, mills, amalgamplates, etc.).
- Mercury emissions after the pre-concentration or concentration phase (amalgamation of concentrates).
- Mercury emissions during gold-mercury separation (generally when “burning” the amalgam, occasionally when dissolving mercury with nitric acid).

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a These rustic methods only recover part of the mercury, endanger the operators and the environment and cannot replace the use of the retort (the same as the famous method of the split potatoes).

- Mercury emissions when refining gold (in the homes of the buyers)
- Mercury emissions during handling and transport (spills).
- Discarding “exhausted mercury”.

The use of mercury in open circuit is without doubt the major cause of mercury losses in gold production. The primary mines in Brazil and Bolivia that use mercury directly in their mills in order to grind and amalgamate simultaneously (64), lose between 5 and 10kg. of mercury (25kg in extreme cases) to recover 1kg of gold. In general, the intent to recover amalgam, is with simple gravimetric traps or amalgam plates. For this reason, the tailings still contain free gold, amalgam and free mercury.

Mercury losses in alluvial mining are almost as high as those mentioned above; when mercury is added to the gold bearing gravels in situ prior to pumping, or in a mixing barrel before passing through the sluice box, or directly in the sluice. Venezuela, Brazil and Colombia are amongst the countries that employ this procedure.

Experience and evaluations in both cases (mercury in open circuit in alluvial mining and addition of mercury to the grinding mill in primary mining), demonstrated that gold recovery in general is lower than when carefully designed and operated gravity equipment is employed. The miners by themselves do not achieve these levels of optimization due to their lack of technical knowledge, and for this reason they continue to use mercury in an open circuit, even though from a technical-economic view point, open circuit amalgamation is of no advantage to the miners. A lower mercury consumption and a higher gold recovery means a higher income, a fact that the miners understand well. A rich concentrate implies less amalgamation tailings (less contamination) or in some cases the possibility of direct smelting. Consequently, improving gravity concentration would play an important role in the reduction of mercury contamination (sub-title 5.4.2).

Unfortunately, we understand that in fact, only on rare occasions can amalgamation be replaced by another technique in small mining operations, as amalgamation is and will continue to be the most simple and effective method for separating gold from other heavy minerals that are obtained jointly in gravity processes. We should restrict amalgamation to concentrates. In concentrate amalgamation it is inevitable that a percentage of mercury used will be lost in the tailings as these are not stored safely. The generation of “ground “ or “floured Mercury” that cannot be satisfactorily recovered by gravity methods nor with amalgam plates, depends fundamentally on the nature of the concentrates and on the way that amalgamation is carried out.

In alluvial mining, gravity concentrates are obtained where the gold is clean and the accompanying minerals are innocuous. In these cases, with careful amalgamation of the concentrates, the mercury or amalgam losses in the tailings are minimum (e.g. <0.5% of the mercury used). However, there are components in some concentrates that contaminate mercury or the gold itself by coating them with layers of different substances (e.g. oxides). This is seen particularly in sulfurous concentrates from primary mines. In these cases, mercury losses in the form of floured mercury may exceed 10% of the mercury used.

During gold-mercury separation, part of the mercury amalgam is generally lost (if some method of recovery such as a retort is not used). The percentage of mercury in amalgam depends mainly on the grain size of the gold and the method used to squeeze the amalgam to extract the free mercury. Generally, fine gold due to the large superficial area exposed, traps more mercury per kilogram of amalgam than coarse gold. The Au/Hg proportions in different mines, vary between 0.5 Hg: 1 Au to 2 Hg: 1 Au.

Mercury losses during clean up of the gold sponge (product of burning the amalgam), are very variable (depending on the grain size of the gold, size of the sponge ball and the temperature of the burning etc.) and can reach several percentages of the gold weight. Generally, the buyers re-burn the gold ball to assure themselves that it has been well burned and has no residues of mercury inside and/or smelt the gold purchased to eliminate impurities (and mercury). The vapors from the mercury and other heavy metals (lead, antimony etc.) released during smelting, are generally dispersed within the same room or store, or are expelled outside (see Photo 27). These businesses are sometimes concentrated in a single street of the mine settlement. High mercury concentrations were detected in the urine of the persons involved in this activity and also of the neighbors (59) (Lit. Brazil).

Emissions due to accidental spills or broken recipients occur during transport and handling of mercury. As mercury is an expensive element, the miners generally try to recover as much as possible from the spills. Mercury spills in the miners’ rooms or kitchens are a permanent danger to the health of the miners and their families, due to its evaporation at room temperature.

As a result of its frequent and intense use (e.g., mercury squeezed several times) it becomes contaminated and loses its power of amalgamation. The miners discard this “exhausted mercury”.

Some governments had the objective in mind to reduce mercury contamination – such as the Brazilian Government (65) – when they passed a law prohibiting the use of mercury. However, the only result obtained from the execution of the law, was the clandestine use of mercury by the miners, and control of its use became more difficult than before.

Conclusions

The information obtained on the **principle mercury emissions** in traditional gold recovery processes, shows differentiated levels with regards to environmental impact (typical average values):

1). Emissions in open circuit concentration processes	(5-40 kg Hg/ Kg Au recovered)[a]
2) Emissions from contaminated amalgamation tailings.	(0.01-1 kg Hg/kg Au recovered)[b]
3) Emissions from gold-mercury separation process [c]	(0.50-2 kg Hg/kg Au recovered)

a In extreme major cases. When well controlled amalgam plates are used exclusively, without prior us of mercury in the grinding mill it is possibly less (depending on the characteristics of the feed). Extreme values where milling and amalgamation are combined, like in the “Quimlabetes” of Southern Peru

b Depending on feed characteristics and amalgamation methods, can vary up or down. High values with poly-sulfide feed and/or when it is combined with grinding and drum amalgamation.

c Generally the “burning” of the amalgam

5.4. Strategies and recommendations to avoid or reduce mercury contamination.

Several detailed technical measures will be presented in the first part of environmental strategies. By using the example of mercury contamination caused by gold production of small companies, it is the intention to demonstrate, that to put successful environmental projects into practice, there are no ideal solutions with guaranteed success, but rather, technical solutions that must adapt to specific local situations. However, there are general strategies that allow for the election of solutions.

5.4.1 Principle and basic strategies

Only in some cases, well mechanized small mines with good technical and financial capacity can **completely** free themselves from mercury use and work with other methods. This occurs for example in an operation in Zaruma-Ecuador, where a small company with a high technical level has a similar process to industrial mines: gravity concentration followed by cyanide leaching. The mentioned plant substituted amalgamation with direct smelting of highly enriched concentrates.

In general, the experience of the authors shows clearly that **in the near future, amalgamation will continue to be the preferred and applied method in small gold mining.**

The principle and basic strategies that demonstrated their validity in the different projects executed by the authors are:

- If it is not possible to eliminate amalgamation, it has to be optimized and restricted to closed circuits.
- Opportunities will always appear to **avoid amalgamation completely** by using known or new alternative methods. This is still the **maximum objective** of the work in this field (providing that the technological change does not cause other grave environmental impacts). But another objective of a project in this field is: to **substantially mitigate the environmental impacts, and to execute this in a near future.**
- **A project** that wishes to improve the grave environmental situation and also the alarming industrial safety situation in small gold mining, **must**

act pragmatically and quickly. We cannot afford the luxury of losing time and money looking for optimum solutions whilst the contamination continues to get worse.

- Technical measures cannot be restricted to elegance, new or interesting from a technological view point. **Everything that functions is good. And the simpler and cheaper it is, is even better.**
- To introduce or change technologies, methods and machinery are not the objective, but rather the means to achieve a reduction of the negative impacts of small mining.
- If the possibility exists, we must suppress or eliminate the use of mercury in the process as soon as possible instead of cleaning the products later: **prevention has priority over healing** [a].
- It is only in rare cases that an entire beneficiation plant or process can be changed: the measures must have the possibility of being integrated into the existing processes and location.
- Protection of the environment and protection of the health of the operators (industrial safety) go together. **A miner that does not take care of his own health does not understand why he should take care of the health of others.**

5.4.2. Limit use of amalgamation by optimizing gravity concentration.

The starting point for field work with small miners is to optimize their gravity concentration processes.

This is especially important because, before introducing new unknown techniques, the miners prefer to improve what they already have and know. There is no doubt that the highest mercury losses occur in open circuits and when the gravity concentrating equipment is insufficient. For this reason, maximum attention must be paid to the improvement of gravity methods that permit obtaining high grade concentrates adequate for closed circuit amalgamation or direct smelting.

Gravity concentration has been and continues to be the most important processing system in small mining. Whilst the miners are not absolutely convinced that their gravity system functions well, the temptation to add mercury to the grinding mill or in the sluice box will persist.

Gravity concentration has been and continues to be the most important processing system in small mining. With gravity concentration, the difference in specific gravity between valuable and gangue minerals is used to achieve their separation. This separation is effected by the diverse movements of heavy particles (in our case, gold, gold bearing pyrites or black sands) and the gangue minerals, by force of gravity and other forces in a fluid medium – generally water or air. No chemical reagents are used. A characteristic of all gravity concentration methods is that the particles have to be separated by fluid dynamics to obtain the formation of layers or borders of light and heavy minerals.

Table 16 shows a schematic comparison of processes, with and without amalgamation, in typical operations.

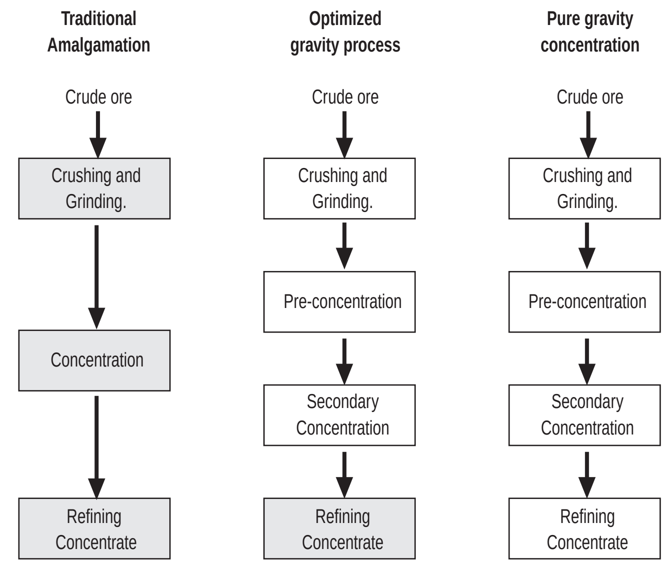
There is limited information on gravity processing techniques in primitive times, however, we do know from the legend of the "golden fleece", that sheep skins were used to recover alluvial gold in a similar manner as the carpets used today in small alluvial mining. The ancient Egyptians used the predecessors of the sluice box and pan, as far back as 2000 BC. Georgius Agricola describes a variety of gravity concentration artifacts used in 1556 that are still used today, such as different types of tables and sluice boxes (66).

The improvement of gravity concentrating techniques has always been a challenge for several generations of miners and engineers, and a great number of artifacts have been developed over the years, and no doubt will continue to be developed for years to come. Some have not passed the experimental stage, but scientific investigation and the constant testing by trial and error have led to constant improvement in those techniques; as for example, recently developed centrifugal concentrators that are constantly being improved and new models appearing on the market.

Gravity concentration is a simple, high capacity, without dangerous reagents, low cost and reasonably efficient system to separate valuable heavy minerals from the bulk feed, which explains its extensive use in small gold mining.

TABLE 16

SCHEMATIC COMPARISON OF PROCESSES WITH AND WITHOUT AMALGAMATION IN TYPICAL OPERATIONS



Traditional Amalgamation	Optimized gravity process	Pure gravity concentration
Characteristics Indiscriminate use of Amalgamation (open circuit) gravity methods insufficient, burn Amalgam in open air.	**Characteristics** Amalgamation only gravity concentrates (closed circuit) within optimized gravity process; use of Retorts.	**Characteristics** No amalgamation; total gravity process; Final process, e.g. direct smelting of concentrates.
Results: Extremely high mercury Emissions (ratio mercury lost : gold recovered; up to 10:1. Gold recovery Relatively low.	**Results:** Low mercury emission (ratio mercury lost in amalgam tails: gold recovered; up to 0.01:1); High gold recovery.	**Results:** No mercury emissions relatively complicated require sophisticated gravity equipment. Gold recover high.

5.4.2.1. Techniques and gravity machines suitable for mining with less contamination

Several machines and techniques are presented below that can serve for cleaner gold mining. The majority of the techniques are well known and widely used but frequently outside their possibilities. Where the authors have had personal experience, a description is given of the advantages, disadvantages, possibilities and limitations of the equipment as found in the field work.

The techniques presented can be used individually or as part of more complex systems. Examples in the form of flow sheets are shown in annex 1.

5.4.2.1.1. Gold pans

Pans jointly with sluice boxes, is the most important instrument in small gold mining. In both alluvial and primary gold mining, there is a strong dependence on gold separation by panning. In effect, several small artisan mines use only this process for mineral concentration. Because of their high selectivity, gold pans are unique and irreplaceable in all phases of small mining, in reconnaissance, exploration and in the internal process of production control and production preparation. Moreover, gold pans are frequently used in the preparatory phase for cleaning and enrichment of pre-concentrates. The gold pan is a simple apparatus, generally circular with a transverse section in the form of a trapezoid or triangle; there are also pans with oval or oblong sections and some of rectangular shape.

In the measure that the miner moves the pan, the gold accumulates at the bottom center. There are two types of movement: one rotary and the other longitudinal. The important thing is that the pulp in the pan forms a fluid mixture so that with the movement, the heavier particles go to the bottom. If the material at the bottom is compacted, the operator loses most of all the fine and laminated gold.

There are basically **two ways to operate a gold pan:**

- The North American pan (trapezoidal transverse section) and also rectangular pans that move back and forth so that the lighter material moves out of the pan. In many cases, a section of the pan has striations that help to retain the gold.

- The other pans (triangular or concave transverse sections) must be rotated in a manner that the center is almost immobile (but suspended), whilst there is a combination of water current and radial acceleration that takes the tails (light material) to the outer rim and out of the pan.

The miner repeats this process until only gold and black sands remain in the pan.

Gold pans are made of different materials:

- Metal
- Wood
- PVC
- Rubber
- Split gourds
- Others (horn, etc.)

Wooden or steel (rusty so that surface is rough and dark) are the most common in Latin America, even though black PVC pans have several advantages: they resist cracking, are light weight and generally durable, and gold is clearly visible in them. When using a pan, care must be taken not to lose the fine gold by floating. This effect occurs also in other gravity processes (sluice boxes, tables etc.) this signifies that as gold has a hydrophobic surface (a characteristic that is increased by coating with oil and grease) it does not sink and floats on the surface of the water. Whilst in the flotation process (as an alternative to gravity concentration, see sub-title 5.6.2.), advantage is taken of this characteristic. In the case of gravity concentration, this causes losses. For this reason, contamination of the material with oils and lubricants must be avoided. A few drops of (diluted) detergent or the juices of certain plants such as, sisal sap (fique or pita), can help to avoid floating.

The yield in gold separation operations with only pans is generally low. If the material has easy separation properties, a miner can handle close to 100 pan loads of 10 kgs per pan per day totaling approximately 1 ton/day. The coarse gravel particles in the material are eliminated previously with a sieve or by hand whilst stirring the material in the pan. The finer the gold, higher are the losses due to the inadvertent escape of the fine gold.

Gold pans are easy to make. Simply a little beating on the lid of a diesel or cyanide drum produces a gold pan. Some small workshops also produce gold pans in wood, PVC or PE.

The grade of panning recovery depends mainly on the ability of the operator. In a careful operation, recovery may be very good with particles down to 20µ. For this reason, pans are also important control devices during gravity concentration, both in alluvial and primary mines.

5.4.2.1.2. Sluice boxes

Sluice boxes are very commonly used in gold mining, principally in small alluvial gold mining and for concentrating milled primary minerals. There is no doubt **that sluice boxes are the most important implements for gravity concentration in small scale mining**. There are thousands of mines all over the world that work exclusively with sluice boxes (and pans). Calculating installed capacity, the sluice box is one of the artifacts most used for concentrating heavy minerals. As a rule, it consists of a channel over which the pulp flows and has traps made of different materials to retain the heavy minerals, these sink to the bottom whilst the water carries the lighter materials out of the sluice.

There are many forms and types of sluice boxes, both for primary (veins) and alluvial gold (placers).

Advantages	
✓	Low cost
✓	High capacity
✓	Needs no power
✓	Good recovery (when good design and handling)
✓	Easy operation
✓	High grade of concentration

Disadvantages	
✗	Needs much more labor (to be cleaned out frequently) [a]
✗	Low recovery of accompanying sulfides [b]
✗	Discontinuous discharge of gold products

DESIGN	OPERATION	FEED
• Width • Length • Types of floor (traps)	• Quantity of feed per hour • Volume of water • Inclination • Wash frequency	• Grain (size of feed particles) • Quantity of accompanying minerals • Quantity of slimes

The function of a sluice box is determined by the following factors:

There are **two basic types of floors that influence separation.**

I) Floor with riffles (thick traps, sometimes over carpets)

In this manner, the pulp has strong turbulence (necessary for cascade effect). The riffles recover coarse gold efficiently, but generally lose the major part of fine gold (67). In addition, considerable pre-concentrate is recovered that increases the work and difficulties for obtaining the final product.

II) Carpet floor (Jute, blankets, carpets etc.)

In this manner, the pulp flows with little turbulence. The advantage is good fine gold recovery and a reduced quantity of pre-concentrate (danger of loosing coarse gold).

Depending on the type of feed material, frequent washing will be required. This type of sluice box is called "blanket table" or "strake". These

a The need for considerable labor may be positive in small mining in under developed countries.

b Sluice boxes recover mainly gold and only a part of the accompanying heavy minerals. This is useful in alluvial mining. In primary mining, sometimes sulfides are a valuable (gold-bearing) byproduct. These (especially the fines) do not have good recovery in sluice boxes. For this purpose, it is necessary to utilize other gravity equipment (e.g. jigs, tables, spirals, etc.).

sluices are not only used in primary mining, but they also function in alluvial mining for fine gold (see Photos: 28, 29, 30, and 31).

An intermediate form is to use expanded metal over the carpet that has given good results in alluvial mining (68).

In cases where the feed material contains both coarse and fine gold, it is recommended that the material be screened and each size teated in different sluice boxes. In many cases, it is also sufficient to have a short section with riffles at the entrance of the sluice box to recover the nuggets.

Design and operation of sluice boxes

Due to the variety of materials to be treated, it is not possible to give specific recommendations on the application of sluice boxes. The following general rules should be followed:

a) In alluvial mining the coarse sterile stones should be eliminated before feeding the sluice box. **The largest feed grain size, should not be more than the largest possible nugget.**

b) **The material should be treated according to the gold size with different types of traps**. Various types of corrugations and linings are used to obtain a "coarse" floor in order that gold can be trapped. The most common materials used for corrugations (riffles) or linings include (33):

- Stones
- Wood or metal riffles.
- Striated rubber mats (as in car floors)
- Sisal or coconut mats.
- Fine and coarse cloth, such as corduroy, velvet, sackcloth, spliced bamboo.
- Expanded metal sheets
- Different types of carpet.
-
- Various combinations of the above materials.

The selection of the floor or lining depends not only on the metallurgical requirements, but also on the availability of the materials in each region. In the work executed in Bolivia, Brazil and Ecuador, various types of flooring were employed, according to the gold characteristics that have given good gold recovery results, concentration and handling levels (69, 70, 71). The following were used to recover:

- **Coarse gold** (size of rice grain and above): metal riffles 1” x 1” or expanded metal over a “Nomad” type carpet (3M manufacture).
- **Medium gold** (size of rice grain down to sugar or laminated gold): “Nomad” type carpet or “Multiouro tariscado” manufactured by Sommer, Sao Paulo, Brazil; without riffles or expanded metal over a “Nomad” carpet.
- **Fine gold** (flour size): carpet “Multiouro liso”, manufactured by Sommer, Sao Paulo, Brazil; wool sack cloth; synthetic cloths.

c) **Sluice box inclination** should be such that the feed material does not settle on the floor, generally between 10 and 20% (10 to 20 cms per meter of sluice box). In some cases, for primary ore with fine gold that requires grinding down to minus 0.1 mm, the optimum inclination may be as low as 4%.This must be established experimentally.

d) **Washing frequency** of the linings depends on the tonnage treated and the amount of accompanying heavy minerals. Generally in alluvial mining, it is necessary to harvest the concentrates once a day, in primary mining the carpets need to be washed every hour (depending mainly on the accompanying heavy minerals such as sulfides etc.). If too much time passes between washings, the floor becomes saturated with heavy material and significant losses of valuable material occur. The optimum frequency must be determined by experiment, such as controlling the tails by panning.

e) **Pulp density** (relation of material: water) should be in the order of 1:4 by weight for (alluvial) material with coarse or medium gold, and up to 1:10 for (primary) material with fine gold.

The majority of operators that use sluice boxes with thick riffles rake the spaces between riffles to make sure that the material between them does not become compact. When this occurs, fine gold in particular is lost in the tailings. To avoid this problem, in New Zealand “hydraulic riffles” are common.Water injection is used in this case to avoid compacting in the sluice box and to facilitate the escape of light minerals.

It is estimated that with hydraulic riffles, recovery is 5-10% higher than with conventional riffles[a] (72).

The prejudice exists that sluice boxes are unable to recover sufficient fine gold. It was not possible to substantiate this in work carried out in Ecuador, Brazil and Bolivia. On the contrary, it was possible to demonstrate and prove the efficiency and reliability of the system and recover fine gold down to 30µm[b] (73).

Sluice boxes in excavated channels ("ground sluices")

Sluice boxes in excavated channels are used exclusively in alluvial mining. This consists of a trench, with or without masonry walls and with varying floor conditions and inclination angles. Usually, the floor is made from coarse stones or sometimes covered with tree branches. In the measure that the unclassified material flows through the channel as a dense pulp, some heavy material is deposited in the spaces of the floor and is recovered as a pre-concentrate. The use of excavated channels results in high gold losses and particularly the fines.

Other sluice boxes

There are other forms of sluice boxes such as:

- Fan shaped
- Vibrating floors
- Plane tables etc.

that are used by small gold mining in some locations. The description of these is to be found in the corresponding literature (74, 75). "Plane tables" in particular can be interesting for small primary gold mining. Tests are being conducted by the authors at this time.

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a Sluice box amalgamation by placing mercury in the spaces between riffles is a frequent practice. This generally works for coarse gold. Fine gold does not have sufficient mass to penetrate the mercury surface and the contact period is too short to amalgamate on the surface, especially gold with the surface covered by oxides or when the mercury is contaminated (exhausted). For this reason, fine gold recovery with this process is low, whereas the impact on the environment is high. A high percentage of mercury is lost in the tailings, and for this reason, this process should be avoided at all cost (see sub-title 5.3.2.1.).

b This is not a novelty as can be seen in TAGGART, 1953 (73).

5.4.2.1.3. Jigs

The jig is a piece of equipment used for gravity pre-concentration or concentration of heavy minerals (tin, wolfram, etc.), and also in gold mining. The jig separates the components of an ore according to specific gravity in an aqueous media that alternates free sedimentation and hindered sedimentation as a result of the pulsation of the liquid produced by different artifacts. In gold mining the heavy components are gold and various sulfides (or black sands in alluvial mining), and the light components are quartz and different types of rock.

The most rudimentary version in Bolivia is the “maritate” composed of a manually movable sieve in a bath of water.

Hydraulic jig

In this device pulsation is produced hydraulically (by water pressure that moves a diaphragm valve). This principle was applied originally with the “Pan-American Pulsator Jig” and later simplified in rustic jigs of the “Baltar” type.

Advantages	
✔	Simple construction
✔	Does not require power
✔	Low investment and maintenance cost

Disadvantages	
✗	Difficult to control
✗	High water requirements
✗	Requires permanent adjustment

Mechanical jig

There are many types of mechanical jigs that have been developed for various minerals and uses. In gold mining, the following types are generally found:

Alluvial gold: Yuba and Pan-American
Primary gold: Denver Mineral Jig (see: Photo 34)

The required pulsation is produced mechanically by a connecting rod and diaphragm driven by a motor.

Advantages	
✔	Versatile, can be adapted to all types of materials.
✔	Variable adjustment, doe not require much attention.

Disadvantages	
✗	Requires a motor.

Jig operation

The operating variables are similar in all types of jigs:
- Mesh size
- Material for the jig bed
- Water injection
- Stroke (amplitude)
- Velocity or stroke frequency
- Feed (t/hr)
- Particle size of feed

Jig application possibilities

There are ample possibilities for the use of jigs in mining. Particularly in gold mining, it can be used both in vein or primary mining and alluvial mining. Experience has shown that **it is efficient in recovering laminated and spongy gold**, with which it is difficult to equal with other gravity equipment.

In primary mining, it can be installed immediately **after the primary mill** to recover coarse, laminated and spongy gold and the free coarse sulfides thus eliminating the unnecessary return to the mill in a closed circuit and avoiding further gold lamination and the over grinding of sulfides that are potential contaminants. It can also be used to **complement enrichment of products** from other phases.

In alluvial mining, the jig can also be used as a primary concentrator instead of, or before the sluice box or, for additional enrichment of pre-concentrates. It is widely used to recover alluvial tin, tantalite and diamonds.

The necessary details on jig operation can be found in the corresponding literature (75). **As opposed to sluice boxes, jigs require well trained operators in order to obtain good results**.

Jigs can be produced locally in metal workshops.

5.4.2.1.4. Shaking tables

Shaking tables are gravity concentrators with a laminar flow over an inclined surface. These work with a longitudinal vibratory movement, where mineral particles are differentiated by forming fan shaped bands according to their specific weight (and grain size). Other types of tables (belt tables, etc.) are rarely used in small mining, and for this reason they are not described here in detail (74).

The table with longitudinal vibration (shaking table) is widely diffused, principally in tin, wolfram and gold mining.

There are different types and makes. In gold mining, the Wilfley, Deister and Holman types are the most widely used (see Photo 32). The differences between one and another are minimum, principally in the Head mechanism, the geometry of the deck and the types of riffles. For the last step of concentration, for example prior to direct smelting, some mines have tables of the “Gemini” type.

Depending on the model and size, **tables are used to concentrate fine and ultra fine minerals** and have a maximum capacity of 1.5 t/h each.

Shaking tables allow for a wide variation in their operational parameters, and this permits adapting to the corresponding feed material. Because the concentrating process is carried out visibly on the table deck, any change in parameters (longitudinal and transverse inclination, quantity of water etc.), results in changes in the behavior of the material and this can be seen immediately. Samples can be taken directly during the operation using gold pans for example. Thus the operation is optimized in a simple manner and can be can be operated by apprentice operators.

As a result of the fan shaped distribution on the table deck, one can obtain specific bands of mineral selectively (this does not occur so clear with spirals where the bands partially overlap). In this manner, it is possible to make the corresponding adjustment, a rich concentrate with free gold as well as a sulfide concentrate containing disseminated gold for example, for subsequent treatment. This implies however, that it is easy to steal the high grade concentrate when using tables for the cleaning phase.

The effectiveness of all tables depends on the homogenous nature of the feed, and the pulp density -particularly the density – as any fluctuation diverts the flow of water towards the outer edge of the current.

Advantages

✔	Continuous discharge or products
✔	Obtains a range of products (concentrate, middling and tails)
✔	Visible behavior of the material on the deck
✔	Relatively low cost (of local production)
✔	Great flexibility
✔	Relatively simple operation and supervision
✔	Possibility of recovering other valuable accompanying minerals
✔	High safety of work conditions
✔	Good recovery and high level of enrichment
✔	Possibility of manufacture in developing countries

Disadvantages

✗	Relatively high price (in relation to capacity)
✗	Requires constant feed (if not, the position of the bands on the deck vary too much)
✗	Requires constant supervision
✗	Requires power

Operating variables

The most important are:

- Feed grain size
- Length of stroke
- Stroke frequency
- Deck inclination

- Quantity of wash water
- Position of splitters

It usually helps to improve the results if the material is pre-classified (e.g. with hydraulic classifiers) and each particle size fraction goes to a separate shaking table. Detailed explanations on the operation of concentrating tables are to be found in the pertinent literature (75).

Application possibilities

The principle use is in vein gold mining for the recovery of fine gold and frequently to recover gold bearing pyrites as a commercial byproduct. The latter also becomes a contaminant when it is discarded as a tailing into rivers and lagoons; its separation or recovery is a valuable contribution to the mitigation of this environmental impact as well as additional income.

Tables also serve to enrich gravity pre-concentrates obtained by other equipment (sluice boxes, spirals etc.) and to produce high grade concentrates (that in some cases can be directly smelted).

Tables can be manufactured locally in metal-mechanic workshops (the mechanism) and carpentry workshops (the decks).

5.4.3.1.5. Spiral concentrators

The spiral concentrator consists of helicoidally shaped sluice with four to seven curves. Its' function ca be compared with a conical pan where the lighter particles move to the edges by the action of water and the heavier particles concentrate in the center. The spiral concentrator can be considered as being a series of connected overlapping pans.

The heavier particles gather at the bottom, where friction and drag come into play and reduce the speed of the material. Due to the spiral form of the bottom of the spiral, the centrifugal force within the pulp takes the lighter material outwards towards the edge of the spiral, whilst the heavier material remains inside.

The modern models of relatively simple design (such as Reichert LG 7, see photo 33), have gradually displaced the older more complicated spirals (the Humphrey or Reichert WW 6) with wash water feed and concentrate cut-offs at different points on the spiral.

At the terminal point of modern spirals, the cut-offs divide the product into four different fractions: concentrates, middling, tailings and water. There are different specific types of spirals used for cleaning enriched concentrates or material with high heavy mineral content (medium and high grade spirals have more concentrate outlets, but are rarely used for gold processing).

The helicoidally shaped form permits a combination of several spirals in a single column (duplex, triplex). The majority of spiral concentrators are made from plastic material or synthetic resin of reinforced fiberglass and coated with polyurethane.

Spirals can be used for a variety of **grain sizes from 2 mm (better 1mm) to approximately 30μm**. Generally, spirals are characterized by their high recovery, but also for their low enrichment factor, it is for this reason that spirals are used successfully in the pre-concentrate stage or as "scavengers" (for the recovery of valuable residual minerals from tailings). Spirals are not appropriate for the enrichment of sluice box concentrates. However, there is no doubt that spirals can be used effectively even as a replacement of sluice boxes, combined with other concentrating equipment for secondary concentration of pre-concentrates (concentrating tables for example). It was proven in various occasions that a combination of spirals (rougher) and sluice boxes (scavenger) after a (hammer) mill followed by a shaking table to upgrade the concentrates gave very good results.

A detailed description on spiral operation can be found in the corresponding literature (75).

Spirals allow for **continuous pre-concentrate production**, and also to extract intermediary products (such as sulfides) they are also extraordinarily **useful for de-sliming material**, as the major part of the water together with the ultra fine particles are extracted separately.

Spirals do not require external power, they **need very little maintenance**, they are also resistant to mechanical wear and each unit can treat up to 2 tons/hr., they require very little space and are easy to operate.

Compared with shaking tables and centrifugal concentrators, spirals are significantly more economical.

Advantages

- ✔ Simple operation
- ✔ Good recovery
- ✔ Requires no power
- ✔ High capacity (up to 50 t/d for a simple spiral)
- ✔ Moderate price

Disadvantages

- ✗ Require **considerable height between feed and discharge**; to obtain this height the natural gradient of a hill slope can be used. Plants located in more or less flat terrain need pumps to feed the pulp to the spiral which requires additional investment; pumps wear out rapidly due to the abrasive nature of the material.
- ✗ Spirals need to operate with **30-40% pulp density** in order to obtain optimum concentration results. When pulp is fed directly from a ball mill, frequently the pulp has to be diluted to obtain the required density; the pulp from sluice box gravity concentration is sometimes too diluted to feed the spiral. Prior to feeding the spiral, the pulp must be thickened (can be with a conical box classifier, or by hydration and a pump).
- ✗ Spirals can be **operated with a minimum of labor**. Even with only one man per shift that sporadically controls the operation, so there is a considerable saving in labor, as against sluice box and table operation. This is an advantage for the formal mining sector, but is considered as a disadvantage in the small mining sector as it means a reduction of jobs.
- ✗ The **technical requirements** for its manufacture (experienced workshop in plastics handling) **make local construction of spiral concentrators difficult**. Assuming an adequate demand, they could be produced on an industrial scale by companies specialized in plastics processing.

At he terminal of the spiral, are the exits for the products (concentrate, middling, tailings and water). The water generally contains slimes. The width of the concentrate band and the middling, can be determined by the splitters.

Depending on the position of the cut-offs, the following products mat be obtained:

Table 17

ALTERNATIVES FOR THE SELECTION OF DIFFERENT PRODUCTS IN A SPIRAL CONCENTRATOR

PRODUCT	CONCENTRATE	MIDDLES	TAILS
Alternative a)	Pyrite and gold (High gold)	Pyrite, gold, quartz	Quartz with some pyrite
Alternative b)	Pyrite and gold (Low gold)	Mixed pyrite for re-grinding	Quartz

Use of spirals in gold mining

The spiral is used principally for **pre-concentrating gold bearing materials**, both primary and secondary. A further use is to recover gold and gold pyrites contained **in tailings from primary plants** (“scavenger”). In this manner, remnant values can be recovered to a maximum degree, avoiding also environmental contamination with pyrite. Furthermore, tailings are de-slimed and can be detained in sedimentation pits (with or without the use of flocculants) depending on the particular case, thus avoiding river contamination. Should there be a scarcity of water, this may be re-circulated. The use of spirals in alluvial mining is restricted due to the difficulty of classifying large volumes of material to < 2 mm.

5.4.2.1.6. Centrifugal concentrators

Centrifugal concentrators are the latest innovation to gravity gold concentration. They have gained great acceptance for gravity concentration in large mines; They are employed frequently in grinding circuits to separate gold and avoid over grinding and to recover coarse gold [a] (76) prior to cyaniding and flotation plants. There are also many applications in industrial plants in alluvial mining. A further particular application for centrifugal concentrators is gold recovery as a secondary product; for example, in gravel pits. All centrifugal concentrators operate with the same basic principle: basically a recipient that rotates and separates the feed by gravity.

The most used centrifugal concentrators work on the same principle but differ in their technical design. There are the Knelson, Knudsen and Falcon and other concentrators of local manufacture (especially in Brazil).

There are two principle types of centrifuges:

- Centrifuges without countercurrent water injection (Knudsen, and the continuous Falcon models)
- Centrifuges with countercurrent water injection (Knelson and Falcon discontinuous models).

As an average, the adequate particle size for this process varies between 5µm and 1-4 mm, depending on the type and model of the centrifuge used. Under optimum conditions, centrifuges are able to recover ultra fine gold much better than any other gravity concentration equipment. Below about 30µm (a size range that frequently occurs in milled primary feed) centrifuges are the only really efficient gravity concentration equipment.

Good free gold recovery can be obtained under the following conditions:

- When the feed is classified to well defined limits.
- Few coarse heavy accompanying minerals.

Centrifuges offer security against theft and are significantly labor saving (which may be a disadvantage in small mining). Centrifuges can achieve high ranges of enrichment for possible direct smelting, although frequently other additional equipment for further upgrading of the concentrates is required (e.g. shaking tables). However, in these stages often a part of the recovered (ultra fine) gold is lost again. Therefore, centrifuge concentrates are recommended for direct cyaniding (usually in industrial mines).

The new continuous models (Falcon and Knelson) are very sophisticated and usually not appropriate for non industrial small mining operations.A disadvantage with centrifuges is that the equipment for small gold mining does not work in a truly continuous manner; the operation must be stopped periodically to discharge the concentrate accumulated within the cone. This implies stopping activities for approximately 5 minutes which is possible only when there is a standby machine available. Otherwise, this causes significant losses as the material would have to be diverted during the concentrate discharge.

a In small gold mining, due to limited capacity, jigs give good results in grinding circuits.

The time intervals between discharges must be determined experimentally. Increasing operating time implies elevating the concentrate enrichment factor but reduces total recovery as the fine gold gets progressively lost during the washing. For Falcon and Knelson models, an automatic discharge control is available to avoid manual discharging. This works fine in industrial plants.

Recently, centrifugal concentrators have been developed with semi continuous discharge (the new Falcon and Knelson) but, there is not much information available on their performance in practice.

Advantages

- ✔ Good recovery even of ultra fine and flaky gold (under certain conditions, see above)
- ✔ High capacity
- ✔ Compact equipment
- ✔ High anti theft security

One of the disadvantages of centrifuges with water injection is the high demand of clean water (countercurrent injection water). It has been seen that in many small mining beneficiation plants, it is difficult to provide water in sufficient quantity and constant pressure. In order to obtain the required pressure it is frequently necessary to use a pump, which signifies additional investment. It is possible to recycle water but this requires additional installations for its purification.

Other **problems with centrifuges** are the following:

- **Minimum possibilities of recovering accompanying heavy minerals.** If the centrifugal concentrator is used for pre-concentration (as the only equipment), all or most of the accompanying valuable minerals would be lost. This is the case with primary mines where valuable sulfides exist. In these cases, where centrifuges are used for pre-concentration, gold recovery is diminished as a certain amount of the gold is disseminated in the sulfides.
- **Operation without possibilities of supervision**. The majority of centrifuges in operation are completely closed and problems in their

interior are difficult to detect (in contrast with concentrating tables and spirals). An incorrect adjustment of the centrifugal concentrator (irregular water injection or modified due to a pumping failure) can lead to zero recovery without it being noticed by the operator. In the majority of cases, only when the concentrate recipient is emptied, is it possible to see how successful the operation was.

- **Propensity to operating alterations**. As a result of operating alterations, such as a power cut, the concentrate gathered during hours of operation could be lost in seconds. This does not occur with continuous concentration equipment (tables, spirals), as the concentrate produced is sure, that is, it is gathered in an external recipient. This risk could be reduced by emergency systems (generator, automatic water and feed cut-off valves, etc.). With regards to other factors such as, an interruption in water injection due to strong fluctuations of the same, can lead to large losses in mineral recovery due to the annulment of the separation effect.
- In alluvial mining, feed to the centrifuge must be fairly fine e.g. < 1 mm to obtain good recovery of fine gold. A < 6 mm feed (as described in the Knelson manual) with **the presence of coarse heavy minerals, requires high countercurrent water** injection pressure in order that the accompanying heavy minerals do not get compacted in the cone. **This causes high losses of fine gold**. The high classification requirements are difficult to fulfill in alluvial small mining. Similar problems occur in primary mining with the presence of many heavy sulfides (e.g. Galena).
- Centrifuge concentrators, **cannot be manufactured of good quality in developing countries for technological and patent reasons**. This generates, amongst other things, their high price and **causes repair difficulties and the purchase of spare parts**.

These points of view should be taken into account before purchasing and introducing a centrifugal concentrator. In South America, due to the disadvantages noted above, centrifuges have found little application in gravity concentration in regional small mining. Unfortunately, used centrifuge concentrators of local manufacture are to be found as amalgamators in open circuits (see, sub-title 5.3.2.1.) (77).

5.4.2.1.7. Other equipment for gravity(pre-) concentration.

Detailed below is other gravity concentration equipment that in some regions and with certain gold bearing material has produced good results.

Oscillating sluice boxes (Rockers)

Oscillating sluice boxes or "rockers" serve for the concentration of alluvial gold, particularly in relatively dry areas due to their **low water consumption**. Basically, an oscillating sluice consists of a classifier and a channel. The classifier is a box in the form of a funnel that receives the feed material. From under the box protrudes a channel with riffles and a gradient that varies according to the size of the material being treated.

Clay type feed requires less gradient than is required for coarser material. The entire unit is mounted on semicircular skids (the "rockers"), so that the entire upper section can be rocked with a lever. As the feed and the water have to be introduced by hand, several persons are required to feed the oscillating cradle: one to extract the crude material another to transport the material to the cradle and discharge it in the bin, another to shake the rocker and others to add water (a hose can also be used) (29). The oscillating cradle can process between 3 and 5 m3 of material in a 10 hour shift. The pre-concentrates of the rocker require subsequent separation by panning. Between 3 and 5 m3 of water are consumed during a normal shift. The principle advantages of the rocker are, low water consumption, does not need power and easy local manufacture, all of which make it an adequate portable concentration device (78).

However, normal sluice boxes may also be used with little water with good results, moving (raking) coarse gravel manually through the sluice.

Hydraulic traps

Hydraulic traps are used in alluvial mining to separate out the particles of coarse gold (nuggets, grains etc.) prior to classification in order not to discard them with the coarse material. They are also used in primary mining

a In Colombia, "rockers" are also used by individuals.

directly after the grinding mill. There are several designs that work with an ascending flow of water that maintains the lighter particles in suspension whilst gold sinks and can be extracted continuously or at intervals.

In another type of hydraulic trap, the pulp is introduced through a pipe and is forced to change flow direction a certain number of times before exiting (labyrinth traps). Gold is deposited at the bottom. This type of trap is sometimes found at the discharge end of amalgam plates. When the feed has a wide variation of grain size , these labyrinth traps fill up fairly quickly, they recover very little fine gold and very little "atomized mercury" which is generally discharged to the tailings (see subtitle 5.5.2).

Dry separators

Analogous to mechanical separation in water where this is used as a media separator, similar devices for mineral concentration have been developed that use air instead of water for use in arid regions. The following variations have been made for the following basic types of dry separators:

- **Air sluices "Dry washers"**. With this procedure, the feed passes through a sluice with riffles that has a floor of fine mesh. A bellows located below the device blows air through the bottom of the sluice. The incoming air maintains the particles in a fluidized bed. Due to the inclination of the sluice, the suspended material flows towards the exit of the same, passing over the riffles which retain the heavy particles whilst the tails pass over the riffles and exit the sluice. Air sluices are simple to build. The bellows can be driven manually or with a small (gasoline) motor.

- **Pneumatic tables**. In many arid regions, air or pneumatic tables are employed for processing gold bearing sands. The pneumatic table consists of an oscillating deck covered with porous material over a chamber from which air is blown through the inclined table. Usually heavy material moves up to the top end, while light material flows down.
- **Wind airing**. Also known as air drying is a popular method of dry separation. The feed is dropped through a stream of air that separates the heavy from the light particles as these last have a higher ratio of volume to weight. In its most simple application, the air flow is the wind. Wind airing must be reserved only for fine dry feed and very carefully classified.

- **Wedge sluices**, with pneumatic fluidized beds. The air blows through a cloth deck generating a fluidized bed for the feed material, and separation occurs in a similar manner to that of a hydrodynamic wedge sluice. The wedged sluices are used mainly to obtain pre-concentrates.

All dry gravity concentrating equipment is characterized by excessive dust emissions (the material must be very dry).

Dust emission is least in manual processes (manual dry washers, manual wind), whilst it is most notorious in processes that use ventilators (pneumatic tables, mechanized air sluices). The extreme dust emission in this system is not only a problem for the environment but also to occupational health. It can be minimized by air flow through a closed circuit, with a dust extractor in a dust chamber, or by a wet air scrubber. This however increases operation costs substantially. Recovery, particularly of fine gold, is generally much lower than for equipment that works with water (74).

5.5. Optimization of the amalgamation process

As has been seen previously, in the majority of cases, amalgamation is still indispensable in small mining for gold recovery in gravity concentrates. In the following, there will be no further mention of amalgamation in open circuit (see sub-title 5.3.2.). This is not worth optimizing as it should be simply eliminated. If mention is made here of improving the amalgamation process, it refers to concentrate amalgamation in closed circuit. There are simple alternatives (direct smelting) or more complicated technology (cyaniding, flotation). Whilst direct smelting works only for very high grade concentrates, flotation or cyaniding requires major investment and technical knowledge to be effective, and it is also necessary to control the negative effects on the environment that can be grave.

As it is so difficult to completely avoid amalgamation, it is absolutely necessary to optimize the form and use it is being given. It is justifiable only when the process benefits from all the technical options for recovering mercury and amalgam so that mercury loss is reduced to a minimum.

Amalgamation in open circuit should be avoided at all cost. Amalgamation in-situ, amalgamation in sluices, amalgamation in ball mills, stamp mills, Chilean mills and amalgamation plates in open circuit, should not be tolerated in view of the excessive loss of mercury in the tailings which cause a serious impact on the environment.

This implies that the **only acceptable form of amalgamation is with concentrates**. We have seen that for this purpose, there are several methods used, such as:

- Manual amalgamation
- Amalgamating cones
- Amalgamation drums
- Others

It is important to note that there is no one single method of amalgamation that is adequate for all types of concentrates. This is because the characteristics of gold and the accompanying minerals may differ, and in general require a specially designed and optimized process.

The objective of optimizing the amalgamation process should be:

- Maximum gold recovery
- Minimum mercury loss (especially "floured mercury"[a])
- High degree of safety and low health risks for the operator.

5.5.1. Reduction of "mercury flour "production

"Mercury flour" or ground mercury (atomized), known also as "floured mercury", is the principle form of losing mercury, and this element is emitted to the environment by small mining in addition to the loss of mercury in the burning process and spills. As described above, the first step to reduce these losses is; **not to use mercury in open grinding and concentration circuits.**

a The amalgam floccules, the form in which much mercury is lost, are formed almost exclusively in the open circuit amalgamation process (such as sluices, in-situ mixtures etc.) where there is considerable pulp turbulence. They are aggregates of fine gold particles covered with mercury and joined to each other; they branch out and form floccules with large surface areas but low absolute weight. The formation of amalgam floccules in concentrate amalgamation equipment is rare (e.g. high revolution cement mixers).

The second step towards reducing mercury losses is to optimize the amalgamation process in a closed circuit. Unfortunately, the so called "closed circuit" frequently has mercury leaks or other exits. Generally, the stacking of amalgamation tailings however small, is not adequate and the mercury in these tailings escapes to the environment. In many cases the amalgamation tailings are leached to recover gold remnants and also, sulfide concentrates are roasted for subsequent leaching. During the roasting process, mercury is usually released to the atmosphere. If these amalgamation tailings are leached with cyanide, part of the mercury is dissolved and often discharged with the used cyanide solution into the environment. Although methods exist to clean these tailings and eliminate the contained mercury (see Sub-title 5.5.3.2), it is advisable to follow the principle: avoid contamination rather than cleaning it.

It is important to note, that in each amalgamation process there will be a certain percentage of mercury flouring. This percentage must be reduced.

The formation of mercury flouring is influenced by two factors:

- The mechanical formation of ultra fine mercury pearls (this depends on the amalgamation equipment and the adjustment of operating parameters; such as amalgamation time, etc.).
- Alteration of the mercury surface (this depends on the characteristics of the feed material).

The formation of small mercury pearls during amalgamation is desirable in order to obtain a large mercury surface area for contact with gold particles.

The degree to which grinding or agitation of liquid mercury forms atomized mercury, depends on the mechanical characteristics of the method employed.

Generally, the small spheres join the large spheres. This is the case when the mercury surface is clean. The contamination of mercury alters the surface and leads to an increase in the formation of ultra fine mercury spheres, that is, "mercury flour". Mercury is contaminated during amalgamation in its contact with the pulp. The minerals, metals and substances that lead to the formation of mercury flour are described in sub-title 5.3.1. Mercury flour is generally constituted by very fine mercury balls between 20 and 40μm (see Photo 26).

5.5.1.1. Methods for cleaning and activating mercury

Dirty mercury reacts much less than clean mercury. The latter forms almost perfect globules (almost spherical with an intense metallic brilliance), whilst dirty mercury lacks luster and has deformed globules that tend to adhere slightly to smooth inclined surfaces developing a kind of "tail". The objective of careful mercury handling is: **not to lose any or throw it away, but recycle it**. The great disadvantage of recycled mercury is that normally in each circuit, mercury loses some of its amalgamating power. So, in order to reuse it frequently it must be cleaned.

There are various forms of cleaning and reactivating dirty mercury:

- Squeezing mercury through a very fine cloth (or better through fine leather)[a]
- Washing mercury with wood ash and water, as potassium carbonate helps to saponize the contaminants.
- Washing mercury in water containing detergent or a solution of the juices of some plants that have the property to saponize and dissolve fats and greasy substances.
- Distilling mercury in a retort to leave behind the non volatile contaminants.
- Washing mercury with a reagent such as, lime, dilute nitric acid[b] , etc.
- Adding a sodium amalgam to the mercury which, on making contact with water, produces NaOH and hydrogen that eliminates contaminants (especially oxides) from the mercury surface.

The correct cleaning method for each type of dirty mercury (depending on the type of contaminant) should be determined experimentally (79).

The preparation of sodium amalgam by electrolysis is very simple. It can be done in a plastic recipient with two electrodes (a negative pole: the positive pole at the bottom: seen from above).

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a Squeezed mercury frequently contains fine or dissolved gold. This can be recovered by distilling the mercury in a retort. It is recommended that liquid mercury be placed in a ceramic crucible inside the retort; if not mercury sticks to the sides of the metallic crucible.

b It is recommended to use diluted (8%) acid in order not to dissolve the mercury.

The process is as follows: the dirty mercury is placed in a recipient until it covers the bottom brush (graphite electrode). Then, a 10 to 15% solution of table salt (sodium chloride) is added. Following this, a 12 volt electric current (from a vehicle battery) is connected in such a way, that the positive pole (+) is connected to the upper brush that is in contact with the saline solution; the negative pole (-) must be in contact with the mercury.

In this manner, the sodium ions (Na^+) are discharged on the mercury surface forming sodium amalgam. The positive pole releases chlorine gas in small bubbles with its typical odor. Sufficient concentration is achieved after 10 or 15 minutes. The reactivated mercury has a bright luster. **Only liquid mercury should be reactivated, never mercury slurry**.

> Note: Never allow the positive pole to contact the mercury as the carbon will burn!
> Never interchange the poles, the mercury will be destroyed !
> Never use the activator when there is mercury flour or particles so fine that they may float. The mercury that is not in contact with the negative pole, due to the presence of chlorine gas, will be converted into mercury chloride – a violent poison!

The reactivated can be used for:

- Recover gold by amalgamation. The reactivated mercury traps gold much easier and amalgamates much smaller particles.
- Decrease mercury and amalgam losses. As a result of reactivation, the small mercury pearls join together more rapidly with other trapped mercury particles, which means that less "mercury flour" is formed; and in like manner, amalgam losses are reduced.

- Mercury flour recovered (e.g. by gravity methods) in the form of slurry, can be joined together (liquefy), in some cases by adding a little reactivated mercury.

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a Additionally, the mercury has considerable potential to clean itself. By leaving mercury immersed in water in a jar for a few days, a great part of the impurities rise to the mercury surface. Upon shaking the jar and washing the mercury with clean water, the impurities go into suspension and can easily be eliminated. Repeating this process several times during two or three sessions, a fairly clean mercury is obtained. This process does not eliminate dissolved impurities.

The effect of reactivated mercury is temporary; when in contact with water during amalgamation or when being stored, it slowly loses its action. The high level of activity is only maintained during one or two hours. For this reason it should be used immediately after activating. Unfortunately, activated mercury is sometimes so strong, that it also amalgamates easily with other metals (lead, copper, zinc etc.), thus soiling the mercury even more. This is why it does not give good results with every type of feed material.

The activation equipment (activator) can be easily manufactured with PVC tube and caps and a plastic glue (of two components) using the carbons from used batteries. It is important to use only the carbons (and no metallic part) to make contact with the mercury or the solution.

5.5.1.2. Manual amalgamation

In some cases, manual amalgamation for example in a bucket is sufficient. It is fast, and produces good gold recovery in the form of amalgam. This can be used for some gravity concentrates taking the necessary safety precautions (rubber gloves, immersed in water, a well ventilated locale etc.). For example in alluvial or primary (gold quartz veins without sulfides) mining. It is without doubt the cheapest, and for this reason, frequently the favorite amongst the miners. The advantage of this form of amalgamation is that it can be very well controlled.

The operator can add mercury drop by drop to reach exactly the right amount necessary for amalgamation. This way, the use of mercury is limited. Total gold amalgamation is frequently achieved in 5 minutes. Because of this and the relatively gentle pulp agitation, mercury flouring can be reduced to a minimum (< 0.1% of the mercury used).

Manual amalgamation is not recommended for difficult material (e.g. sulfides), where the operator has to rub the material for hours, by using a heavy stone in an iron pan or in a hollow in another stone. Exposure of the operator to mercury vapor and the generation of mercury flour is high (see subtitle 5.3.2.1.).

5.5.1.3. Amalgam plates

Amalgam plates not recommended in an open circuit, can in some cases be useful for recovering gold from a concentrate. The gold and the mercury surface on the plate must necessarily be very clean because the time of contact with mercury is very short and not very strong. This is why gold recovery from sulfurous material or gold coated with oxides is low. To increase recovery the tailings may be recycled several times. The mercury losses to the tailings are low due to the small quantity of material being processed (the contrary to what they would be in an open circuit). Due to the large surface area, mercury evaporation during the preparation and discharge of the plates has an elevated intoxication risk for the operators.[a]

5.5.1.4. Amalgamating drums

With considerable amounts of material, the use of a mechanical amalgamator is inevitable. There is no doubt that the most used mechanical amalgamators are the amalgamating drums or barrels (see Photos 35, 36). The amalgamating drums or barrels are used to amalgamate concentrates. The main advantage of these drums is that the feed and the mercury are enclosed, there are no pulp leaks or direct participation of the operator in the process. The reactor as such is normally of cylindrical shape with a horizontal axis similar to a ball or rod mill except that it operates with fewer revolutions and is discontinuous. **The objective of the amalgamation drum is not to grind the material during the process. If this were necessary it would have to be done in a prior phase before adding mercury.**

All amalgamation barrels, no matter what type, have the common advantage of preventing the loss of ground metallic mercury (mercury flour) during the amalgamation process as against open circuit amalgamation. Depending on the handling of the amalgamation barrel and of the accompanying minerals, a large percentage of the mercury used can be

a According to information received from a manufacturer of amalgamating plates in Brazil, recent investigation on a pilot scale has shown a new form of application of the same: the mercury in highly contaminated sands ("hot spots") was recovered on amalgam plates (82).

converted into mercury flour. Consequently, barrel amalgamation has to be carried out in such a way that mercury flour production is a minimum.

The feed treated is a high grade concentrate. The drum is loaded with the concentrate and water and approximately twice the quantity of mercury of the estimated gold[a], and some material for friction purposes. It is preferable not to use grinding balls; it has been demonstrated that pieces of thick steel chain give better results and produce less flouring. To avoid mercury contamination with metallic iron, and improve amalgamation, round stones and an interior lining of rubber or plastic is frequently used.

As the drum slowly rotates, its contents are intimately mixed and the gold particles make contact with the mercury and amalgamate. The friction media presses the gold into the mercury, so that even the smallest particles, that might otherwise have escaped amalgamation due to the surface tension of mercury, can also be recovered.

Frequently however, small miners simply load stones into a cement mixer that replaces the “amalgamation drum”. The “Berdan” pan for example, is a slow rotating roller mill with a single ball that follows a circular-oblique trajectory. As the mill rotates, the ball tends to stay at the lowest point. It is rarely found in actual small mining.

If the gold has a coating or covering of some substance (e.g. iron oxide or manganese oxide), amalgamation becomes more difficult. This occurs frequently in alluvial (paleo- canals) or primary mining (oxidized gold bearing materials; gold coming out from a ball mill [a]). When this is the case and depending on the nature of the coating, a previous cleaning phase is necessary (removal) to remove it, either by physical (abrasion) or chemical (dissolving with reagents) means, and generally a combination of both. **In this phase, which is necessary for many types of material, no mercury is added to the drum**.

a Opposed to, for example a hammer mill , where the gold comes out in a short time and fairly clean, gold in ball mills stays in the mill much more time and comes out flattened and sometimes covered with a thin layer of iron coating, which gives the gold a gray-greenish color.

In the majority of cases, concentrates also contains coarse gold (e.g. particles greater than 1 mm [a], that does not require amalgamation as it can be recovered by mechanical means (sieving, panning etc.).

Considering the above, the complete drum amalgamation process includes the following methodological steps:

- Sieve the concentrate to separate coarse gold.
- Wash the concentrate to eliminate barren slimes.
- First step: cleaning of the concentrate (if necessary)
- A first cleaning stage, for which the drum or recipient is loaded with concentrate, sufficient water and different additives (detergent, lime etc.) to facilitate the removal of the coating that may inhibit amalgamation [b].
- Add fresh water to attain a dense pulp.∑ Once the drum is hermetically sealed, rotate for an hour (sometimes it may require more time). Stop the equipment and allow it to decant for a moment and carefully remove the dirty water.
- Add fresh water to obtain a dense pulp.

- Second step: amalgamation
- Add mercury in the minimum amount necessary. Any excess will only contribute to its atomization and consequent loss in the form of mercury flour. In general, it is better to produce a dry amalgam. If necessary add some kind of helper (salt, sugar, lime etc.).
- Close the drum hermetically and start it. With sulfurous material, an hour is usually required. Sometimes, depending on the material, more time is required. Clean alluvial material sometimes requires only 5 or 10 minutes to amalgamate. To exceed in amalgamation time results in an increased generation of mercury flour and losses in fine gold trapped within floured mercury.

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a The minimum size of coarse gold that can be separated before amalgamating the concentrate, depends mainly on the accompanying minerals and the shape of the gold: the heavier the accompanying minerals and the flatter the gold, the more difficult it is to recover from the concentrate, for example in a pan, and the coarser gold that is subsequently amalgamated.

b The cleaning stage is only necessary if the gold is dirty, in the case of clean gold, amalgamation will function well without previous cleaning.

- Stop the machine, allow time to decant, proceed with the discharge of the amalgamated material and carefully wash the interior of the drum.
- Proceed with the following step to separate the amalgam and free mercury from the amalgamation tailings (see sub-title 5.5.4).

Reagents for the improvement of amalgamation include: quicklime, sodium hydroxide, sodium amalgam, potassium cyanide, dilute nitric acid, detergents and others[a]. If a method is not available for the subsequent destruction of cyanide (e.g. strong oxidizing agents) in the residual amalgamation waters and tailings, this reagent should not be used. Any acid used must be well diluted otherwise they may dissolve the mercury.

> The type and dose of reagents as also the duration of the cleaning phase and the time of amalgamation should be determined experimentally according to the type of material.

The basic mechanical parameters for the operation of amalgamation drums are: a). The type and quantity of feed material, b). the speed of the drum. The rotation speed for amalgamation is approximately half the speed of a ball mill of the same diameter.

The slow revolutions of the drum help to reduce the generation of floured mercury.

Amalgamation of concentrates rich in sulfides is sometimes optimized successfully by the addition of white quartz sand in the drum. It appears that the sand mechanically cleans the hydrophobic sulfide particles outside of the mercury and cleans their surface.

Never grind and amalgamate at the same time in the drum. This combination of processes that is frequently found in pre-concentrate treatment where there are still interlocked particles, is extremely damaging to the environment as large quantities of mercury flour are generated that stay in the amalgamation tailings.

However, in some cases of drum amalgamation with auxiliary reagents, the expected results are not obtained, especially with primary mine concentrates that contain many antimony, arsenic or bismuth sulfides. In this case, the quantity of sulfides should be reduced by gravity methods to enrich the concentrate and proceed with direct smelting.

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a An excess of detergents results in a high generation of mercury flour

Amalgamation drums can be manufactured locally. The metal mechanical workshops can produce simple drums from large diameter pipes, metal sheets, etc. Many simple amalgamation drums used today are powered by small hydraulic wheels (see Photo 36).

Other types of amalgamators used in Latin America include amalgamation cones with an electric agitator that has a similar appearance to that of the manual bucket amalgamator with a pole to move the pulp (see sub-title 5.3.2.1).

5.5.2. Techniques for mercury recover in an open circuit.

The damage caused to the environment by mercury used in open circuit has been discussed several times. Therefore, the objective of any technological development should be based on offering alternative processing techniques to small miners. Experience in different projects of this type indicates that a complete change in processing techniques is a long process, especially where investment on the part of the miners is involved.

If the use of mercury in an open circuit cannot be avoided in some regions, at least over a short or medium term period, mercury should be more recovered more effectively from the open circuit to reduce the amount emitted. This action should be put into effect in a **medium to short term period**. Fortunately, when the miners agree to accept external technical assistance as a first step, then the second step (eliminate the use of mercury in an open circuit) is easier.

We emphasize once more that the basic rule is: **that prevention should be implemented preferably before cleaning later** It is preferable not to contaminate the tailings during the process than cleaning them later ("end-of-pipe-solution") .

To recover mercury from the tailings discharged from a plant, there are different possible methods:

- **Mercury traps**: hydraulic traps are used to recover mercury from fine grain pulps resulting from the combination of amalgamation and grinding. Although large drops of mercury and pieces of amalgam are easy to recover, mercury flour is recoverable only in small quantities. There are hydraulic labyrinth and water injection traps available.

- **Amalgam plates**: In many primary small mining plants, amalgam plates are used as the only concentration or gold recovery phase, for example, immediately following grinding mills, stamp mills, Chilean or hammer mills, where mercury is added to combine grinding with amalgamation. The amalgam plates require clean mercury, amalgam and gold for recovery. The gold and amalgam particles go to the bottom of the pulp due to their specific gravity, and if they are clean, make contact with the mercury surface of the plate and are trapped, whilst the atomized mercury, dirty mercury and gold and amalgam floccules pass over with out being trapped. The losses of mercury and gold with amalgam plates, depending on the feed material and handling, can be very high.
- **Sluice boxes**: with a textile or carpet lining, if handled carefully (frequent washing) can recover atomized mercury better than traps or amalgam plates. Contrary to the latter, sluices depend only on the specific gravity of mercury, amalgam or gold and not on a clean surface. Though the movement of particles towards the bottom of pulp is similar, the process of adhesion to carpets is not hindered by dirty surfaces.

Sluices can also recover part of the amalgam floccules that pass over the traps and plates.

A project that wishes to quickly improve the environmental situation of a region where open circuit amalgamation is being used, can install sluices with carpets for the tailings of the amalgamation plants to recover some of the mercury/amalgam being lost. In this way, it is possible to demonstrate the high mercury and gold losses that occur in open circuit amalgamation, and the miners are made aware of the need to change their process. This is inexpensive and serves to facilitate an agreement with the miners for substantial changes.

5.5.3. Amalgamation tailings

Amalgamation tailings are always contaminated with mercury in varying quantities. There are two possible actions (apart from the most important, that is to stop **open circuit** amalgamation and to minimize the mercury content in tailings from concentrate amalgamation, see above):

- Stack them in the appropriate manner
- Clean them

Ii t is not possible to apply either of the alternatives in **open circuits** under the present conditions of small mining. The quantity of tailings from a typical primary small mine operation (in Bolivia, a 3’x4’ ball mill, in Brazil and Venezuela, Hammer mills and in Ecuador, Chilean Mills) with an **average capacity of 20 t/d**, over a year sum **6.000 t**. A small **alluvial mine** with for example a 5” gravel pump, moves about **100 m³** of material per day, over a year the tailings sum **30.000 m³**. Although there are forms of cleaning mercury contaminated tailings (see below), it is unlikely that a small mine will carry out this process (this happens only if the tailings are rich enough in gold to be processed a second time).

The construction of a safe contaminated pre-concentrate tailings pond (with HDPE lining over an impermeable clay base) for tailings from open circuit amalgamation, is not affordable by small mining due to its elevated cost. In addition, the management of a tailings pond requires technical knowledge and has many hazards.

For these reasons, and it is worth repeating: Amalgamation should not be carried out in an open circuit.

For the case of amalgamation tailings from concentrates, we must consider other volumes:

Gravity concentrates that are amalgamated in “closed circuits”, are, for an equal mine capacity (20 t/day primary mine and 100 m3/ d for alluvial gravel pump mine), no more than 10-50 kg per day, if the gravity process is carried out correctly (re-cleaning of the pre-concentrates to get a highly enriched concentrate. Cleaner tailings back to feed). The volume accumulated over **a year is 3-15t.** As they are mainly heavy minerals (with an average weight of loose heavy sand of 2-3 t/m3), this is a maximum of about 10 m3 per year. This small quantity of contaminated material can certainly be stacked in a safe or clean manner. It is frequently possible to demonstrate that this material still contains considerable quantities of gold; in this way there is an incentive to stack it in a safe place for future treatment. Thus the possibility of re-treating the material with de-contamination methods in the future is not lost.

5.5.3.1. Deposits for contaminated tailings

There are various forms of stacking contaminated tailings. The appropriate manner depends on the location, the possibilities of obtaining certain materials etc.

For sulfurous gold bearing tailings, which can be sold from time to time to leaching plants, a temporary pond may be built. This is generally a covered well ventilated concrete bowl where the tailings are stored until transported to a leaching plant as bulk material or in bags (it should be mentioned that the same care is also required in the leaching plants [a]).

Tailings contaminated with mercury that cannot be sold as gold bearing byproducts, must be accumulated in appropriate deposits.

The requirements for these are:

- Avoid contact with underground water
- Protection against rain drag
- Protection against wind drag.

The impermeable base and walls can be built with local materials such as clay, bentonite, Kaolin etc. If available, it is recommended that a material with a high content of hydrous ferrous oxide be emplyed (limonite present in laterite soils) due to its high capacity to absorb mercury (80) or, thick plastic (e.g. HDPE) that is easily found where large mines operate. Greater security is obtained by combining both materials.

In the case of primary mines, the tailings can also be re-introduced into the mine in a dry location without air flow towards the work fronts (that remains dry even when pumps are not working).

Another protective measure is to cover the tailings with a layer several centimeters thick of uncontaminated pyrites under a layer of impervious materials (clay etc.). The anaerobic environment induces the stabilization of mercury in the form of cinnabar (HgS) that is scarcely soluble and little toxic (81).

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a To assure correct handling of treated material, it is recommendable that the entire route of the material sold to leaching plants and final reception be verified. The objective should not only be to transfer contamination to another location.

5.5.3.2. Methods for cleaning contaminated tailings

There are various methods for cleaning inorganic materials contaminated with mercury.

- **Gravity methods**: As mentioned before, part of the mercury flour can be recovered using gravity methods (sluices with carpets, concentrating tables, centrifuges, etc.).
- **Amalgamation plates**: If the surface of the contained mercury is not too dirty, part of the mercury can be recovered with amalgamation plates (82) (see sub-title 5.5.2.).

The two methods presented above, will not achieve total cleaning of the tailings. The results depend mainly on the particle size (in the case of gravity equipment – mercury in thick balls is fairly easy to recover) or the particle size and surface conditions of the mercury (in the case of amalgamation plates).

- Thermal methods: Heating the concentrate in a closed recipient to over 400ºC and passing the gas emissions through a filter (preferably of activated carbon). This implies high energy costs and a safe storage of the used filters
- Chemical methods: Leaching with various chemicals. Good results have been obtained over the last few years with “Electro leaching”, using a reagent, NaCl, HCl and direct current to leach the mercury and deposit it over graphite electrodes. In this process, although mercury extraction is good, it requires major investment and very good technical knowledge on the part of the operators (83). It is therefore difficult to apply in non industrial small scale mining. It would probably be applicable in centralized processing facilities.
- Flotation: Flotation of mercury particles with collectors such as Xanthate. The process, although it has given good results in some cases, is not easily manageable and requires major investment and experienced personnel.

This list demonstrates that **the methods for cleaning contaminated concentrates are of limited efficiency, or complicated and costly; for this reason, in the majority of cases in small mining, the most applicable and recommendable action is accumulation in appropriate deposits**.

5.5.4. Techniques for amalgam recovery from a concentrate

After amalgamating a concentrate (in closed circuit), the amalgam and the mercury must be separated from the amalgamation tailings. During this phase of the process, large amounts of (fine) amalgam and mercury may be lost. In order to minimize gold and mercury losses in the tailings, these must be handled carefully and the appropriate equipment must be used.

5.5.4.1. Pan

In the majority of small mining plants this process is carried out with a pan. This is very slow and implies the risk of theft. Also, depending on the ability of the operator, mercury and amalgam losses may still be high.

5.5.4.2. Hydro separator (elutriation)

The hydro separator is a simple apparatus for the separation of amalgam from black sands and pyrites after gold amalgamation (see Photo 37).

Its advantages are:

- Fast and safe process
- Good recovery
- Simple operation
- Does not require a motor (but yes, at least 5 m of water pressure)
- Low cost

The hydro separator separates particles by their difference in specific gravity; separates amalgam and mercury from amalgamation tailings (pyrites and black sands) in a column of ascending water by a counter current fed with the solids.

The pyrites and/or black sands of less weight are elevated by the ascending water column and exit over the edge of the separation funnel and collected in the receiving collar; then emptied into an external recipient (bucket).

The amalgam, the mercury and any free gold, sink due to their high specific gravity and go to the amalgam collector which can be withdrawn easily from the separation tube after terminating the process.

The ascending force of the water can be regulated by the inlet valve.

VALVE MORE OPEN RESULTS IN:	VALVE LESS OPEN RESULTS IN:
• Major flow of ascending water • Faster separation • Exit of thicker particles • Possible loss of fine amalgam and mercury • Cleaner amalgam recovered	• Less flow of ascending water • Slower separation • Exit of finer particles • Improved recovery of amalgam and mercury (atomized) • Amalgam recovered with pyrite and/or coarse sand impurities.

To obtain efficient separation, it is recommended that the material be sieved (classified) to avoid the entry of pyrites and/or black sands larger than 2 mm that are difficult to suspend and eliminate with a reduced water flow. The coarse grains can be treated separately by panning. If the coarse grains are not eliminated, these will sink together with the amalgam to the bottom of the collector recipient.

It is necessary to feed the hydraulic separator continuously with a constant volume of material.

The ascending water current should be regulated to a degree that the pyrite and/or black sands are eliminated slowly.

In order to assure good amalgam recovery, the process can be repeated as many times as necessary with less water pressure until a good separation is achieved or, install 2 or 3 separators in series to facilitate recycling. It is recommendable to pass the discharge of the separator over a carpet sluice where fine amalgam and mercury is recovered.

Once the feed material is finished, the valve is closed and the amalgam recipient is withdrawn. Normally, the product is not totally clean and continues to have particles of coarse heavy minerals that can be eliminated with a pan.

The hydro separator can easily be made in local workshops.

5.5.4.3. Mechanical pan

The mechanical pan is another piece of equipment for the separation of mercury and amalgam from the amalgamation tailings. It consists of a dish with spiral grooves and rotates powered by a small motor. The material is fed to the dish and water is added by a jet. The amalgam travels along the grooves to the center of the dish and then passes through a central tube and is recovered in a recipient, whilst the tailings exit the dish over the lower border (see Photo 38).

The mechanical pan is slower than the hydro separator but functions better where there are coarse or heavy accompanying minerals (arsenopyrite, casiterite, etc.). It can be manufactured in local workshops.

5.5.4.4. Other equipment for separating amalgam from amalgamation tailings.

A combination of locally fabricated amalgamation drums and metal sluices with metal riffles for recovering amalgam are frequently found. These last are vibrated by a mechanism coupled to the drum motor. The results for recovering amalgam and liquid mercury are good as the system permits the union of the mercury pearls; recovery of mercury flour is low.

Frequently, the miners separate amalgam from tailings by rustic “elutriation methods”. The mixture of amalgam with black sands or sulfides are fed to a pan or bucket that is paced inside a larger recipient together with a stream of water; the amalgam stays in the first pan and the heavy minerals spill over the sides into the larger recipient. The recovery after several repetitions is quite acceptable.

It is worth repeating, that it is not possible to recover all the floured mercury in the tailings with any of the methods mentioned before. The tailings always have a lower or higher degree of mercury contamination.

5.5.5. Techniques for the separation of gold and mercury amalgams.

The separation of gold and mercury to obtain a final product is generally the last step taken by miners before selling their gold. Contrary to the mercury emissions from its use in an open circuit – which generally has little effect on the miners – the emissions produced in this step of the process ("burning the amalgam" [a]) constitute – apart from a negative environmental impact – a high risk to the health of the operators who inhale the mercury vapors.

5.5.5.1. Retorts for mercury distillation

A retort is a recipient similar to a crucible but with a mechanism to open and close it and an exit tube from the top (lid) with an elbow bend directed down similar to a condensation tube. This serves to distil the amalgam and recover the condensed mercury.

The simplest type of condenser consists of a straight tube wrapped with wet rags. More elaborate designs have a water jacket or even a countercurrent cooler with water in an open or closed circuit as the cooler. When separated the amalgam enters a crucible; this can be wrapped in paper and its ashes form an intermediate non adhesive coat between the gold and the walls of the retort.

Better results are obtained by applying a thin layer of lime, chalk or talc to the interior of the crucible before discharging the amalgam which avoids the gold ahering to the bottom and walls of the retort after distillation (greasy material should never be used as it will evaporate together with the mercury and deactivate the surface for further use in the process). Following this, the crucible is closed and heated to raise the temperature to approximately 400ºC at which point mercury evaporates. As the vapor passes through the condenser, the mercury vapor condenses in the tube and drips into a bowl with water.

a Although "burning" amalgam is expressed, this is not true burning. It is in effect mercury evaporation in the form of metallic vapor (not oxides) by heating.

The water prevents further evaporation. The best result is obtained by attaching a transparent plastic jacket to the end of the tube, hermetically sealed with a rubber band and immersed in the recipient with water. In this manner, the “crucible-cooler-wrapping” system is totally closed and even minimum mercury leaks are avoided. The retorts should be heated in such a manner that the heat is applied to all sides including the exit tube.

Otherwise, some mercury may condensate before reaching the condenser; in which case it would return to the crucible and be redistilled.

In any case, once the heat has been removed, care should be taken that the cooling that follows does not attract water into the crucible. If this should happen, the still hot crucible could explode as a result of instantaneous water evaporation. This risk can be avoided by: a). the terminal point of the condenser tube should be exactly over the water in the recipient and b). using the plastic jacket mentioned above.

The retorts can be manufactured locally at low cost with few problems or difficulties if care is taken to respect certain basic design details (see Photo 41). First, the mercury condensation area should be kept as small as possible to minimize losses from the adhesion of fine mercury droplets on the inside walls of the retort. For example, the cooling tube should be of small diameter and made from iron or, better, stainless steel as zinc or copper plate would amalgamate with the mercury. The interior of the tube should be smooth so as not to hold back the mercury flow. Despite these precautions, some fine mercury balls may stay in the retort which must be washed in order to recover them.

The closure of the retort is another critical detail. Whatever the type of retort used, the most important detail is the hermetical closure. If it seen that a retort has a leak, it should first try to be repaired mechanically (filing, sandpapering etc.); if this does not result, a wet mixture of clay and ash can be applied (before distillation). The clay should not be coarse grained.

The simplest retorts made from commercial pipe accessories, couplings and pipe sections, have certain disadvantages with regards to ease of handling. This type of rustic retort tends to develop leaks.

A retort has several disadvantages which is why many miners do not like using it (84):

- Using a retort generally takes more time than burning amalgam in the open air.
- The amalgam and gold are not visible during the process, causing susceptibility amongst some of the traditional small miners.
- Depending on the accompanying minerals, the gold processed by the retort sometimes has a grey colored surface. Frequently this is caused by the burning of sulfides trapped in the amalgam[a]. Gold buyers, who always look for a reason to lower the price, pay less for this “dirty” gold.
- Gold from a retort frequently melts partially. The buyers pay a lower price alleging that it could contain black sand or metals such as copper. Additionally, small miners are accustomed to distributing the gold amongst themselves after burning the amalgam. This becomes difficult when the gold is smelted.

Generally, the miners prefer new mercury and consider mercury recovered by distillation or other processes as being “tired” or “exhausted”. They are afraid they will lose gold by using recycled mercury because they are unaware of the techniques for cleaning contaminated mercury. These techniques should be included in a campaign diffusing the use of retorts.

5.5.5.2. Dissolving in nitric acid

Dissolving mercury with nitric acid could be a viable alternative for gold-mercury separation, providing that the mercury is recovered later from the residual solution by cementation.

The dissolution reaction is as follows (85):

$$6Hg + 8HNO_3 \Rightarrow 3Hg_2 (NO3)_2 + 2NO_2 + 4H_2O \qquad \text{(low temperatura),}$$

or

$$3Hg + 8HNO_3 \Rightarrow 3Hg (NO_3)_2 + 2NO + 4H_2O \qquad \text{(heated solution)}$$

a Jim Hollaway of Zimbabwe informed us that bone ash (mainly calcium triphosphate), for cupels in fire assays (that consists of the same material) are strong absorbents for impurities. For this reason he recommends placing the gold in the retort over a layer of this material to obtain clean looking gold.

The solution is exothermic and heats rapidly. The gold in the amalgam is not affected by the process.

Once the spongy gold residue has been separated from the dissolved nitrate solution, the mercury can be recovered through an ion exchange with copper or other non precious metals, producing a copper nitrate or a nitrate of other metals. Cementation with copper permits over 98% mercury recovery from the solution and produces liquid mercury. Cementation with iron yields almost 100% mercury recovery, but produces mercury in the form of a sludge that then needs to be distilled with a retort to obtain liquid mercury (86).

The chemical reaction for cementation of mercury with copper is:

$$HgNO_3 + Cu \Rightarrow Cu\,(NO_3)_2 + Hg$$

The principle problem related to this chemical separation is that the miners in general do not proceed with the last step: mercury precipitation. The highly toxic mercury nitrate, Hg (NO3)2, is generally released directly to the environment. Less toxic, but nevertheless not acceptable, is the emission of copper nitrate. Copper can be precipitated out of the cupriferous solution by using iron wire that leaves a residual solution of iron nitrate that can be neutralized with lime.

Reviewing all the necessary steps, it can be concluded that dissolution with nitric acid is a relatively complex method. **Adequate use, especially in informal mining would therefore appear to be unlikely**.

5.5.5.3. Hood and filter (“large open retorts”)

In larger mines and also in the stores of gold buyers, amalgam burning is carried out under a hood with an electrical fan to suction the mercury vapors. In the majority of cases, the chimney is just outside the building or, in the worst case, inside the same room (see Photo 27). In more sophisticated operations, the air flow enters through a system of filters (e.g. water sprays), where mercury condensation or precipitation occurs.

In Ecuador and Peru, the authors made various attempts to optimize this system. Its main advantages are:

- the handling is exact the same as the traditional burning (using a torch)
- the miners can see the gold while it is burned
- the color of the gold stays clean and bright
- small amounts of amalgam, which in closed retorts are seldom burned because of the relatively long heating time in comparison with the small mass of product, can be treated

Mercury vapor leaks from the hood must be prevented as this means that a relative large quantity of air is sucked in and the mercury vapor is diluted. As a result, the condensation of the vapor to liquid mercury within the cooling tubes (which are several meters long inside a water basin), is not as efficient as in small, closed retorts. Therefore, the mercury recovery is lower than in closed retorts (80-90% instead of plus 98%).

Other disadvantages are the elevated costs and the immobility of the stationary equipment.

Nevertheless, large open retorts are much more easily accepted by the miners than small closed retorts. They have been installed in Southern Peru as centralized facilities in miners villages and have been accepted very well. Their operating costs (maintenance, gasoline for the fan motor) can be easily covered by re-selling the recovered mercury.

This is a typical example of clean technology, but probably only the second best (best would be small closed retorts), but which has been accepted by the miners. Whereas, years of promotion of closed retorts did not have a positive result in the area.

5.6. Alternative processes and methods

The alternative processes are those that **completely obviate the use of mercury**. Until the present, these processes were the last to be considered for the following reasons: there was little receptivity on the part of small miners; their introduction within the margin of small mining projects was difficult and required additional costs, obliging the miners to accept modifications or changes that would only be successful in isolated cases.

5.6.1. Application of cyaniding in small gold mining and its environmental risks

Cyaniding is a technology used since 100 years ago for the recovery of primary gold, particularly in large and medium mining operations. Its use in (informal) small mining is recent.

Because some gold bearing materials (refractory or fine gold) cannot be concentrated satisfactorily by gravity methods, over the last years cyaniding has spread among small gold mining in Andean countries such as, Peru, Chile, Ecuador, Colombia and Venezuela, and also in African countries.Besides the undeniable high recovery advantages of cyaniding when it is used rustically, it can and is causing a serious environmental impact. Cyanide is highly toxic. However, contrary to mercury, cyanide is bio degradable. Described below are some techniques used in artisan cyaniding, its risks and environmental dangers, and some of the possibilities to control or lower environmental impacts.

5.6.1.1. Artisan cyaniding technology

There is a significant difference in the way of employing cyaniding in a controlled an optimized manner and the form it is presently used in small mining. Unfortunately (for the environment), cyaniding as a basic process does not require “advanced technology”. On the contrary it can be employed without experience or ability; this is shown by many examples in practice. What is more, rustic cyaniding requires less technical capacity, and its most rustic forms, even less investment capital than a good gravity plant as we can see by the following examples.

Materials processed

In general, the feed material for cyanide leaching in small mining is the tailings from gravity processes. Production of mineral from veins is very selective, the fresh material that enters a gravity plant is relatively rich, but because of incomplete recovery in gravity processes, the tails of these processes still contain appreciable gold contents. Cyaniding of low grade material is only justified if there are large tonnages.

Generally, the material leached has no prior treatment. If the gold in the tailings is associated with sulfides, and the non sulfurous gangue contains little gold, in some cases the material is enriched by gravity before cyaniding.

By the use of cyaniding it is possible to completely eliminate amalgamation of gold concentrates, by direct smelting the richer concentrates and recover coarse gold. The “seconds” (products with significant gold content) can be cyanided later.

This is the procedure practiced in many large and medium mining operations. Lamentably, in almost all of the small mining operations, concentrates continue to be amalgamated and the amalgamation tailings are cyanided later, thus using two dangerous processes both for the environment and the workers health.

Differing from other countries, in Bolivia, the few small companies that use cyaniding for amalgamation tailings purchased from small mines, normally roast the sulfurous material before cyaniding. The filters used in the roasting process are generally not the most adequate. Consequently, not only the sulfur and arsenic oxide vapors are released to the atmosphere but also the mercury in the concentrates which is sometimes substantial.

Percolation

Percolation leaching is the process most used in small mining (see Photos 12,13.)

The basic technology and details of the process can be found in the corresponding literature (79, 89).

Percolation leaching has the following advantages:

- Simple process
- Low investment
- High operational safety

The disadvantages are:
- Long leaching period
- Less recovery

The low recovery with percolation leaching can improve with the following measures:

- Using cleaner feed material;
- Covering the tanks with a fine mesh cloth to prevent organic material from entering (avoiding consumption of additional oxygen and at the same time protection for fauna).
- Improving solution circulation and as a consequence, oxygen.
- Screening out fine particles (e.g. with a hydraulic classifier) that can be leached separately by agitation.
- When precipitating with zinc, improve the air seal or create a vacuum (water jet pump);
- Generally improve control of the process.

Additionally, a high consumption of reagents can be controlled by improving general control of the process. It is almost impossible to effectively separate the cyanides (substances that consume or attach cyanide and hinder the leaching process) without employing for example, flotation for preliminary enrichment of the gold bearing minerals.

Agitation

The material is leached in agitation tanks adding air and/or oxygen. Faster and more effective dissolution is achieved.

This technology has definitely higher investment and operating costs than percolation.

For this reason, agitation leaching is not yet common in some regions. In some places it is used especially for leaching high grade concentrates (e.g. amalgamation residues).

5.6.1.2. Environmental impacts due to cyaniding

Environmental impacts caused by cyaniding in small mining are the following:

- Emissions from inadequate storage of leach tailings contaminated with cyanide and heavy metals that in many cases contain sulfides.

- Emissions of exhausted solutions containing cyanide and heavy metals
- Heavy metals dust and gas emissions during roasting and smelting of precipitates.
- Nitrous and nitric gas emissions from Dore refining with nitric acid.
- Heavy metal emissions during the discard of acids used in refining.

Heavy metal contents in tailings and spent solutions are directly related to the mineralogical composition of the feed material. The heavy metals that contaminate solutions can originate from the following sources (Table 18):

TABLE 18

SOURCES OF HEAVY METALS IN CYANIDE LEACH SOLUTIONS

Zinc	• Metallic zinc (from the shavings for precipitation) • Partially dissolved zinc minerals (sphalerite, marmatite, smithosonite)
Copper	• Copper minerals (azurite, cuprite, malachite, bornite, etc.)
Arsenic & Antimony	• Sulfides (aresenopyrite, realgar, antimonite etc.) and sulfo salts (enargite, tetrahedrite)
Lead	• Lead salts additives to improve process, lead minerals.
Iron	• Metallic iron has little or no toxic effects neither some of its oxide minerals such as Limonite. Amongst the sulfides, pyrite, marcasite and pyrrhotite partially dissolve forming Ferro – cyanides; of the three, pyrite is the most stable and pyrrhotite the most soluble. A high pyrrhotite content causes high cyanide consumption.

It is known that many operations work with high pyrite minerals without any pre-treatment, confirming the low cyanide affinity of pyrite. However, many other types of sulfides make cyaniding quite complicated. Detailed recommendations for handling this type of material are to be found in the corresponding literature (79, 90).

Dissolved lead salts assist the leaching and precipitation process; for this reason they are added carefully in many gold leaching plants.

Although it is true that solution regeneration is possible, this requires substantial technical resources and security measures. At this time, only large scale operations apply this process.

It makes absolutely no sense to combine amalgamation and cyaniding. If cyaniding is the second processing step, coarse gold can first efficiently be recovered by gravity concentration and directly melted. If in the gravity concentration step some fine gold is lost, it will be recovered in the later cyaniding step.

Unfortunately, in many cases, the owners of the gravity/amalgamation plants are not the owners of the cyaniding plants (like in Venezuela, Peru). So the ore is first treated by amalgamation and the (contaminated) tailings of this process are then sold to leaching plants. Or, like in Ecuador, the miners rent the mill (gravity/amalgamation) plant from the mill owner and he keeps the tailings as payment, which he treats later in his cyaniding plant. In all of these cases, where amalgamation and cyaniding are made by different actors, we have two environmental problems instead of one.

Where cyaniding is used, amalgamation is not necessary and should be stopped. This is only possible where the whole process is under one management, e.g. where the miners have their own complete processing plants. If they are not owners of the mill tailings or where they don't have their own cyaniding plant and they sell their tailings to another, it will be difficult to convince them to stop amalgamation, because then, their recovery , depending on the nature of their material and the quality of their gravity concentration, will be possibly less.

5.6.2. Flotation

In flotation, advantage is taken of the different physical – chemical characteristics of mineral surfaces, to separate some minerals in a fine grained pulp where they become hydrophobic after adding certain reagents (collectors and activators).

The hydrophobic particles attach to air bubbles that are injected into the tank containing the pulp (flotation cell) and rise to the surface where they float in the form of a froth which is taken out. Thanks to the variations in the pH of the pulp and the reagents added, different minerals can be selectively recovered.

Flotation is rarely used in gold mining for the purpose of recovering only gold, but it is used more frequently to recover gold bearing pyrites together with free gold ("bulk flotation"). There are several types of flotation cells used in which pulp agitation is combined with aeration. **In many cases it has been shown that flotation can separate free gold from sulfide concentrates, thus replacing amalgamation** (91). This functions only for limited particle sizes as coarser gold due to its mass, does not float easily. It is also difficult to float ultra fine particles. However with the appropriate grain size (approximately 100 to 20μm), the separation of gold and sulfides can function.

Flotation involves other environmental problems because it is necessary to use several reagents, particularly lime to regulate the pH, and collectors (xanthates), frothing agents and others, as in the case of selective gold flotation where cyanides or chromates are used to depress pyrite. Generally, small mines do not have the knowledge or the funds necessary to control these reagents that are subsequently discharged into the rivers. Additionally, the flotation process because of its complicated operation (pH control, reagent dosage, conditioning times etc.), requires a certain degree of technical knowledge which is rarely found amongst non industrial small miners (see Photo 10). Because of this, flotation is restricted (with rare exceptions) to industrial mining operations.

5.6.3. Other technical alternatives

5.6.3.1. Magnetic separation

In alluvial or primary deposits with oxidized gold (e.g. the superficial parts of sulfurous gold veins), magnetic separation may be applied to black sands or some iron oxides. Strong and permanent magnets such as those in loud speakers work very well with magnetite. These magnets are placed in a plastic or cardboard recipient which is then passed over the particles to be separated.

In this way, the magnetic particles are attracted to the exterior wall of the recipient. The magnetic material is transferred to another recipient, the magnet is withdrawn and the particles fall. By repeating this process several times, the efficiency of magnetic separation improves significantly. If all the accompanying minerals are highly magnetic (e.g. magnetite), it is possible to obtain a high grade of gold concentration without the need to amalgamate, which can be sold or smelted directly.

There are also high intensity magnetic separators that can separate ilmenite, hematite, garnet, tourmaline etc. from gold. New development in high intensity magnets (of rare earths) at relatively low cost, have now lead to high intensity permanent magnetic separators (“high intensity roll separators”), which are within reach of small mining.

5.6.3.2 Separation by smelting (direct smelting)

To avoid amalgamation, in some cases direct smelting of concentrates is applied. The gold concentration required (>30% Au) is achieved by gravity concentration methods (shaking tables, centrifuges etc.) sometimes combined with magnetic separation. To obtain a very high grade concentrate, losses have to be accepted especially with fine gold. This is the lesser problem in operations that involve gravity concentration followed by tailing cyaniding.

Gold separation from heavy minerals or to clean gold obtained from amalgamation/leaching operations is achieved by placing the concentrate in a crucible with borax and other fluidizing agents and heating to 1200ºC. Oxides such as limonite, ilmenite etc., melt and form a solid-liquid system in which liquid gold goes to the bottom of the crucible beneath the slag. The following materials may be used to form slag and to fluidize: Quartz, lass, borax, manganese dioxide, bicarbonate of soda, potash, ammonium chloride, saltpeter, fluorite and cryolite. The selection of the reagent to form slag and improve fusion depends on the mineral composition of the concentrate. Even the election of the type of crucible (clay, graphite or ceramic) depends on the nature and composition of the concentrate.

If the smelted pre-concentrate contains high sulfurous components, the result of the smelt could be a system of three segregated components: slag, a matte and the precious metal. Sometimes, a considerable amount of gold is attached to the matte which then has to be leached or sold separately.

Generally, it is advisable to grind the slag and concentrate it by gravity. Frequently, considerable quantities of gold are found in the form of "bubbles" encrusted in the same.

5.6.3.3. Roasting and airing

A concentrate purification technique used frequently by African miners is a combination of roasting and airing. The concentrate is heated to at least 600ºC to disintegrate certain components of heavy mineral sands, such as hematite. Then, after cooling the concentrate, the undesired ashes can be aired out.

5.6.3.4. Separation by blowing

In many very small operations, the gravity concentrates are not composed of large quantities of material. In this case, the concentrates are sometimes dried and the miners separate the heavy minerals by blowing carefully[a]. Depending on the experience of the operator, this method functions fairly well with fine gold. The disadvantage is that the capacity of the process is minimum (92).

5.6.3.5. Selective crushing

Small miners in New Guinea take advantage of the malleability of gold to purify their concentrates. The concentrates are first screened to classify into sizes.

Then, every size of particle is worked separately with a hammer. The blows forge the gold into larger size lamina, whilst the other particles break into smaller pieces as a result of their friability. The material is once again passed through the same screen and this selectively separates the gold from the pulverized concentrate.

5.6.3.6. Ballistic selection

In this process, the “bounce” property of particles is used depending on its hardness or malleability. A hard particle that hits a solid wall, bounces farther than a soft one. This principle can be used to separate gold that is relatively soft, from other minerals or metals.

a The process is used frequently by the “barranquilleros” (freelance panners) in Bolivia. Another process used in the alluvial gold regions in Bolivia is the “inclined rough surface”: when the alluvial gold in the zone is laminated, the accompanying heavy minerals in the concentrate (ilmenite, garnet etc.) are in the form of small balls. By sliding the concentrate very carefully over a flat inclined surface (preferably over sand paper) and agitating the surface with small blows with the hand, the laminated gold is trapped on the rough surface and the heavy minerals slide over the edge.

Small miners in the Colombian Pacific coast region, separate their platinum (PMGs) and gold minerals by placing their concentrates on an enameled sheet which they then hit with a finger. When the sheet is slightly inclined, the PMGs which are harder than gold, jump higher on the sheet and slide down slowly and in this manner separate from the gold.

5.6.3.7. Carbon-gold agglomeration

Carbon-gold agglomeration is a process that utilizes the surface characteristics of natural gold, hydrophobic and oleophylic (when clean). Its surface can be easily covered by an oil coating (e.g. diesel) and agglomerated with another oleophylic material, in this case carbon, and separate the other minerals by flotation. To increase the hydrophobic condition of the gold surface, flotation reagents (xanthates) are employed. The process, developed by BP Great Britain, requires experienced operators and has not yet been diffused in small mining (93).

5.6.3.8. Gold-Paraffin process

A new process and similar to gold-carbon agglomeration is the gold-paraffin process. Here also, the hydrophobic nature of the gold surface is utilized and reinforced by flotation collectors to combine it with paraffin and subsequently separate it from the other minerals. As this process is new, it requires further investigation to be optimized and apply it in practice (94).

5.6.3.9. Sulfide dissolution with nitric acid

To avoid amalgamating a highly enriched concentrate and when there are no possibilities to smelt it directly, in some cases, nitric acid is used to dissolve pyrites and recover the gold. This process emits great quantities of nitrous gas (especially when using concentrated acid) and puts the operators at risk (see Photo 42). However, filters could be built (of charcoal, water showers with lime etc.) to filter the gasses. The process functions with some sulfides but not with black sands. The residual solutions may contain high concentrations of heavy metals. For this reason **the process is not recommendable**.

5.7. Selection of possible solutions

For a project dedicated to technology transfer to be successful, the correct and appropriate selection of technical solutions to be applied and diffused is decisive. In many cases the object group have preconceived ideas and preferences with regards to advisory personnel and/or idealizations of the counterpart, based on subjective criteria that are frequently antagonist

On the other hand, through wide experience in development projects and the application of technologies, it has been possible to identify factors and criteria that determine acceptance and the economic and environmental effects of the application of these technical innovations.

The techniques to be applied should not be selected only for their technical merits. Specifically, the social-economic and social-cultural backgrounds of the miners, and the local and regional infrastructure of the zone, should be integrated in the planning. This includes particularly, the possibilities of local equipment manufacture. The majority of the equipment required for the techniques employed in small mining, should and can be produced in national, regional and local factories (see Photo 58).

The workshops or small equipment manufacturers are able to:

- Deliver the product quickly and at less cost
- Satisfy the client's needs with precision and flexibility
- Reduce necessary maintenance and repair time

Small workshops and medium sized manufacturers in particular, can make a profit producing machinery and offer payment terms to small mining and as a result, diversify their product lines especially when:

- Competitive products are not available in the local market, and
- If the local mining and processing equipment market is protected against imports by import taxes, scarce foreign interchange and high transport costs.

Before selecting a specific technique, the traditional techniques used by small miners should be examined carefully. **In any case, it is important to take into account that in the majority of situations, it is better to optimize a known technique and improve its operation than to introduce a new one**.

Small miners in general are very reticent in regards to technology unknown to them. An optimum technical package can fail because the miners reject it. Consequently, an analysis of this acceptance should form part of any technical project plan. **Experience has shown on many occasions that improvement on known existing technology has a better chance of being employed and diffused than new techniques unknown to the miners** (95).

After selecting a technique, it should be carefully examined through extensive field tests. Only when there is absolute certainty that the technique to be applied is perfectly operational, should it be presented to the miners. By anticipating the application, it could provoke rejection on the part of the miners if it does not function satisfactorily. By such an action, a long process of convincing and conscienciation may be ruined. Once again, it is essential to proceed with calm and caution when dealing with small miners.

Based on these considerations, that many times have unconsciously influenced the advisory activity and decision taking, a table has been prepared with criteria that makes decisions more transparent and objective when appropriate technical solutions are sought for mining-environmental projects. The table is presented below (Table 19).

TABLE 19

CRITERIA FOR ASSESING PROPOSALS OF TECHNICAL SOLUTIONS

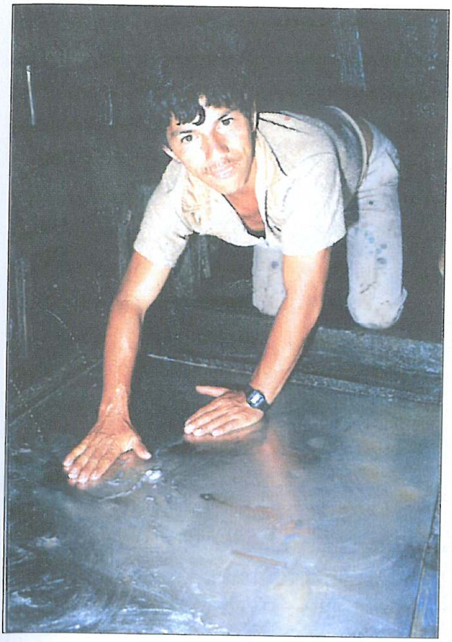
FACTORS	CRITERION FOR THE EVALUATION OF A TECHNICAL SOLUTION
Social and cultural	• Useful for the miners • Is accepted an approved by miners • Tradition in the application of this component in the country (e.g. industrial mining) • Tradition in the use of this equipment by the small miners • Facilitates work • Possibility of observing process (visible, control) • Comprehensible (technically and administratively) • Operative personnel available (in quality and quantity) • Equipment should not interfere with customs, superstitions or beliefs of targeted group • The new process should not require substantial organizational/structural changes, (hierarchy, responsibilities etc.)
Technical -	• Increased yield • Increased recovery • Low investment cost • Low operating costs • Individual equipment should be inter-compatible and with existing equipment.. • Solutions should be able to integrate in the present process • Availability of used equipment in the local markets • Local manufacture is possible • Easy to manage and to maintain • Compatible with available energy sources • Long life
Factors relevant to the environment	• Less environmental impact • High degree of worker safety • When possible, integrated into process, not “end of pipe” • Improved environmental performance obtained by little work and low cost • Application of solution should be within national environmental standards • Application of solution should enable companies to obtain legality and environmental permits. • Lower future environmental costs
Factors related to Strategy of project. **of the project.**	• Necessary for integrated solution (environmental protection, production, Health, energy etc). • Solution contributes to balanced development of men, women in accord with the spirit • Application of the solution should be accompanied by training of the targeted group. • Tests/experiments should be done quickly in order to generate decisions • The target group should participate in selection, experiments and adaptation to solutions. • Solutions should have capacity for diffusion in the area of the project • Miners should previously approve solution concept. • Solution should be compatible with financial possibilities.

It us understood that technical solutions will never simultaneously resolve all requirements. It is important that technical, economic, environmental, cultural and strategy criteria be included in the evaluation. For this reason, the processes selected should be those with the most possibilities of success.

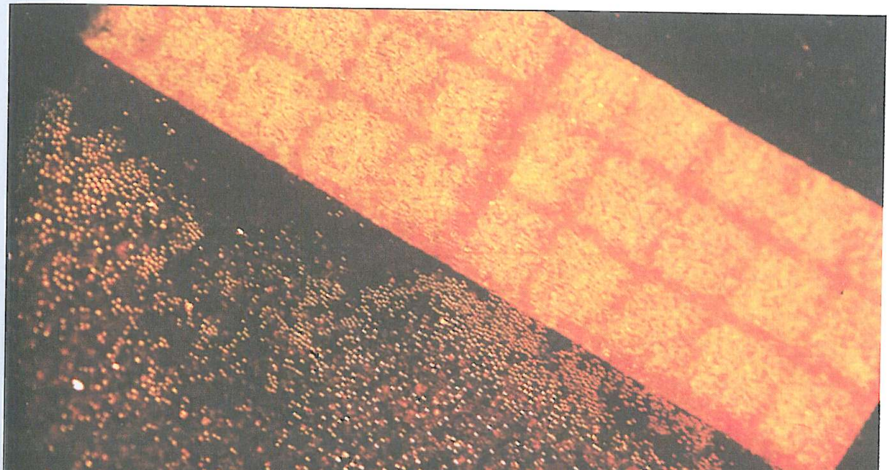
Small mining in general, confronts a situation where technology and environmental problems are characterized by deficient equipment, administrative and organizational deficit, and untrained personnel. Under these circumstances, even small organizational and technical improvements can considerably increase the environmental performance of these companies. This is in view of the precarious situation of the environment and the possibilities available with simple administrative, organizational and technical innovations.

Starting from the little background experience and the administrative innovative principles for small mining with respect to the environment, this contribution can be considered as an objective for international cooperation projects.

The larger the company, the greater the expenditure on environmental measures, the more qualified is the personnel, and the more varied and specialized are the innovations required to increase performance with regards to the environment, and the greater is the material and financial cost to achieve this improvement. In this manner, environmental responsibility is introduced and considered as being a part of the private company and therefore should not be taken into account for international cooperation projects.

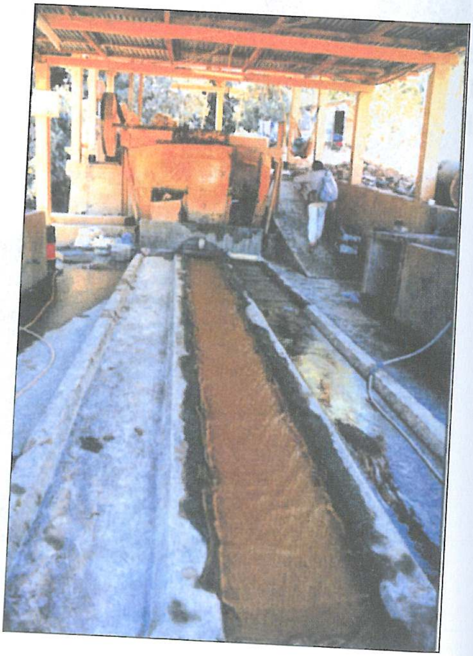


25. Preparation of amalgamation plates (Nariño, Colombia)



26. Floured mercury (graph paper scale)

27. Hood for burning amalgam and gold smelting inside a gold buyer's house (Puerto Maldonado, Peru)



28. Sluice lined with coarse cloth (Zaruma, Ecuador)

29. Caixa (sluice) experimental; high turbulence: traditional, low turbulence: modified (Piririma, Tapajos, Brazil)

30. Cobrinha (small sluice for pre-concentrate enrichment) (Piririma, Tapajos, Brazil)

31. Sluices with different floor linings (carpet, expanded metal) for different grain sizes of material classified by a trommel at the exit of a ball mill ("La Libertad" Cooperative, Bolivia)

32. Concentrating table
("Cotapata" Cooperative, Bolivia)

33. Spiral concentrator with two weeks production of gold bearing pyrites. Previously, these were discharged together with tailings to the river ("Kantuta" Cooperative, Bolivia)

34. Jig "Denver Mineral Jig" type in grinding circuit ("La Suerte" Cooperative, Yani, Bolivia)

35. Amalgamating drum
("Virgen del Rosario" Cooperative, Bolivia)

36. Amalgamation drum coupled to water wheel ("Los Guavos" mine, Nariño, Colombia)

6 Project organization: Methodological aspects

The development of small mining guided towards sustainable development, starting from a complicated situation with respect to technical, organization, administration, social and most of all environmental possibilities, is a possible field for international cooperation projects. These projects have the objective of developing innovative and multidisciplinary focuses in order to adapt them to local situations in such a manner that at a future date, they become stable and capable of achieving the objectives.

The project is temporarily limited and wherein a work group executes certain actions to later carry out a planned objective. When the objective has been achieved, the project should terminate. Sometimes, the work and activities within the project do not correspond with the standard activities of the counterparts. The organizations or institutions involved train themselves in the theme during the course of the project. The jobs developed at the margin of the project – for example, developing sustainable small mining – will later be part of the work of the existing institution or of an institution specifically founded for this objective.

Due to the innovative character of these types of projects, some advice is given in the following chapters regarding the methodological and organizational aspects that influence in the probability of success, just as much as the specialized technical knowledge.

6.1. Planning/preparation phase

Particularly with international cooperation projects, in the strict sense of the word, or those that are resolved on a government level through international agreements, it is indispensable to prepare very detailed planning and equally it is necessary to evaluate all the background, risks and suppositions taken as the basis. **However, further on in the project, the possibility exists (and sometimes the necessity) to vary and adjust the strategy of same**.

For this reason, an orientation phase is frequently established to investigate and correctly appreciate diverse factors such as: political risks, duplicity and conflicts with other strategies, or conflicts of interest within the target group. An orientation phase (normally short), at the same time allows a fairly broad preliminary evaluation to be made of the project and also, how to make an early start with parts of the project that would not be altered by changes in strategy, thus saving time and financial resources.

6.1.1. Planning methods

When planning international cooperation projects, the participation of the mediators, the target group and the beneficiaries is of prime importance. Only in this way can a project "oriented towards demand" be successful. Focusing on "oriented towards offer" is the execution of standardized or planned project packages "in the office", has not produced the expected results in the past. For this reason, donating organizations and the executors of projects have developed instruments that facilitate participative project planning. As an example, we mention here, goal oriented project planning (GOPP) (96). In this case, the following steps are taken:

- Analysis of the persons and institutions involved
- Analysis of the problems
- Definition of the objectives
- Comparison of alternative solutions for the project and finally,
- Preparation of a general mold of project planning

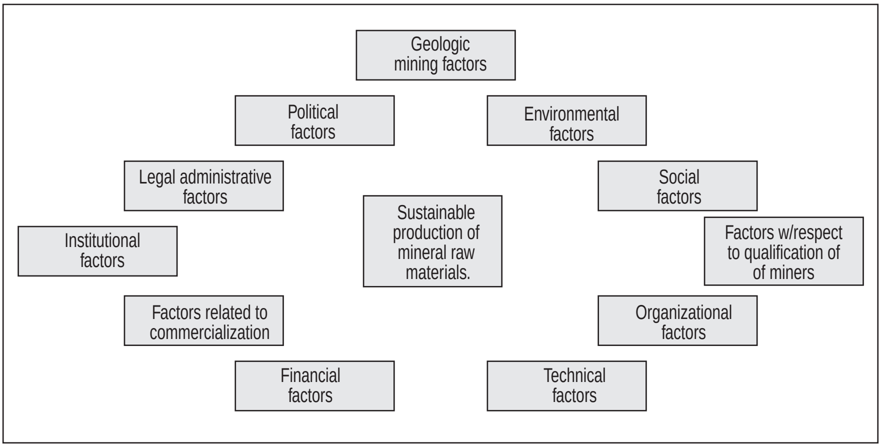
The detailed presentation of these planning instruments is beyond the scope of this publication, but apart from the standard literature on the subject, COSUDE published a comparative resume of planning instruments named "Planning Cooperation" as a work aid (97).

6.1.2. Important general conditions

International cooperation projects are understood to act as catalysts to initiate and reinforce desirable and relevant development processes in the respective countries. The mining sector to be promoted presents a problem as it is surrounded by a complex net of diverse interrelated factors that influence the production of raw materials. A summary of the most important factors for the development of a project are presented in the following Illustration 7.

ILLUSTRATION 7

IMPORTANT GENERAL CONDITIONS FOR THE DEVELOPMENT OF PROJECTS FOR RAW MATERIALS PRODUCTION



In order to make possible the successful application of environmental projects in small mining, requirements for every case are; **basic integrated interdisciplinary focuses** that cover all the sectors involved. One-dimensional strategies, for example those that are limited to technical solutions or, legal-administrative or social, will not be able to generate environmentally compatible mining.

Meanwhile, large scale mining – favored by their international activities – import systems for environmental management, environmental policy standards, etc. (with which, as a consequence, harmonious and homogeneous conditions for the mining and environmental laws) are achieved, whereas with small mining, problems continue to present themselves, strongly determined by the specific situation in each country. This is because, due to their different general conditions at political, institutional, legal and social levels, each country has different policies and methods of handling the respective informal sector. And, for this reason, it is impossible to offer “

Kitchen recipe" type standards for the planning and execution of environmental protection projects on a company level in the informal sector, be it small mining or small industry.

6.1.3. Intervention areas

Due to its nature, the possibilities of exercising influence for problem solving through international cooperation projects vary and are frequently quite limited. Additionally, unfavorable general conditions can be obstacles for the development of a project and even determine the premature withdrawal from a project (killer factor). That is why it is indispensable to make a detailed analysis of these decisive factors from the very beginning of the planning stage by discussing the development and scope of the project. The following tables (Table 20, 21) show some of the possible components of the projects.

TABLE 20

POSSIBLE COMPONENTS OF A MINING-ENVIRONMENTAL PROJECT (98)

FACTORS	POSITIVE INFLUENCE BY INTERVENTION
Geologic	• Compile studies and information • Prospecting and exploration of deposits • Make available information on deposits and prospection results
Environmental	• Use of audits, systems of environmental management • Forming and training in environmental issues • Establish adequate laboratories • Introduce mitigation measures
Social	• Assure employment • Increase labor safety • Coordinate between the diverse interested groups (small mining vs. large scale mining; mining vs. local population etc. • Balance development between men and women (gender aspects) • Introduce sustainable livelihood programs
Qualify personnel	• Increase the educational level by formation and training at all levels (transfer of "know how") practical training programs (training on the job), dual professional formation (at least in medium and large mining, technical schools, university cooperation etc.).
Organizational	• Introduce mechanisms for administrative organization • Apply privatization intentions • Development of cooperatives, associations, unions, chambers, federations etc. • Support formalization and legalization of informal mining companies
Technical	• Technology transfer • Technical improvement of companies. • Support research and technology development. • Create local capability for the production and service of mining equipment.

FACTORS	POSITIVE INFLUENCE BY INTERVENTION
Financial	• Place at disposition adequate financing instruments (Development Banks, Credit cooperatives, equipment leasing "pools" etc.). • Increase profitability of existing companies by advising on, organization, administration and management.
Marketing	• Increase sales prices (e.g. create competition between intermediaries) • Increase exports • Make market research • Deregulate markets
Institutional	• Create and reinforce control and development institutions. • Institutional coordination • Develop offer of demand oriented extension services.
Legal-administrative	• Promote a just and transparent legal system (mining laws, environmental laws, Economic and fiscal laws etc.) also, guidelines, rules for correct application. • Introduce good governance programmes Accelerate administrative processes (concession titles, company permits, EIA approvals etc.). • Create possibilities for legalizing the informal sector.
Policies	• Incentivize adequate structural policies, mining policies, development strategy national and regional development and planning. • Support an increase in the investment climate

TABLE 21

POSSIBLE AVAILABLE SOURCES TO ENCOURAGE ENVIRONMENTAL INNOVATIONS IN SMALL MINING

TYPE OF INCENTIVE	AREA	INSTRUMENTS
Direct incentives	Financial	• **Credit for investment (mining-environmental)** • Rotating funds for environmental investment • **Pre-financing for environmental investment** • Expense coverage for environmental investment
	Material	• **Infrastructure made available** • Equipment rental or leasing • Program of "food for work" (work in exchange for food)
Indirect incentives	Supervision/Tax	• **Tax and royalty reductions and relief** • Exemption of license and concession fees, legal and administrative.
	Legal and administrative	• **Relief from administrative procedures for small mines (e.g. environmental impact studies)** • **Stimulate participation of private investment.**
	Professional support	• **Technical assistance** • **Formation and training** • **Support institutional & organizational structures** • **Support for sales and marketing** • **Pilot tests of environmental technologies** • **Centralized operational materials supply**

The highlighted instruments are the most recommendable.

Not recommendable, particularly in view of the sustainability of the measures is:

- Subsidized purchase price of the product
- Operational subsidies for environmental investment
- Free or subsidized operating materials
- Free or subsidized safety equipment

6.1.4. Target groups

It is most important to address the project to clearly defined target groups. Normally, there are the following two target groups in environmental projects for small mining:

- **The small miners**: direct beneficiaries of the project. The advantage lies in the direct contact without intermediaries, with this target group. On the other hand, working exclusively with the miner's presents a danger with respect to the sustainability of the project once it is finalized if a structure has not been created or reinforced to assume the responsibilities created by the project.
- **The population affected by mine contamination**: normally livestock breeders, farmers or fishermen suffer from contamination produced by small miners. By applying measures to mitigate contamination, these groups are benefited with an improved quality of life due to less contamination.

This second target group is very important to the project due to its capacity to exercise **social control** against contamination that is normally much more efficient than legal control on the part of the government. However, there are mines in such remote areas (e.g. desert areas or tropical forests) that there is no direct contact between those affected down stream and the miners. In these cases, the desired social control is difficult.

In some cases it is possible to apply environmental measures (e.g. settling tanks for sulfurous slurries before reaching irrigation canals) directly by this group. This is interesting if for example, the rivers are contaminated by sulfides from existing or closed mines. The application of measures to recover sulfides in operating mines avoids new contamination, but cannot eliminate existing sulfides in rivers.

6.1.4. Institutions involved

Within the areas of international cooperation in the small mining environmental management sector, it is convenient to develop activities on three levels: macro, meso and micro. This is advisable as in any case an intent should be made to assure work by those responsible for the environmental problems (micro), and through an institution at the meso level with a view to sustainability. Efforts will be made to win government sensitivity (macro level) with regards to the problems of the sector in order to provide advice with respect to possible and reasonable adjustments on a legislative level and on the objectives of local government.

Development of the productive capacity of the counterpart organizations with whom the projects are executed is a key function. Support should be given principally to complementary cooperation between government and private organizations. The ideal in many cases is a combination of government and private counterparts depending on the work to be executed.

A project should adapt itself to special institutional and financial possibilities, and aim towards the systemization effects. Wherever possible, cooperation on a micro level will be interconnected from the start with the meso level. On a macro level, cooperation will be sought by alliances with other development cooperation agencies when specific sector experiences are available. With strategic sectors, a political dialog with the government, the civic organizations and with private economic sectors will be held and encourage conscientious decision making on favorable development conditions.

As a consequence, it would be convenient if a project be planned in such a manner that it can exert influence at the three levels of intervention. The different groups and institutions at these levels are shown in Table 22.

TABLE 22

INTERVENTION LEVELS IN THE MINING AND ENVIRONMENTAL AREAS

MACRO LEVEL (GOVERNMENT, GOVERNMENT INSTITUTIONS)

- Ministry of the environment
- Ministry of Mines
- Government environmental institutions
- Government mining institutions
- Government development banks
- Other international cooperation projects
- Supra regional institutions
- Departmental and Provincial governments
- Municipal governments
- Development institutions

MESO LEVEL (NON GOVERNMENT ORGANIZATIONS, ASSOCIATIONS)

- Chambers of mines, other small mining associations
- Unions
- Training and formation institutes
- Universities
- Research and development institutions
- NGOs and Foundations
- Communal initiatives
- Local politicians
- Private financing institutions

MICRO LEVEL (PRIVATE ECONOMY)

- Enterprises, cooperatives, mining companies.
- Affected population
- Service companies
- Banks

An adequate decision to assure control of execution and inter-institutional coordination, was the formation of two organisms, a board of directors and a technical advisory council (see also chapter 7.1.).

Apart from the person representing the executor of the project, the directors are composed of representatives of the corresponding government institutions and a representative of the financing entity and of the civil population. The board of directors decides the global policy of the project and the assignment of financial resources.

The technical advisory council is composed of all the relevant and inter-disciplinary groups dedicated to the subject, institutions, public entities and individual persons. The advisory council differs from the board of directors inasmuch as that it is an open and advisory group. The scope of the important institutions in this sector is wide as can be appreciated from the above table. The function of the technical council is the interchange of information in a specialized field and to advise on the project execution.

With those institutions that are not formally included in the project, a coordination agreement should be reached at another level.

In the innovative area of environmental management and development of environmental technology in particular, it is advisable to consider including training and research institutions.

Apart from the institutions and groups mentioned, it is also advisable to maintain an intensive interchange with other projects of the same nature in other countries, with other cooperation's and with groups involved in the relevant subject. In this manner, in the case of the mercury problem in small mining, there exists a possibility of coordinating with several or all projects, for example, all the states in the Amazon region.

The selection of counterparts or cooperators on the meso level, in many cases requires a high degree of sensitivity. Frequently, these institutions have developed innovative intervention ideas and concepts, and presented them in the form of projects, sub-projects or project components for projects already in execution to the cooperation agencies. With these proposals, it is necessary to evaluate their convenience and feasibility, the capacity for their execution and also the image of the institution making the application.

If the proposal is convenient and feasible, and if it is presented by an institution that complies with the criteria of a sustainable institution (see subtitle 6.2.5), the risk of its application is minimum. Possible conflicts occur in cases where the proposal requires major adjustments or if the applicant does not comply with sustainability criteria.

- The adjustment of the proposal to the requirements (formal and of content) for cooperation projects, may be considered by the applicant as being a <distortion of it's idea> when clear participative planning procedures are not followed (see sub-title 6.2.6.)
- Even more delicate, is applying proposals with convenient and feasible ideas for the solution of problems pertaining to the target group, presented by institutions that do not satisfy the institutional sustainability requirements:
  - Non application of the proposal is prejudicial for the target group.
  - Applying the proposal on the part of applicant has high risk.
  - Application by other institutions goes against the principles of profes sional ethics and the rights of intellectual property.

The decision to be taken under these circumstances must be evaluated very carefully in order to avoid deep resentment, the creation of enemies and damage to the project image.

6.2. Execution phase

6.2.1. Awareness

As we have already mentioned, prior to any technical application it is necessary that the miners be aware of the environmental problem and that there is an atmosphere of confidence between the miners and the project. An efficient form of creating awareness can be achieved through seminars and workshops to achieve direct contact between those responsible for the project and the target group (see Photo 56). Complementary to these information and awareness events, is the recording and diffusion of didactic videos that makes it easier to “take home” the information presented. Also, these will be diffused amongst their colleagues and family that will show them in their homes (it is assumed that one or two persons in the majority of mining camps have a video player).

Experience has shown that sometimes seminar participants prefer to retain information or they do not find it necessary to reveal it; also, it does happen that they do not know how to transmit it or only transmit part of it. It would seem opportune to prepare information pamphlets, stickers, posters and calendars (appropriately written, as reading is not always a custom).

Without doubt, the most efficient way to diffuse knowledge is by practical and tangible examples. Only in this way can techniques and procedures be divulged in small mining. The seminars, workshops, pamphlets, videos or books prepare the way, they awaken interest and provoke questions; the small miners then find the respective answers in practical demonstrations that form part of the seminars (see Photo 57), but can better be seen at the examples installed in the model mines.

Together with awareness at the level of those responsible for environmental problems, hard work is required at all other levels, such as:

- Members of the family (that in part, play an important role in family decision taking; in many cases, differentiated offers are required for men and women);

- The population in the neighborhood of the project that is frequently affected by the environmental contamination [a];
- Government organisms at different levels, starting with the decentralized administrative units in the rural areas, and up to central government level;
- The population in general through the communications media (press, radio and television).

Awareness amongst the population in general generates, indirectly, an obligation on the part of the miner, as those affected will subsequently demand of mining, adequate environmental management. Creating awareness with the authorities has the same objective with the difference that legal-administrative power permits a high grade of commitment enforcement.

The means for this type of awareness are varied and must adjust to previous requirements and knowledge of the target groups. In the majority of target groups, there is absolute ignorance of the situation and environmental problems. A notorious sub-estimation as also an over-estimation of the real problem can be noted. Knowledge of the real situation is possible only by visits to the region and the presentation of well founded data [b].

In many cases, some forms of presentation such as attending conferences and seminars, can also serve adequately to achieve awareness.

6.2.2. Qualification

One aspect that carries considerable weight in cooperation focused on the transfer of healthy environmental technology is the formation and

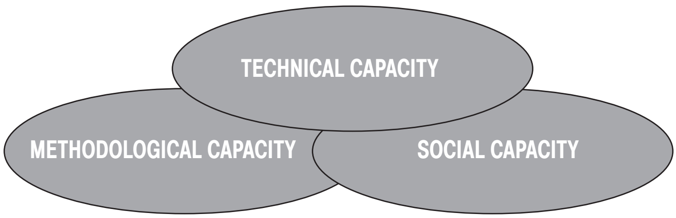
a In those cases where government taxes or environmental laws cannot be put into practice for lack of knowledge or control, the local population and groups with common interests, can exert pressure in good measure on those responsible for environmental problems (social control) especially when there are conflicts over common usage, as for example water for irrigation purposes or human consumption. However, to proceed in this manner can generate distrust with the miners, so actions taken must be very sensitive.

b This should not be the cause for a measure planned as a project be overloaded with environmental analyses, as by experience in these processes, the contaminating components, the quantities of material and those responsible are known. However, this should not exclude monitoring the progress of the project.

qualification of national counterparts and target group personnel [a] (Table 23). Differing from traditional concepts of professional formation, the idea is not to reach a technical level at depth, but to cover and simultaneously connect three areas (Illustration 8):

ILLUSTRATION 8

THE THREE IMPORTANT ASPECTS OF CAPACITATING



By methodological capacity, it is understood that this includes all the skills necessary for problem solving, search of knowledge, application of methods, concepts etc. In addition, by social capacity, all the skills required to jointly participate and cooperate in a project.

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a In the formation and education field, point 34.3 of agenda 21 is predominant:
Formation/education which includes formal formation, the creation of collective conscience and professional formation, can be regarded as a contribution process whereby persons as individuals and as society, can develop their full potential.
Formation is an indispensable requirement for the encouragement of sustainable development for the improvement of the capacity of persons and to confront the problem of development and the environment. Whilst basic education provides the foundations for a formation oriented towards the environmental and development problem, this has to be considered as a fundamental part of the apprenticeship. Both formal and informal formation are indispensable requirements for awareness in persons; so that they can weigh their interests with respect to sustainable development, and can finally take action. Also of vital importance for the creation of an ecological and moral conscience and also values and opinions, is the capacity and behavior that can harmonize with sustained development, so that public opinion participates and takes effective decisions.

TABLE 23

TRAINING OBJECTIVES

ECONOMIC TECHNICAL ENVIRONMENTAL COMPETENCE	COMPETENCE IN METHODS	SOCIAL COMPETENCE
• Good interdisciplinary technical knowledge. • Capacity to estimate social and economic consequences of action taken. • Capacity to estimate ecological consequences of actions. • Capacity to quantify economic implications of the actions (determine costs, profit analysis, feasibility studies etc.	• Analytical mental faculty • Capacity for research and prepare information from primary & secondary sources • Capacity independently acquire and assimilate new knowledge. • Capacity to advise, instruct, train and professional formation. • Capacity to prioritize • Capacity to manage work (structuring etc.) • Capacity to manage resources (time, personnel, funds) • Capacity to work in groups, inclusions and the participation of other groups. • Capacity to evaluate possibilities of future development. • Knowledge of methods for the development of strategies, planning instruments, execution, direction, evaluation (monitoring) • and project adjustment. • Knowledge of presentation, motivation, awareness, moder-ation, communicate and transfer of knowledge. • Management and adjustment of methods instrumented to present necessities.	• Compatible character and social manners , (frank, polite, tolerant, independent, integrity, loyalty, reliability, natural authority, adapt-able, natural auto-con-cious, optimism, willing to learn, oriented toward results). • Capacity to communicate • Capacity to bear conflict and criticism. • Capacity to convince & arrive at consensus. • Sensitivity & comprehend social – cultural conditions. • Disposed to yield/tenacity • Assume responsibilities. • Cooperation capacity • Teamwork capacity. Flexibility, creativity, spirit for innovation and risk. • Interest in continued improvement oriented towards the future.

6.2.3. Diffusion and application of techno-environmental solutions

The diffusion and application of techno-environmental measures is the key part of a project whose objective is to reduce environmental contamination. It is only here that one can see if the awareness and training measures have been appropriate and efficient enough to open the way. **A project is successful only if it has managed to substantially mitigate environmental impacts that will be achieved through the application and mass diffusion of technological changes**.

A project can concentrate its activities in a region (to mitigate environmental impacts caused by small mining in the surrounding region) or on a special impact (e.g. to avoid mercury vapor emissions when burning amalgam). It has been mentioned, that to focus only on one determined environmental problem separated from adjacent problems, is not recommendable, as integral solutions must be sought.

However, the development of complete and integrated systems is complex, requires more personnel (that must also be more capable), more money, and takes much more time. For these reasons, in order to enter, win confidence and get to know the clients, it is sometimes convenient to start with one individual problem (that has a high probability of acceptance and diffusion) and complement it later by relating it with others.

The situations found in mining areas can be differentiated by the following principle characteristics (local conditions) shown in Table 24:

TABLE 24

LOCAL CONDITIONS IN MINING AREAS

Type A:	All mines in the project area, work similar deposits with the same or similar technology, organization and size, with similar environmental impacts (e.g. San Simon, Bolivia; Portovelo-Zaruma, Ecuador).
Type B:	In the project area, there is one type of deposit, but operations differ considerably in technology, organization, size and environmental impacts (magnitude and/or type) (e.g. river Consata, Bolivia).
Type C:	In the project area, there are several types of deposits (e.g. primary, alluvial in terraces, alluvial in riverbeds etc.), but in each type of deposit, technology, organization and size of operation is the same or very similar and in each group, the environmental impacts are similar (e.g. Tapajos, Brazil).
Type D:	In the project area, there are several types of deposits (e.g. primary, alluvial in terraces, alluvial in riverbeds etc.), but in each type of deposit, operations vary considerably in technology, organization, size and in their environmental impacts (e.g. Department of La Paz, Bolivia).

The complexity of the problems and their solutions increase from Types A to D, as the idiosyncrasy of the miners.

In order to plan the technical-environmental measures, it is important to determine the type of local conditions (A-D) where the project is located. For this purpose, it is indispensable to carry out an inventory of the operations. This should collect following information as the most important:

- Location, available infrastructure, access, neighboring communities, climatic information etc.;
- Use of soils (protected areas, community areas, forest reserve etc.);
- Type of deposit, geologic-mineralogical characteristics;
- Mine organization (cooperative, company, partnership etc.;
- Technology employed (production methods, extraction, beneficiation, indicating capacities);
- Environmental impacts;
- Social-economic and cultural data.

Exceptionally, government and non-government organizations (especially sector organizations) have this information. Generally, the project itself has to prepare these inventories. With this basis, it is possible to qualify, quantify and classify the mines, the technology employed and the environmental impacts in the project area, also infrastructure and social-economic conditions of the target group. After this, it is at last possible to establish priorities of the project work with respect to the application of the technical-environmental measures.

The project can concentrate on the most relevant environmental impact in an area, or even better, attack a minor impact where the technical-environmental measures are easier to apply. This last step serves to gain the confidence of the target group and attack the graver problems at a later date. In addition however, in some cases it is better to attack the problem that has greater conflict potential (e.g. confrontation between miners and farmers regarding water contamination). In such a case, there is not only great interest on the part of the authorities to arrive at a solution, but there is also predisposition on the part of the miners to change their processes and avoid problems with their agricultural neighbors (see social control/pressure, sub-title 6.1.4.).

It is unlikely that the project can find known existing solutions to the technical-environmental problems in its area that can be applied directly.

It is also improbable that a project can develop truly new technology. What does exist, is considerable technical information on processes, machinery and methods compiled by different authors (63, 46, 99), and the corresponding technical literature.

The quality of the project executors may be appreciated principally by their capacity to select the technologies to mitigate environmental impacts, that are based on profound technical and social-cultural knowledge, and that can be diffused in the project area.

In order to pre-select technology with a potential for diffusion, they should be evaluated using the list contained in sub-title 5.7. (Table 19). Before any diffusion, **the technical-environmental measures selected, must be adapted and tried jointly with the miners and approved by them**.

Generally, the low cost and simple techniques have much more diffusion potential than high cost and/or complicated methods. It is therefore preferable to use simple technology with high diffusion potential, that possibly will not solve the totality of the problem, rather than to try and impose highly effective technology with a low probability of diffusion.

It is important to count on possibilities to experiment with several techniques and optimize them under real conditions. The so-called "Pilot Mines" serve this purpose. In these, one can investigate the possibilities and limitations of the pre-selected technology under real conditions in the area (not laboratory). It is impossible to anticipate every practical problem beforehand (not always a technical problem). Techniques that in the past seemed efficient or that produced good results in some areas may turn out to be impossible in others. It can happen also, that techniques seemingly of little interest become applicable under certain special conditions of the location. Hence, it is not recommendable to enter a project with a preconceived solution. As an example, the several intents to apply and diffuse centrifugal concentrators –mostly unsuccessfully- seemed to be the only solution for the problem of the use of mercury in small mining (as a single step to obtain a commercial or smelting product). Should the location be in a Type B, C or D area (see Table 24), the project must offer a wide range of feasible techniques to satisfy different necessities at different technology levels and different local conditions.

Normally, neither the authorities of the mining-environmental sector nor the engineers of a country know the idiosyncrasies of the small miners, and even less the international experts. For this reason, the seminars and workshops with the miners and the visits to the mines by the technical group (e.g. whilst conducting the inventory), not only serve to make the project known to the miners, but also for the project to know the miners.

Special attention should be paid to understanding the organization of the mines and groups of miners, the social-economic relations between miners, mine owners, beneficiation plants and equipment, gold buyers, equipment and consumables, sellers and the social-cultural aspects (religion, customs, superstitions etc.). In many cases, these aspects and conditions have more influence on the facility for diffusing technical-environmental measures than on their technical implications. As opposed to technical methods, the social-economic-cultural aspects are much more difficult to change. Although in the majority of cases the miners accept external technical assistance, if a project intents to change their customs, beliefs or established structures, they regard this as interference and lack of respect.

In order that technology changes can function, they require substantial organizational changes (e.g. work organization or responsibilities in a mine), that are much more difficult to achieve than changes in technology that fit into an existing structure.

An aspect that can be observed in almost all small mines, is that the work system established is because one or several of its members have worked in another mine, and in the majority of cases as volunteers before incorporating themselves as <partners> or founder members of a new operation, thanks to the experience acquired previously. This practice permits the identification or classification of the various <original models> of mines or beneficiation plants. All present plants are copies of these "original models" with improvements in very few cases. Even worse and without further reflection, these malfunctioning plants continue to appear. The information on types of equipment and machinery available, its construction, installation and use, continues to be passed on and copied by other operations. In practice, there is not a single technological innovation resulting from a directed demand resulting from "self-capacitation" of miners through books, manuals etc. Unfortunately, there have been too many cases where "occasional engineers", have promised miracles to the miners and have been complete failures, this has generated a natural distrust of “exogenous” technology, and conformity with the known and familiar.

This “auto-diffusion” of home made technology not directed towards the objective of obtaining optimum results, but based on the premise “what functions with others, will also function in my case”, has brought as a consequence, that many of these mines are in a critical technical and economic situation (low recovery and productivity, high operating costs etc.).

There is a lack of predisposition amongst the miners to adapt to new situations, either to those referring to production or to major demands such as protection of the environment. As an example, the reality of alluvial operations is given; as an operation moves further down stream, the gold gets finer but they continue to use the old sluice boxes of the good days when gold was coarse grained. They remain there without knowing what to do and watch a great part of the fine gold returning to the river with the tailings. As they ignore other appropriate techniques to improve their recovery, some start adding mercury to their sluices in the hope of capturing fine gold, but they only achieve contamination of the environment.

The difference in technical levels between different operations in the same region and working the same type of deposit, is not due to different situations that may exist (e.g. geological and mineralogical characteristics of the deposit, available infrastructure etc.), but mainly on the difference of investment capacity of the different groups. Although there are miners who for a long time have been satisfied with their work system and the profits earned, the general tendency is to mechanize and further enlarge their operation to make more profits.

It has been seen that the processes of technological development have always started as “experiments” by individual companies that have tested an innovation with some success, and have achieved technical-economic advantages. Subsequently, these solutions have been copied and applied by neighboring companies. The substitution of stamp mills by Chilean mills in Ecuador and Colombia and the introduction of cyaniding in the northern Andean countries are just two examples that corroborate this means of diffusion.

The diffusion of technology based on “models”, is the mechanism the project can use to transfer clean technology, utilizing the traditional form of diffusing knowledge. As technology cannot be proved in the laboratory, and with reason, nobody would accept a demonstration there as being “authentic” or real; appropriate mines will have to be located that are willing to run the risk of converting to new technologies.

This requires not only the predisposition to assume a risk and to have complete confidence in those cooperating with the development project, but also considerable labor, time, and last but not least, availability of financial resources.

Decision taking is not easy or fast in all mines. In the case of cooperatives or partnerships, where the number of members varies between 20 and over 100 (directly responsible for any decision), it takes some time for clear decisions to be made. This implies a long period of preparation and assigning personnel to the project. Despite all these procedures, a failure cannot be discarded causing an abrupt change of decision (e.g. a sudden change of the cooperative’s directors).

The success of a measure depends principally on the selection of the mine where the new technologies will be applied for the first time. Errors not only cost money, but also above all, much time. A mine selected for “pilot” work must have the following characteristics:

- Good geographic location (center of a mining area).
- Good access (road transit all year, without landslide problems etc.).
- Deposit with potential (reserves) for many years.
- Efficient and functional organization (work sharing, no internal intrigues, no debt problems etc.)
- Willingness to invest human effort and financial resources.
- Good relations with neighboring communities.
- Availability of infrastructure or facilities to incorporate (camp, energy, water, space).
- Sensibility and interest in environmental problems (environmental awareness).
- (“Successful operation”).

There are very few cases that these requirements will be met, but the closer the pilot company gets to this profile, the inherent risks of successful solution diffusion will be less.

The only thing left to define is what is understood by “successful operation”:

The small mines of a region are differentiated by their technological level, however, there are some that stand out and are above average, that is, they have achieved better technical equipping and more refined procedures than their fellow miners have. These "successful operations" stand out from the others by their greater productivity, rigorous organization, higher grade of mechanization, better work conditions, high wages, better living quarters and other factors. In mining circles, they are highly regarded and recognized as a model to be copied. The mines that have reached their present status over the years thanks to hard work, but also luck (good deposits, access to credit etc.) are usually old. They are especially suited to be equipped as model operations. Because they function well, their partners do not have to worry about their daily subsistence and can concentrate on possible improvements, increase production, new acquirements etc. Consequently, in such a case there is a natural predisposition, based on a sense of security, to stop their plant for a few days in order to make modifications, whilst neighboring operations cannot afford this luxury, simply because it means renouncing their daily bread.

The description "successful operation" is in inverted commas because this election is not always advisable. Without doubt, this concept has given good results in some cases. However, in some areas the successful mines are not always the larger and richer, but also the most saturated and sluggish due to their success and high profits. If the projects offer to help and improve technology does not attract interest in one of the successful mines in the district, the project must seek other opportunities for the application of its technical-environmental measures.

A very appropriate objective or argument that suits the case to achieve this opportunity, are mines that wish to improve their production (income) but do not have the technical capacity to do so. In these cases, **the project has the possibility of offering technical assistance with the condition that parallel to this, they will apply environmental measures**. In the case of small primary gold mining in Bolivia, this strategy has functioned very successfully.

For any model mine where technical-environmental measured have been applied to demonstrate the bounties to the other miners, it is indispensable that this mine works under the same conditions as its neighbors, and that no distortions of these conditions are produced due to the presence of the project (e.g. subsidies paid by the project, machinery and processes managed only by the project technical staff etc.).

The measures applied must demonstrate their feasibility and be operated by the miners themselves (after a necessary period for adjustment and training).

One of the important experiences in small mining projects refers to the adequate interpretation of the development strategy. In this case, two separate focuses must be distinguished:

- The broad effect based on reaching the greatest number of beneficiaries or members of target groups simultaneously with a development offer. This naturally implies that fewer funds are available for each individual action.
- Determined development, or pilot type focus. In this manner, the project is limited to few and selected individual measures where the project funds are concentrated.

Experience leads us to believe that it is favorable to apply both criteria for project execution:

- A determined development of the pilot type in a first phase, instead of offering development over a wide spectrum, until diffusible solutions can be found.
- Diffusion and massive application of technical-environmental measures in a second phase.

It is of paramount importance to surpass the "pilot mine" phase and enter the mass diffusion phase within the duration of the project. New technology can only survive when there are sufficient improved operations (much like the minimum population in the case of animal species in danger of extinction). A single pilot mine – due to any problem (legal, the deposit, financial etc.) – can disappear rapidly. Additionally – the objective of a project is generally sustainable mitigation of environmental impacts by small mining in a given area – and this is not achieved through a single pilot mine.

In executed projects, a certain "self diffusion" has been detected of successful measures (especially when the application results in economic advantages). Many times, auto- application has been found to be the greatest success of a project. Unfortunately, the technology package developed by the project runs the risk of being distorted by auto-diffusion:

- Only technologies of economic interest are (self) applied.
- Without technical assistance (advisory and follow up) and without quality control; the same techniques are altered over a time and can lose their effectiveness and lessen their future use.

For this reason, it is indispensable to offer and guarantee a long follow up period of the applied measures. This can be done with the same project or an other if activities are transferred to a sustainable organization (see sub-title 6.2.5.).

A condition of the application phase should be that the miners pay for the measures to be applied. This however, is difficult with pilot or experimental measures. In these cases, it is advisable that the projects finance the applications and sometimes pay the operating costs of these measures during the experimental period (cost sharing for the pilot and/or coverage of "increased costs").

It would seem unlikely that a project of limited duration could change/ improve all the mines within its work area. Nevertheless, the objective should be to improve the greatest number possible. The effort required to change a mine is variable. **A "pilot mine" serves initially to experiment and optimize different technological alternatives, and subsequently become a model for others**. The effort (personnel, time, knowledge, financial etc.) for a pilot mine is considerable and difficult to estimate (due to the insecurity of the technology research). Once adequate solutions have been found they can be applied more easily, cheaper and faster in other mines.

In order to accelerate application and create more "model mines", in some cases the project can lend the machinery or equipment, with the condition that once installed, adjusted and proven by favorable results, the miners will have to pay for these. In this manner, it will be possible to overcome the reserved (distrustful) attitude of many of the miners about investing in new technology. If the number of successful applications increases, the interest and disposition to invest by other miners will also increase. This strategy has given good results in the MEDMIN project in Bolivia. In this case, however, after the miners had paid for the equipment installed, the technical assistance and follow up by the program is still free. The participation of miners in the costs of technical assistance is desirable but not easy to obtain, at least during the phase counting on international financing.

6.2.4. Gender aspects

6.2.4.1. General considerations

The gender aspects are of special importance in the execution of a mining environmental project. The balanced development between men and women is part of the development vision. From an integral outlook of sustained development, economic growth and human development, they are different dimensions but are complementary at the same time.

Equal opportunities for different population groups and the extension of participative democracy are a condition for overcoming poverty. It is in this sense that the development we are trying to support should not only look to elevating environmental and economic indicators, but should also worry about supporting the development of people from different groups and ethnics, and the improvement of the quality of life which will allow us to talk about reinforcing potentials.

A consideration of development actions from the gender[a] point of view, will allow not only the optimization of social and economic investment by taking into account the particular aspects of each group, but it will allow us to advance in the most adequate form in support of an equality process, as a basis for the sustained development of persons in the communities.

On a micro level, the economic and social impacts on the beneficiaries of the project should be emphasized. Consideration of the logic of internal functioning of the productive systems is important for a differentiated support by gender. A proposal for technical changes for example, may implicate changes in the assignment of labor, which could brake or hamper the situation of women, old and young.

A project proposal should incorporate a differentiated situation by gender within the frame of its objectives and subject proposal. This assumes that proposal preparation is the result of a participative planning process together with the population and the presentation of clearly differentiated results by gender.

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a This is, from the perspective of those men and women resulting from social-economic, cultural and historic structures on a biological basis.

At the meso level, when the instruments for application and development promotion are being reinforced, emphasis should be made on supporting actions towards equal opportunities for men and women, with the intention of changing routine institutional schemes. Frequently, work methods, ideologies and intentions confront each other.

At the macro level, exert influence on the surrounding conditions. An effort would be made to actively participate in the political dialog to favor conditions that support legal reforms in, environmental areas, economic, and legal tendencies to reduce the inequality and/or the recognition of rights, in order to support the immediate and concrete advances achieved through the project.

In the selection of work groups, those responsible for the project should place emphasis on contracting female personnel, particularly for directive positions.

In this regard, assistance should be provided to existing female personnel by providing them with information and helping them to attend training/qualification programs (national and foreign).

At the target group activities level, the work of the project team is to find work that includes both men and women during the complete project cycle, develop categories and indicators by gender, monitoring instruments and differentiated evaluation and impact.

In like manner, the job of the same team is to find ways to modify cultural systems and work processes that discriminate gender. Without these changes, concrete advances will not be sustainable with time.

In general, this objective implies the development of more participative methods that recognize and respect differences; search for approaches that are more sensitive to the realities and perspectives of the different participants, local inhabitants and institutional agents.

This sub-title is based on conceptual and strategic guidelines to take into consideration a balanced development of men and women from the COSUDE (100) in Bolivia.

6.2.4.2. Peculiarities of the mining sector

Mining activities are characterized by their high risk: not only for the environment, but particularly for those persons dedicated to underground mineral production. The darkness in the mines, the complexity of geological and geotechnical phenomena, the danger of accidents (falling rock, caving, etc), and the hard physical work, create very particular working conditions.

Taking these circumstances into account, one of the first social achievements of labor movements in the industrialized nations was the prohibition of mining work by women and children. The concept of equal gender development, this protective measure is frequently confused with a form of discrimination.

A further aspect related to the particular mining situation regarding the participation of women, is spiritual. In many cultures, the earth and the entire subterranean environment are related to religious aspects such as the “Pacha Mama” (mother earth) in the Andean Cosmo-vision, comparable to the inferno in the Christian religion, or with multiple other forms of subterranean beings. The presence of women in underground workings according to these beliefs, can annoy these spiritual beings and consequently produce accidents[a]. These beliefs are of a moral character, that in some religions (that give the earth a female status), prohibit “entry” to other members of the female sex[b].

The participation of women in mining activities is frequently found in the final phase of mineral beneficiation (see Photos 47, 48). In many cases this participation is because women are considered as being more meticulous and detailed. In practice, this direct participation allows women to have better control over family income and even “retention at the source” for the family budget and greater independence. There are projects that have failed for not taking into account these factors (101).

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a The personal experience of one of the co-authors has demonstrated that belief in the existence of underground ghosts, has nothing to do with mine technology development: In one of his first practices as a student, he was expelled from a highly mechanized and automated coal mine for having whistled during his work in a mine tunnel, as according to the beliefs of the miners, this provokes rock falls that awaken the ghosts that then emerge violently from the rock. The same effect (wakening the underground beings and causing accidents) is attributed to women when they enter a mine in many mining regions.

b These beliefs exist principally in regions with a long mining history (Europe, Bolivia etc.). It is interesting to note that in countries with a short mining history, women are not excluded from underground work. An example is Venezuela in the famous “Km 88” where men and women work side by side in underground production.

Typically, the less mechanized a small mine, the more equitable is the participation of men and women (not so with industrial mining). In artisan mining "panning" or small sluices, for example in Bolivia amongst the "barranquilleros" (individual panners) that work alluvial deposits or tailings, or the "relaveros" (tailings workers) that pan tin tailings (Bolivia, Thailand, Malaysia etc.) there are men, women and children working together. Another typical women's occupation is to operate the "toloca", or hand operated stone mill in primary gold operations in Bolivia, or the "quimabalete" (a large semicircular rocking mill) in Peru. Generally, the operation of any "machine" in small mining is reserved for the men who consider themselves as being the only ones capable of mastering this work. That this – especially in concentrating work – is not true as is demonstrated by the women that operate concentrating tables in some of the cooperatives tin plants in Bolivia, as they generally pay much more attention and obtain better results than the men.

A series of jobs carried out by women considered as being "inferior work" result from the need to work and take care of the children or feed the baby at the same time. Because of this "double occupation", the women in this situation cannot do mining work that requires total effort. When working as "palliris"[a] (hand pickers) or "barranquilleras", women are accompanied by their children that frequently also work selecting stones containing mineral or washing with small pans (see Photos 49, 50).

The argument that women cannot physically resist hard work is simply not true; this is demonstrated by women miners in Venezuela where they carry sacks with 80 kg. of material equaling their male colleagues.

However, there is work that is not recommendable for women, particularly those jobs that involve working with chemicals that could have negative effects on a fetus. **In small mining, this is particularly applicable to mercury handling**.

Many large scale open pit mines have started to employ women, particularly for the operation of delicate and expensive machinery such

[a] "palliris" are women that select valuable material from mine dumps in Bolivia

as, high tonnage trucks. Statistics show lower repair and maintenance costs and also fewer accidents than their fellow male drivers (102).

Women play a role of special importance in environmental projects. As they are responsible for the health of the family, the possibilities of introducing awareness through arguments and training in the health field are more viable with women than with men. In this manner, women can contribute to social and civic control in mining activities, demanding of the companies or cooperatives, adequate environmental management. The convincing power of women should not be underestimated, as successful awareness programs have been executed based on female characters. With respect to environmental awareness, the “feminine information networks” should be very much taken into account, which although the majority function informally (personal diffusion, “tales”) they are no less efficient than formal diffusion (pamphlets, radio, videos, seminars etc.) generally controlled by men.

In some cases, the absence of direct participation and involvement of women in the mining activity results in an advantage for them. In the case of the Zaruma/Portovello region in Ecuador, it was detected that, amongst other aspects, the economic attraction of mining activities caused many school boys of between 12 – 15 years to abandon school without completing their studies, whilst a great number of girl students entered college and graduated (116).

6.2.5. Institutional sustainability

Organizations and institutions play an important role in the execution of any project. These require above all, support to allow them to fulfill their long term objectives. Apart from technical knowledge, there are also a series of criteria for “adequate” institutions that can be summarized under the term, institutional sustainability. In sub-title 6.1.5, mention is made of the different institutions at different levels (micro, meso and macro) that can participate in the execution of a project.

The foundations for sustainability in the institutional area are defined by the creation and execution of a project. Achievements of sustainable effects in the institutional area go together with a series of aspects that can be differentiated broadly into four groups: administrative, financial, personal and institutional (Table 25).

TABLE 25

IMPORTANT ASPECTS THAT CHARACTERIZE A SUSTAINABLE INSTITUTION

ADMINISTRATIVE	FINANCIAL	PERSONAL	INSTITUTIONAL
• Low bureaucratic level of administration of the operations • Low fixed costs • Professional management of institution. • Clear structural organization, responsibilities known to all. • Decentralized decisions • Democratic admin. • Efficient internal control.	• Self financing capacity • Assets of institution guarantee institutional sustainability • Capacity to raise funds • Capacity to create resources from different sources. • Efficient financial management. • Voluntary internal control and auditing. • Remuneration system, incentives according to operator's performance	• Availability of appropriate human resources for executing necessary work. • High motivation of personnel. • Personnel identified with the institution • Low personnel changes • Capacity to resolve problems. • Take advantage of external know how. • Competent planning • Pragmatic objective achievement. • Professionalism • Possibilities of internal training. • Possibility of external training. • Good relation between financiers and target groups. • Capacity to carry out public relations • No unfair competition between colleagues • Accustomed to team work. • Accustomed to interdisciplinary work • Decision taking independent of external influence.	• Clear vision of institution's mission. • Unmistakable mandate for work execution. • Institutional planning for medium and long term. • Existing demand of institution's services. • • Good public image • Decision takers independent from political or other influence. • Clear organization structures (unequivocal responsibilities). • Know how systemization and documentation. • Comprehensible and repeatable decisions in the future. • Capacity to work in institutional • networks and inter-institutional cooperation (strategic alliances) • Capacity to react to changes in general conditions • Limitation of the tasks to those areas for which there is the nece-ary competence (center of excellence) • Control of efficiency and reverse action in decision processes.

These different aspects are a guide for institutional consolidation and to help judge the existing situation of an institution within the margin of evaluation for example. In the long run, after the period established by external financing, the "sustainable institution" (ex-project) must continue to execute for example, environmental measures with small mining.

6.2.6. Participation

One of the basic principles in environmental protection is consensus. This suggests, that especially with environmental projects – also those with small mining – participation of those groups not formally included in the project should be achieved. The following illustration shows the inclusion of these groups and individuals that should be taken into account in the environmental measures and, the advantages and effects for the project in the social area (Illustration 9):

ILLUSTRATION 9

METHODS AND EFFECTS OF PARTICIPATION IN PROJECTS

Reverse action (stimulating effect for participation in project)

SOCIETY

- Reduction, mitigation, and elimination of differences.
- Creation and mobilization of new cooperation.
- Reduction of conflicts, development and execution of compensation strategies.
- Encourage political and democratic structures.
- Mediate between basic social conditions and new policies.
- Consensus policies.
- Politization
- Encourage competitive initiatives in private economy.
- Reinforce co-management in companies, institutions and in the population.

PROJECT LEVEL

INFORMATION□AWAKEN COOPERATION INTEREST

PARTICIPATIVE WORK IN THE PROJECT

PHASE	METHODS
Planning	• Administrative process during identification and application • Planning Methods • Surveys and interviews
Project execution	• Follow up of the planning methods • Evaluation and control of the project advance • Inter-institutional coordination and cooperation • Participation in project directorate, technical consulting council, also in committees, commissions and technical work groups. • Personal support, material and non-material of basic groups, ONG s etc. • Participation of private investors in sub-projects • Transfer of project services to private companies • Inform public on sub-projects, participation of population, right to protest and petition • Participation of public in ideas and design • Hours for public attention, days with open doors. • Inquests and demoscopy well calculated interviews with marginal actors. • Publication, forums, seminars, workshops, work camps • Participative work on a micro level (determine actions) • Participative concepts for study preparation • Political dialog, round tables • Suggestions service, box for ideas • Evaluation by personnel, short term experts etc.

EFECTS

- Creates majorities
- Makes technical and work dialog more objective
- Amplifies the available know how pool
- Efficiency increase, effectiveness and impact
- Possibility of recognizing and resolving conflicts on time
- Motivation of groups and persons with outside participation
- Diversify services offered
- More actors responsible for the success of project
- Make use of synergy effects
- Avoid work duplication, coincidences and conflicts of objectives

The inclusion of participating groups stands out in the previous illustration whether or not they are formally included in the project, be they government or non-government organizations, private companies or individuals; they can all contribute positively either on a project or social level.

6.2.7. Quality control

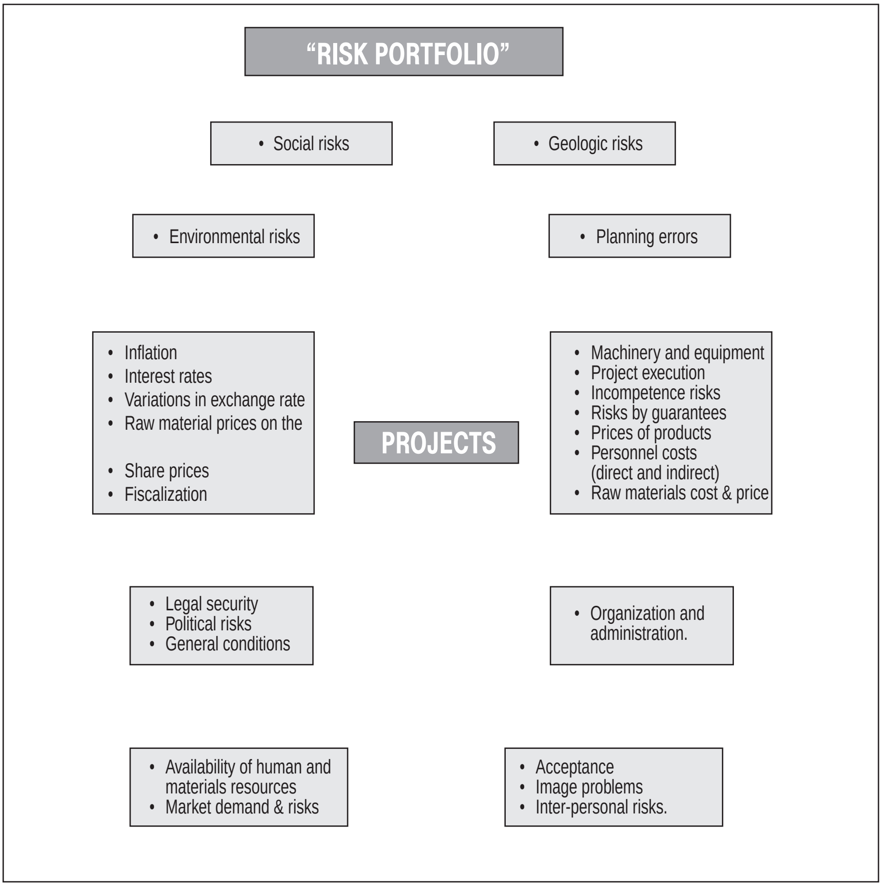
Apart from technical, administrative and organizational requirements, each project needs a quality control system. This is made up of several components that are described in detail in the following paragraph.

6.2.7.1 Risk management

International cooperation projects are exposed, the same as commercial companies, to risks that can endanger the success and sustainability of the project. These risks can be of an objective, external, or internal nature. The following illustration describes these risks (Illustration 10).

ILLUSTRATION 10

“RISK PORTFOLIO” (103)



Due to the enormous amount of risk, international cooperation projects should also apply modern auditing and risk management methods. The scheme shown above (the bases of which were taken from “Risk Management” and adapted to international cooperation projects) in the form of a check list shows the most important risks related to the project. The risks may be external (in the form of natural disasters, inflation etc.) and also internal (such as planning errors or image problems). The early detection of these potential risks and taking preventative measures in the design and execution of the project, help being prepared to flexibly react to altered, changed or deteriorated working conditions.

An adequate measure for the detection of risks on time is to maintain a monitoring system during the project to evaluate sensitive aspects.

Thus, those projects with credit components should consider financial aspects as risk factors.

In order to evaluate risks, it is important that these be arise as a product of the probability of its occurrence and the dimension of the damage. For this reason, risk management within international cooperation projects should be focused on minimizing the probabilities of damage caused by individual risks already identified and make forecasts of the moment that these damages may occur in addition to limiting possible losses.

6.2.7.2. Monitoring and evaluation

Important parts of quality control are, follow up and evaluation, that where possible will detect involuntary changes in the plan on time, and important changes in the basic conditions of the project.

With the follow up, the relevant data regarding the current status of the project or the general situation will be periodically controlled and evaluated. As an example, the data concerning risk management mentioned in the prior illustration. These details permit conclusions to be reached with respect to the changes or discrepancies produced.

To make an evaluation, it is important to be knowledgeable on the aspects to be examined and the dimensions of the corresponding objectives (indicators). The achievements detected in the current situation within the monitoring of the project (described with quantified values), are later compared with the objectives determined.

Three levels are defined on which evaluation is executed:

- Efficiency level, where the financial, material and personal resources are examined to determine if they have been used efficiently.
- Level of effectiveness, where the activities carried out are examined to determine if there has been an effective contribution towards the achievement of the projected results and if it has contributed to the objective of the project.
- The impact level, wherein the project is examined to see if it has had a significant positive impact on population development.

The danger in a schematic evaluation of this kind, is that the planning documents are always used as reference. As a consequence, the adjustments (necessary and flexible) of the project strategy can be evaluated and adapted to changes in conditions such as non-compliance with planning.

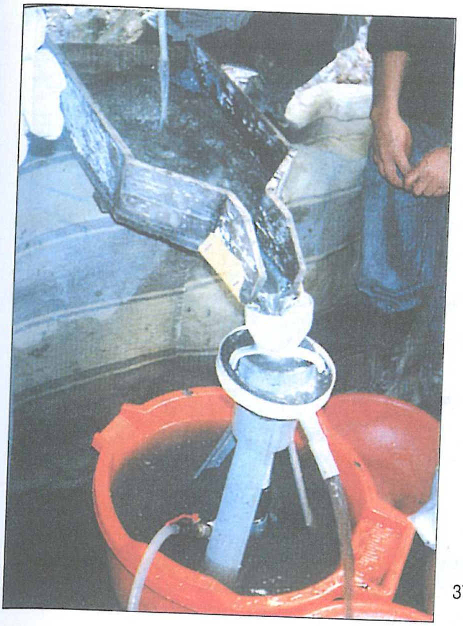
Additionally, the most important administrative jobs in a project are generally not strictly defined on a results level and they are therefore not taken in to consideration. Finally, in the formal control of a project, rarely is the following question asked; “What have we learned in this project?”, thus the opportunity is lost to discover the essence of the work which, as an important experience could also be applied to other projects.

Monitoring and evaluation of this type can be applied both internally and externally.

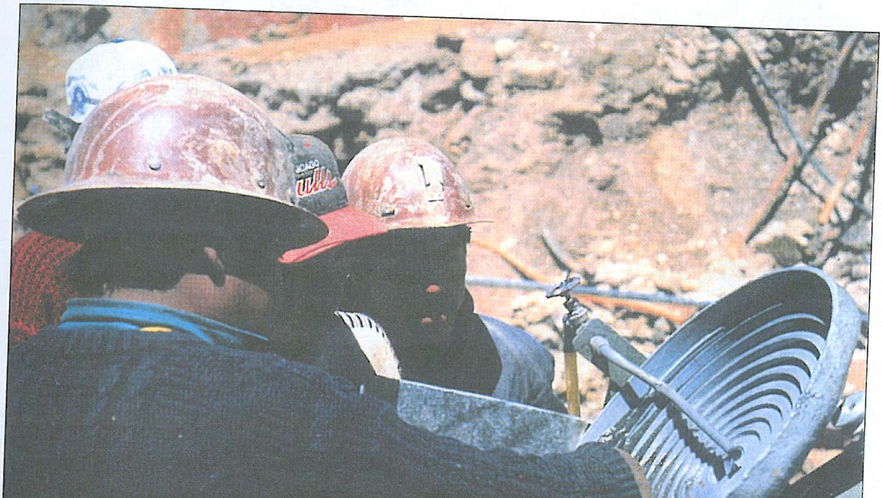
6.2.7.3. Flexible adaptation of the project concept

Project planning is frequently done after a relatively short pre-evaluation, partly executed by external personnel that do not dispose of in depth information. For this reason, this process contains many suppositions. These are verified and objectified during the execution of the project. The priorities and general conditions may vary during the execution of the project. **These variations require flexible adaptation of the project strategy to the new reality**. However, it is important that these adaptations are made only at activity and result levels. The objective for which the mentioned levels have been defined **must be followed without alterations**.

In order to carry out this adaptation, during the planning phase of the project provision must be made for regular monitoring, internal or external evaluations and planning workshops.



37. Hydraulic separator,
(Consata Cooperative, Bolivia)



38. Automatic pan (La Libertad cooperative, Bolivia)

39. Retort made from a carbide lamp (La Suerte cooperative, Bolivia)

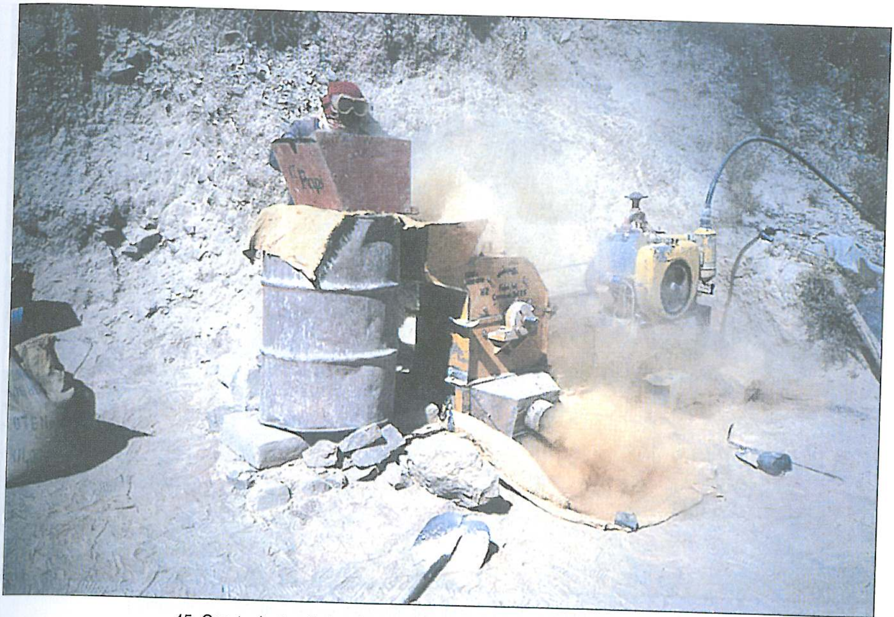
40. Manufactured retort (Brazilian)

41. Retorts of different sizes manufactured locally (PMSC, Ecuador, MEDMIN, Bolivia)

42. Dissolving sulfides with Nitric Acid (Huayna Potosi Cooperative, Bolivia)

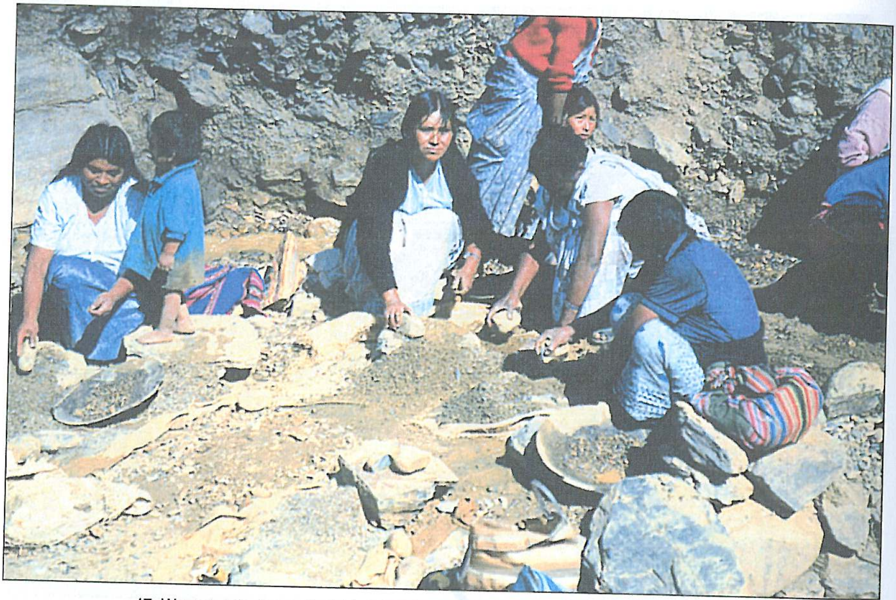
43. River contaminated by garbage, sewage, flotation tailings (La Ribera River, Potosi)

44. Used oil from a compressor (La Libertad Coop. Bolivia)

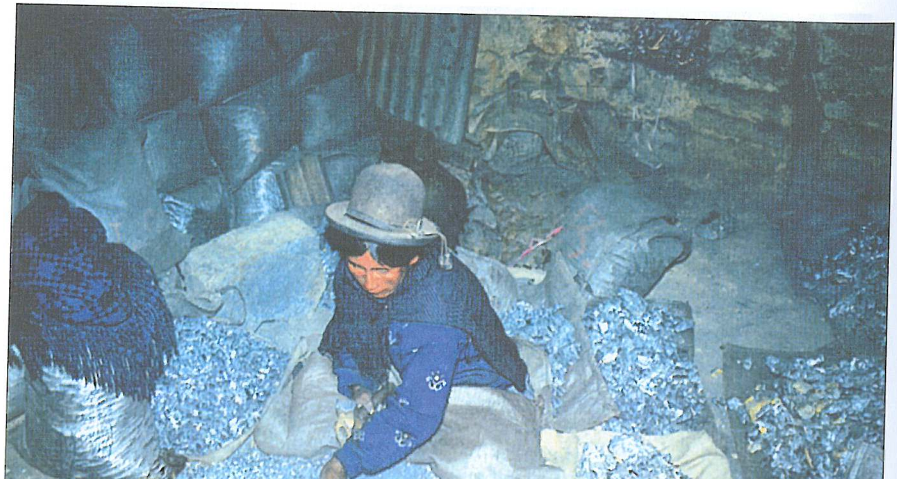


45. Quartz dust emission from dry grinding (Machacamarca mine, Bolivia)

46. Pigs in the River Tarapaya (contaminated by sewers and flotation tailings) (Potosi, Bolivia)



47. Women selecting material from a semi-consolidated alluvial deposit ("paleo-canal") (Pallayunga, Bolivia.)



48. Women selecting ore from primary mining (Bolivia)

7 Examples of projects executed

In this chapter, three examples of concrete projects will be presented and their most interesting aspects dealt with in depth.

7.1. Bolivia program “Integrated management of the Environment in Small Mining” (MEDMIN).

7.1.1. MEDMIN Presentation.

The Integrated Environmental Management Program in Small Mining (MEDMIN), is a project for the protection of the environment financed by the Swiss Agency for Development and Cooperation (SDC), and is executed by the German company “Projekt-Consult GmbH” together with the Ministry of Sustainable Development and Planning (MDSP) as the counterpart.

The projected commenced its activities in April 1994; the first phase lasted three years; at present MEDMIN is executing the second phase which will last until December 1999.

Of approximately 7 million inhabitants in Bolivia, about 500,000 live directly or indirectly from small mining (104). This activity causes serious damage to the environment due to the archaic work methods employed which affect the miners and their families as well as the population of the mining areas. Amongst the damages to the environment considered as the most dangerous are:

- Mercury emissions caused by small gold mining
- Introduction of slurries to the river systems and destruction of the landscape by alluvial mining.

- Water contamination caused by emissions of sulfurous tailings from the primary mining concentrating plants.
- Uncontrollable acid waters from mine tunnels, dumps and abandoned mines.

Inter-institutional cooperation

In view of the fact that environmental protection in Bolivian small mines has been barely taken in to account to the present, established inter-institutional cooperation has been and continues to be considered as the basis for the successful execution of the project. Only in this manner was it possible to get the project recognized and accepted at the highest political levels. Additionally, through inter-institutional cooperation, intensive coordination is guaranteed with other environmental projects in Bolivia.

There is direct and permanent communication between institutions that act as counterparts with MEDMIN, on micro, meso and macro levels, and also with the corresponding international organizations.

The MEDMIN counterpart at the highest political and environmental level in Bolivia is MDSP through their Vice Minister for Sustainable Development and the Environment. The activities are also coordinated with the Vice Ministry for Mining and Metallurgy (VMM), the maximum authority in the country for mining.

On a meso level, cooperation with the Federation of Mining Cooperatives, Chambers of Mines and small mining unions, facilitates direct contact between MEDMIN and the target group.

On an operational level, cooperation is given to The National Fund for the Environment (FONAM) that in turn delegates Bolivian institutions to execute measures in the mining/environmental area, from a special fund financed with resources from COSUDE.

On a target group level, environmental technologies are applied with the direct collaboration of the companies and mining cooperatives, the measures are also executed and coordinated with non government organizations (NGO), Universities and government organisms responsible for the mining/environmental sector.

The maximum organism in MEDMIN is the Board of Directors. This is composed of representatives of MDSP, VMM, FONAMA, COSUDE, the National Federation of Mining Cooperatives and, Projekt-Consult GmbH.

The inter-institutional group and the participation of institutions, is also reflected in the Technical Consulting Council of MEDMIN. The participants in the six monthly meeting of the Council are very diverse and represent institutions and persons connected to the mining/environmental theme, that among others are, the NGOs , government organizations (ministries, prefects, municipalities, technical institutions etc.), universities, private and cooperative mining, consultants and international projects (see Illustration 11).

Project activities

Due to the intense and broad mining activities in Bolivia, the environmental problem has multiple facets. MEDMIN is concentrated in the following sectors:

First, gold mining in the department of La Paz and second, water contamination in the department of Potosi.

Additionally, particular attention and priority is given to the environmental problems in the national parks and other protected areas where there are impacts created by small mining.

Gold mining in the department of La Paz

The MEDMIN activities are concentrated in the following order of activity:

- Reduction in the use of mercury for gold concentration and also, mercury emissions connected to this process.
- Simultaneous recovery of sulfides that harm the environment, as a commercial gold bearing by-product.
- Adequate storage of tailings and clarification of effluent waters from the process.
- Monitoring.

The above implies that both the development and experimentation of technical methods, instruments, machinery and materials, and the preparation and diffusion of audio-visual information material, bulletins, organization of seminars and workshops for the target groups and representatives of institutions and authorities involved, and also, training and specializing national technical personnel.

The methods and equipment used are carefully verified and tested jointly with the miners, both in regards to the preservation of the environment as also their practical application and profitability before propagating their applications. Due attention is paid here to give priority to available technology of local manufacture rather than imported technology. Various pieces of equipment are produced with instructions from the project personnel together with local workshops; some examples are: mercury retorts, hydro-separators, amalgamating drums, jigs, spirals, etc. In the MEDMIN program, the concentrating plants of 16 cooperatives and small primary gold mining companies, were rebuilt and totally modified with the objective of avoiding the use of mercury in open circuits. With these measures and the use of the major part of over 60 retorts sold to date, it was possible to reduce small mining mercury emissions by over 5 tons per year.

In this manner, MEDMIN became the first project worldwide to achieve a significant reduction of mercury emissions generated by small mining. By the application of these measures, production improved amongst the small companies through higher recovery by 10 to 20%, and contamination of water, soil and air was reduced.

By the application of these measures in primary deposits, the reduction of sulfurous emissions at this time is in the order of 300 tons per year. It was possible to avoid milled solids (sands) emissions to the rivers by building several tailings deposits. In order to reduce the effects of fine solids (slimes) on the waters, a first water clarifying installation will function in January 1998.

As a complement to the technical environmental measures, a series of social-economic and medical studies were prepared that provide information on the contamination effects on miners and the population and also, basic social and economic information on the target group (95, 105, 106, and 107).

Seven mining-environmental inventories were prepared in the most important gold producing areas in Bolivia, these constitute the data base for the enormous number of problems and the basis for planning the diffusion of the measures mentioned above that, over a medium period can achieve a reduction of the environmental problems in possibly all the regions where there is small mining in Bolivia (108).

Water contamination in Potosi

Mining has been practiced in Potosi for over 400 years and even today this activity is still intense. This brings with it grave environmental problems that are caused, on the one hand by present activities, and on the other, those inherited from the past.

The mining activities in the Cerro Rico de Potosi provoke the most gravitating problems. The most active, apart from government and private entities, are the mining cooperatives. There is a total estimated mining population of 8,000 miners in the Cerro Rico. Mine production averages 1,500 tons per day and is processed in about 40 flotation plants located within the city limits. The flotation residues (over 1,200 tons per day), are discharged directly to the river Ribera without any environmental prevention, converting it into the most contaminated river in Bolivia (see Photos 9, 46). This river is a tributary of the river Pilcomayo (Rio de la Plata river system) and on provoking this grave contamination, occasions not only national problems but creates tension with neighboring Argentina and Paraguay.

In order to avoid these emissions from flotation plants in the future, MEDMIN contracted the services of Golder Associates U.K., to prepare a project for the construction of a communal tailings dam to retain the tailings from all of the plants (109). The decanted water will be totally re-circulated so that the dam will not produce any contaminating emissions. This project (San Antonio Tailings dam, Potosi, has a cost of approximately US$2.5 million), counted on the advisory services and financing by MEDMIN for the feasibility study. The works financing was committed by the German Financial Cooperation (KfW). At this time, all the administrative, organizational and responsibility aspects for the functioning of the dam are being established or determined before initiating final design and construction.

An additional problem is the emission of acid waters from the existing abandoned mine tunnels, that not only have an extremely low pH, but also a high content of heavy metals. As water is scarce in Potosi, contaminated waters are used for agricultural irrigation – totally inadequate for this purpose and conduce to serious problems with the farmers – producing high heavy metal contents in agricultural products.

For this same reason, a pilot installation is being built to treat acid waters with high heavy metal content in another conflictive zone in the department of Potosi. At the same time this is a shared project between MEDMIN, the community, a local NGO, the University of Potosi and a regional project of the European Community. The objective is to provide the farmers with water suitable for irrigation in the future.

Other activities

Five different demonstration and teaching videos were prepared for the sensitivization and training of the target group and authorities (MEDMIN presentation; problems and solutions for mercury emissions in gold mining; San Antonio Tailings Dam, Potosi: the environmental problem in tin, zinc, lead, silver etc., mining; Presentation of pilot projects).

As a complement to the mentioned projects, courses and seminars were organized that are considered as a fundamental part of the work plan. Also included were special courses to train miners to be environment promoters.

A series of pamphlets, stickers and calendars showing different environmental problems and their possible solutions completed the information material. Our own publications and the support of information campaigns diffusing the mining/environmental theme also formed part of the proposed work, as did also the permanent increment of documentation in the MEDMIN offices.

MEDMIN has a "homepage" on the Internet:

http://coord.rds.org.bo/miembros/medmin/index.htm

and actively participates in the mercury net:

http:/www.geocities.com/reinaforest/8985/mercurio.html

MEDMIN administers its own small financing line for research work, particularly for Bolivian students preparing their thesis within the Mining/ Environmental area.

Additionally, MEDMIN has actively participated in the preparation of environmental legislation in Bolivia. It is currently supporting the mining and environmental authorities in the diffusion of the pertinent laws, regulations and norms in the mining/environment sector (110, 111).

A reduction of environmental problems in small mining can only be achieved by means of an integral focus. With the MEDMIN concept, government institutions can concentrate on their specific jobs; this means, the preparation of political guidelines and their corresponding systems of control and coordination. Non government organizations (ONG s), through specific advisory channels, have the possibility of qualifying as competent counterparts for the execution of diverse environmental projects.

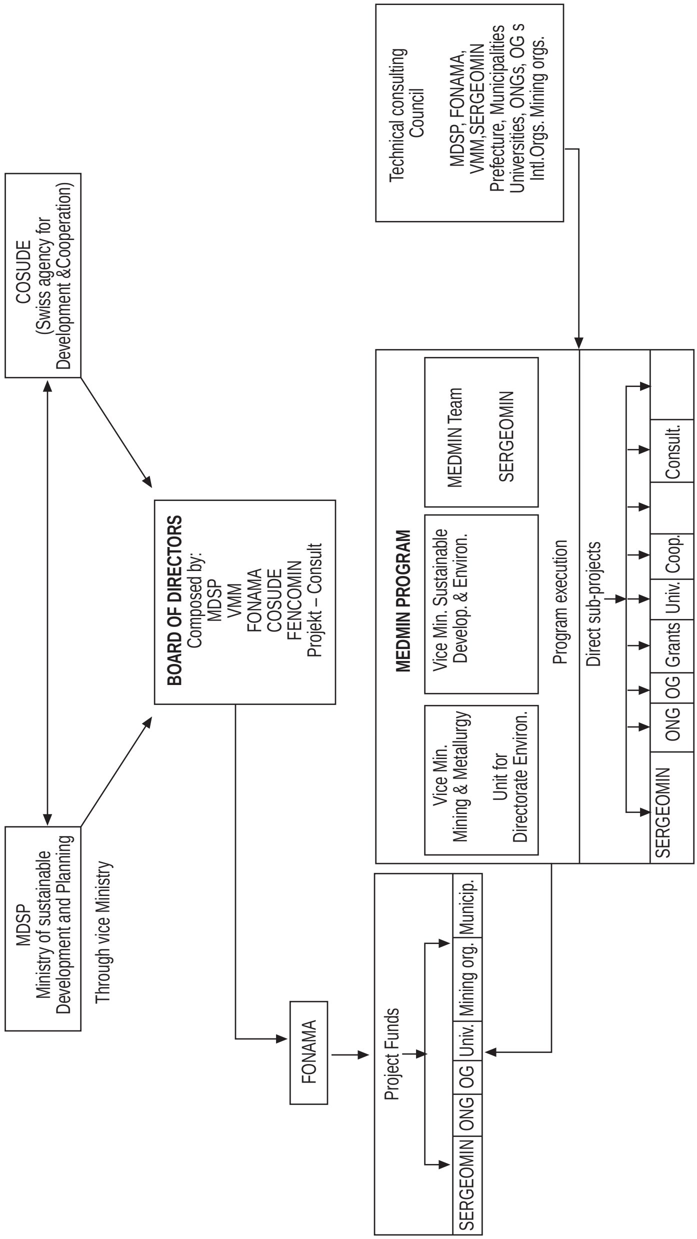
In this manner, they can take optimum advantage of specific ONG benefits and insist that they have great sensibility for social and cultural aspects and obtain better access to target groups. It has been demonstrated that by applying this focus, synergy effects have been transmitted to other environmental protection sectors.

Only individual techniques or technical concepts that offer economic advantages to small miners can be considered successful. A basis for MEDMIN sustainable impact, is the fusion of positive effects for the economy and for ecology.

The project is known not only for its practical work, but also for numerous press publications and conferences at national and international events on the subject, but also as a competent interlocutor. Our collaborators have been and still are invited by a series of international projects and foreign authorities for work visits to Brazil, Peru, Ecuador, Colombia, Venezuela and Guyana amongst others.

ILLUSTRATION 11

MEDMIN ORGANIZATION CHART

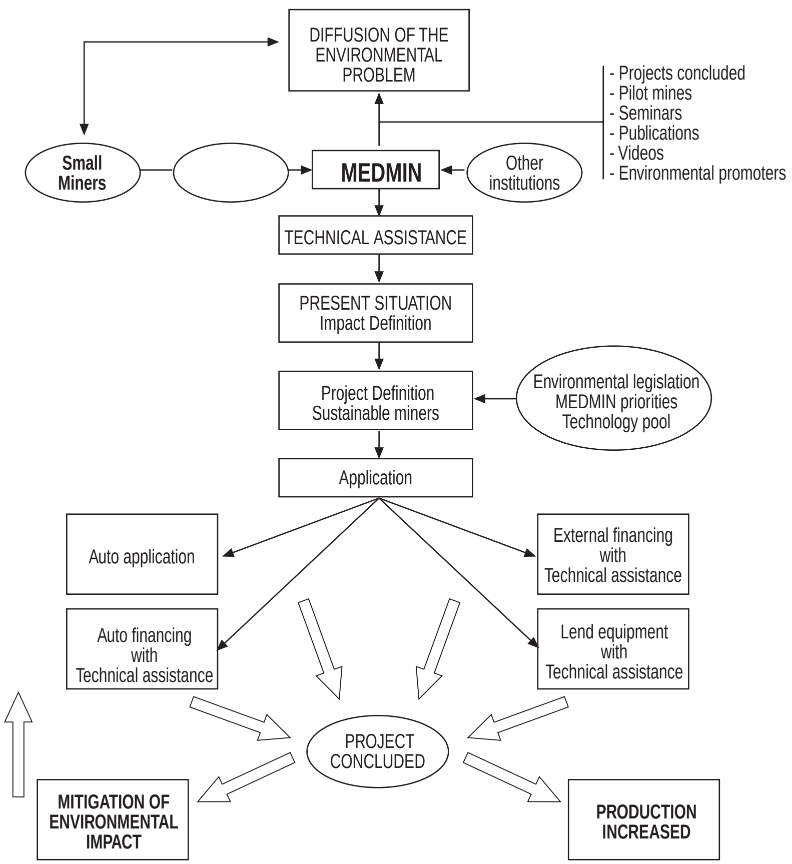


7.1.2. The mercury problem; solutions and their diffusion

In order to achieve substantial mitigation of environmental contamination, rather than repeating the abundant technical studies on environmental impacts, the MEDMIN project has been dedicated to the application of appropriate measures. After a period of experimenting and testing with different improved methods, the project gave priority to ample diffusion and execution of technical changes. The strategy for the diffusion and application of technologies is shown in Illustration 12.

ILLUSTRATION 12

STRATEGY FOR DIFFUSION OF ENVIRONMENTAL CONCEPTS AND THE APPLICATION OF MEDMIN TECHNOLOGIES



7.1.2.1. Characterization of small gold mining in Bolivia

Small gold mining in Bolivia covers the exploitation of both primary and secondary deposits, each with its own characteristics and problems. It is estimated that annual production exceeds 10 metric tons and the population that lives off this activity is in the order of 100,000 persons (miners, their families and others dedicated to complementary or side activities).

Small alluvial gold mining had its boom during the past decades in the rich deposits in the Tipuani area. Later, there was a notorious decline due to the natural depletion of its deposits. At present, production is concentrated mainly in the Tipuani and K'aka river basins. The small miners, grouped into cooperatives or small companies, exploit the ancient paleo-canals and the more recent river terraces. The range of technologies varies from manual operations (with tunnels in the paleo-canals or with small gravel pumps in the river banks) to small and large mechanized operations (underground workings with as many as 500 workers, or operations in terraces and river beaches with heavy equipment such as: bulldozers, back hoes, dump trucks etc., that move up to 2,000 m3 per day). These large operations, because of their size, surpass the limits of investment capacity of the small miners. However, due to their structure (cooperatives), in Bolivia they are categorized as small miners. As a result of these activities, numerous environmental impacts are generated (mercury emissions, muddy rivers, altered river courses, erosion etc.).

Small primary gold mining has acquired more and more importance in the last 10 years. Today, there are about 100 cooperative and private small mines operating in this category, the majority of which are located in the "Cordillera Real". A wide range of technologies are employed, from manual artisan mines to semi-mechanized mines with processing plants with capacities of up to 20 tons per day. The number of small primary gold mines grows constantly due to the migration of old miners searching for sources of work and who have emerged from the government tin mines (COMIBOL) that closed operations during the 80's. Of these 100 operations, 30 are mechanized and the rest work manually.

It is estimated that gold production from small primary gold mining is about 5 tons per year which is an important contribution to the Bolivian economy. Experience has shown that this sector absorbs about 30,000 persons. This important activity generates several other peripheral activities (transport, gold marketing, tool provisions and other consumables, all types of workshop services, etc.). However, the production and treatment of primary gold ores is accompanied by numerous environmental impacts both locally and in the surrounding areas. These are principally, toxic mercury emissions in different forms (liquid and vapor), and river contamination with sulfurous tailings, finely ground slimes, fuel and lubricant spills.

7.1.2.2. Traditional processing

This sub-title describes the situation as it was **at the beginning of the project** although mercury handling has changed substantially due to MEDMIN's efforts.

Alluvial mining, depending on the type of deposit, differs only in the methods of production (open cast and mechanized in platforms and terraces, and generally underground in paleo–canals). Gold extraction is practically the same; the only difference is in the volumes being treated (major volumes in platforms and terraces and small in paleo-canals). The gold recovery system is quite simple, consisting of initial washing and classifying (mechanized in platforms and terraces; manual and rudimentary in paleo-canals), the second phase is concentration in sluices (from the most primitive where they are lined with rounded stones, to something more advanced using metal riffles), in both cases only coarse gold is retained and the fines got to the river with the tailings. The employment of mercury is limited to the amalgamation of the little fine gold retained in the sluice. Finally, the amalgam is burnt to eliminate the mercury and liberate the gold.

Apart from mercury contamination and its negative effects on the miners health, there are other impacts of consideration such as: altering river courses as a result of dump fills containing large boulders; muddying the river waters with overburden clays; and finally, and perhaps the gravest, the destruction of fertile beaches and alteration of the landscape.

In general, the processing techniques used in **small primary gold mining** have a large variety of individual techniques that depend mainly on the financial situation of the miners and their technical knowledge. These range from the most primitive (stone mills), through to methods found in "De Re Metallica" by Agricola [66] (pans, sluices, manual jigs, etc.), to modern equipment that differs little with that used by sophisticated mining (shaking tables, spiral concentrators, centrifuges etc.).

The most simple and primitive processing method used by small primary gold mining is the following:

- Manual selection of ore with visible gold chips;
- Crushing and grinding with a manual sledge hammer;
- Washing the ground material in a pan to separate coarse gold;
- If the gold is fine, manual amalgamation of the concentrate in a pan;
- Squeezing the amalgam through a fine cloth to separate free mercury;
- "Burning" the amalgam in the open air to evaporate the mercury.

The last step is carried out without any equipment for mercury recovery or without any safety equipment against the vapors. They use various sources of heat ranging from charcoal, kerosene blow torches, propane or acetylene and even kerosene kitchen hot plates in the homes.

Another processing system, also rudimentary, uses a kind of large stone mortar called a "toloca" (a hollowed out rock and a block that moves inside), where grinding takes place simultaneously with amalgamation of small portions of rich ground ore, thus eliminating an additional amalgamation phase. In this combined phase, considerable atomized mercury is produced that is unavoidably lost in the tailings during the panning process to separate out the coarse amalgam. The amalgam is subsequently treated in the manner described in the above paragraph.

There are several variations of the techniques described, and as they are all manual and discontinuous, it is only possible to process small quantities of 20 to 50 kgs per man per day, depending on the hardness of the material. Frequently, the material is pre-crushed by dry methods, using the so called "quimbalete" also made of stone, which permits crushing approximately 200 kgs. per day per man.

The first step towards mechanization is the use of the so called "Chilean Mill" or "Trapiche". In this mill, the use of mercury is almost generalized, combining grinding with amalgamation. Its mode of functioning produces excessive mercury atomization. Generally, amalgamated sheets are placed at the exit of the Chilean Mill or, simple sluices with the floor lined with stones (tojlla) to trap free gold and amalgam. Obviously neither the sheets nor the sluice guarantee a good recovery of free gold or atomized amalgam or mercury.

In larger operations, it is common to use:

- Small jaw crushers;
- Ball mills from 2’x3’ to 3’x4’ with capacities of 5 to 15 tons per day;
- Cobbled sluices, amalgamated sheets, concentrating tables, etc.

In the same manner as with Chilean mills, it is also common practice to add mercury to ball mills that have a similar or greater atomizing effect on mercury and consequently floured mercury losses in this concentration step are considerable. [a]

The few mines that do not use mercury in the mill (especially those with coarse gold), amalgamate their concentrates manually in pans or small amalgamation drums. With the latter, if the operation is not appropriate (high revolutions, excessive mercury, absence of pre-washing step, excessive grinding media, prolonged amalgamation time, etc.), large quantities of atomized mercury are produced and lost in the tailings.

Gold recovery in primary mine plants is generally low, as part of the gold is frequently non-recoverable with their rustic gravity or amalgamation concentration methods.

Additionally, free gold is also lost in the tailings in fine and laminar forms (laminated during grinding). A part of the gold is also lost due to insufficient liberation. Combined grinding and amalgamation causes high losses of fine particles of gold trapped in the floured mercury or in the form of floccules of amalgam-gold that sometimes contain air bubbles or trapped water. Generally, these floccules have a relatively lower specific gravity and a large surface area and are easily dragged to the tailings. The presence of sulfides (pyrite, arsenopyrite, etc. in an amount of approximately 5 – 10 kgs per ton of vein material) are an interesting bi-product with gold contents varying between 40 and 200 gms/ton, but due to the ignorance of their value they are not recovered and are lost in the tailings.

a In San Simon close to the Brazilian frontier, hammer mills are being used followed by amalgamated sheets. This technology is widely used in Brazil. Mercury is added to the mills in these plants with excessive losses of the same in the tailings (up to 2.5 kgs to recover 100 gms of gold). San Simon is not within the original area of the project. In order to solve the grave contamination problems, it has been decided to extend future activities of the project to this region.

The tailings are generally strewn over areas adjacent to the processing plant or thrown into the rivers. The consequent muddying of the rivers, provokes – as much or more contamination than mercury or sulfides – a strong decrease in the aquatic fauna and consequently, justifiably so, confrontations with the population down stream that consume the river fish.

The emission of sulfides to streams and small rivers or the deficient storage of the same, generates sulfuric acid and releases iron in solution as a result of oxidation, lowering the pH and creating conditions that leach out other heavy metals (Fe, As, Sb, Zn, Cd, etc.), which are clearly detectable in the rivers.

The mercury emissions from burning amalgam in the open air produce not only an environmental problem, but also of industrial safety. Normally, 500 to 1,000 gms of mercury per 1 kg of gold evaporate into the surrounding atmosphere; most of the vapor re-condenses and precipitates in the proximities of the burning area. The miners are constantly inhaling mercury vapors and in some cases exposing themselves to acute mercury poisoning. Medical investigation has reported high mercury concentrations in the urine of the miners and their families that sometimes become clinical cases. The hard living conditions of the miners (deficient nutrition, lack of hygiene, absence of medical attention, high consumption of alcohol, etc.), make it difficult to clearly establish the relation between the use of mercury and health problems. It is even more difficult to make the miners understand that irrational use of mercury endangers the health of the communities along the riverside.

The most serious environmental problem is the use of mercury in open circuits. The addition of mercury to different types of grinding mills – because of the way they function -, atomizes and becomes “mercury flour”. The presence of grease, oil, aluminum and copper from detonators and electric wire, minerals such as talc etc., in the feed material contaminate mercury in such a way, that it loses its properties to adhere to other small mercury spheres to form larger mercury pearls, ostensibly diminishing its capacity to amalgamate. A major part of floured mercury is lost due to the difficulty of recovering it by any gravity method. Generally, 5 – 10 kgs of mercury are lost for 1 kg of gold recovered from combined grinding-amalgamation methods in open circuit. These losses are several times more that those lost by burning mercury in the open air. Other sources of mercury emissions are from insecure storage of amalgamation tailings. Table 26 shows emissions, their causes and possible solutions (cyanide leaching in replacement of amalgamation is not employed yet in Bolivian small mining).

TABLE 26

EMISSIONS, CAUSES AND POSSIBLE SOLUTIONS IN BOLIVIAN SMALL MINING

EMISSIONS	CAUSES	SOLUTIONS
Mercury	Use of Hg in open circuits	Elimination of combined grinding - amalgamation and amalgamating sheets, by improving gravity concentration methods.
	Burning amalgam in open air	Use retort
	Insecure storage of amalgamation tails	Build secure tailings dams
Sulfides	Inappropriate gravity concentrating Methods	Improve traditional gravity concentration methods
Fine and coarse solids	Lack of appropriate tailing storage and water treatment facilities	Tailings dam construction and system for decanting slimes, fill in worked out pits
Effluents of acid waters	Sulfide oxidation	Sulfides recover, see above
Heavy metals	Leaching processes in the mine and in tailings ponds. mass absorption..	Sulfide recovery, precipitation Plants, artificial lakes with bio-

Frequently, due to the critical economic situation of Bolivian small mining, it is comprehensible that the prime interest of the miners is not directed towards the environmental conditions in their operations. The production of many miners scarcely covers their vital needs and without a doubt they would prefer to purchase a television set or a motorcycle – if at some time they have a profit margin -, rather than invest in environmental protection. Government control is deficient or simply does not exist, despite the fact that the Environmental Law and its corresponding regulations is in full force. In order to change present techniques and make them environmentally healthy, it is necessary to offer miners a "complete package" of technical assistance directed towards specific needs such as, improving production and industrial safety together with environmental measures.

Technologies have been sought that are not only environmentally clean and economically appropriate, but that are compatible with the culture of Bolivian small mining, based on the following requirements:

- The equipment and machinery, where possible, should be of local manufacture
- The technology should be technically efficient (more than the traditional)
- Low investment and operating costs
- Simple and safe handling and maintenance
- Durable and with projections for the future
- Have a low environmental impact
- Not be an environmental "time bomb"
- Acceptable socially and culturally

In the case of Bolivia, from past experience, the variety of ore deposits, different technical and financial possibilities of the miners, the variety of existing processing plants, it became clear, that the sometimes preferred "standard model Plant" or "demonstration mobile plant", did not function. For this reason, the installation of different fixed plants was decided on. Systematic improvements and adaptations were made for each particular requirement with a series of well known unitary techniques adapted to these plants, but which were used below their capacity.

This modular system permits combinations and adjustments in each individual case.

7.1.2.3. Improved techniques

During the first two years of the project, the methods and equipment described below were tested with the miners in their daily productive practice with their plants. At the same time, the manufacture of proven equipment commenced with local metal mechanical workshops under close permanent supervision and follow up of the technical design parameters. In the third year, diffusion of the improved techniques was initiated with their application at numerous existing and new operations.

Simultaneously, research work continued to resolve the still existent technical problems.

The introduction and revelation of clean technologies are complemented by courses and workshops for the miners, educational videos, technical guides, etc., in which emphasis is made on suppression of the use mercury in open circuits which is considered as being the most critical of environmental problems, and the recovery of accompanying sulfides. Different gravity flow sheets were optimized to achieve good gold recovery without using the combined grinding-amalgamation process. The traditional sluices were improved as also the use of concentrating tables, jigs and spiral concentrators, all of which had already been used in casiterite recovery plants.

The starting point for the work on gravity concentration was the low recovery obtained with traditional methods. A point of interest for the miners was the reduction of high mercury consumption which not only represents an economic loss but there is also a problem obtaining it in remote areas. At this time, the majority of the miners are open to changes in their work systems and to the introduction of clean technology with the knowledge that this will mean greater recovery (profit) with lower operating costs. Small equipment such as amalgamation drums and retorts for mercury distillation, complete the processing methods promoted by the project.

Sluice boxes

During the sluice box investigations, experiments were carried out with different linings instead of the cobble stones or “tojlla”. Different special carpets, expanded metal and combinations of both were tried as also different types of cloth.

It was observed that with fine textured cloth, a less turbulent flow was obtained substantially improving fine gold recovery. However, the disadvantage of these cloths is the limited retention of heavies which is why more frequent washings are required.

In primary mining, classifying the ground material at the mill exit and before the sluices was most useful. For this purpose, a trommel with different mesh sizes can be attached to the discharge side of the mill, or a simple hydro-classifier of the “spitzkasten” type. Recirculation of oversize material (> 1mm.) for further liberation gave positive results.

The carpets or linings (see sub-title 5.4.2.1.2.) are available in the Bolivian market. They are durable and can be washed easily. They proved to be more efficient than the locally produced cloths, wool blankets etc.The frequency of washings vary usually between 0.5 to 2 hours depending basically on the sulfide content that tends to saturate the carpets. The sluice box inclination should be adjusted during the operation in such a manner that the gangue particles do not settle (generally between 5 and 15%). Free gold recovery can be as high as 90% depending on the care taken in managing the system. The very fine and laminated gold and a good part of the gold bearing sulfides are lost in the tailings. The principle advantages of this method are: very low investment, simple handling (well known), does not require energy and good recovery.

The disadvantages are: low sulfides recovery and the need for frequent washings. The latter is particularly sacrificial in winter when water temperatures are in the order of 0º C. Another disadvantage of the improved sluice is the necessity of an amalgamating drum for the concentrate. On occasions when there are large quantities of pre-concentrates, they should previously be passed through the sluice box or a concentrating table or finally be panned.

In alluvial mining, it has been demonstrated that good gold recovery, especially fines, is obtained using carpets of the “Nomad” type manufactured by 3M occasionally combined with expanded metal. Due to the low gold content, carpet washing once a day is sufficient.[a]

Resources (and more income for the miners); second, the decrease in the volume of pre-concentrates means less material to amalgamate, and consequently less amalgam contaminated tailings.

Contrary to high metal riffles or cobbled floors, an enriched concentrate is obtained (contains less accompanying heavy minerals in proportion to recovered gold), in other words, less material to amalgamate.

a As previously described, the use of mercury in sluices is very rare. For this reason, the improvement of traditional sluices has the principle objective of increasing recovery and decreasing the volume of pre-concentrates obtained. First, good recovery means good utilization of non-renewable.

The improved sluice boxes are quickly accepted by the miners and have shown that they are capable of self-diffusion as the recovery achieved is better than with the traditional methods (cobbled sluice boxes or amalgamated sheets in primary mining, or cobbled or metallic riffled sluice boxes in alluvial mining), and the conversion to the improved system is easily achieved.

Jigs

In primary mining, the gold lamina or flakes generated in the grinding stage were unavoidably lost in the traditional recovery systems and formed a considerable part of the free gold losses. To resolve this problem, a Denver type jig was introduced, a machine that has been used for many years in Bolivian tin mining. This was installed at the discharge end of the grinding mill and the circuit closed with a spiral classifier, a very well known circuit in sophisticated gravity concentration [3]. With this system it is possible to recover not only the major part of laminated gold, but also an important part of the gold bearing pyrites, thus avoiding unnecessary over-grinding. The only disadvantage – if it can called so – is that it requires considerable training of the operators.

In alluvial mining, jigs have not been tried for pre-concentration because the results obtained from the improved sluices were very satisfactory. Nevertheless small Denver type jigs have been used to upgrade pre-concentrates before going to amalgamation with very good results.

Concentrating tables

Despite the fact that concentrating tables have been and still are widely used in tin plants and are easy to acquire, they are used in very few small gold mining plants.

These tables have shown very good results in recovering fine gold and accompanying sulfides in primary mining, but too much laminated gold is lost and is better recovered in jigs. The tables are used to treat material in two or three size fractions after classifying with a spitzkasten. The principle advantages are: continuous operation and their capacity to recover sulfides. In some operations, tables are used for additional upgrading of concentrates obtained from the sluice boxes, thus reducing the volume of the material to be amalgamated and consequently minimizing the quantity of contaminated amalgam tailings.

Spiral concentrators

Different types of spirals were introduced (MD LG&, MD WW6, etc) to be used as scavengers at the tailings discharge point of plants in primary mining. Despite the fact that these are used in small operations well below their capacity (only 0.5 to 0.8 tph), they have shown very good results in the recovery of fine free gold and sulfides from the tailings that otherwise would have been lost. It has been demonstrated that by installing these machines for plant tailings, they pay for themselves in few months. Although their use in alluvial mining (especially where there are other valuable heavy metals such as cassiterite) can be interesting, it has not been possible to apply them due to the difficulty of classifying large volumes of material -2mm.

Amalgamating drums

The manufacture and distribution of amalgamating drums was an important activity of the project. A short time after starting the project, it was shown that the idea of completely replacing amalgamation with other methods (such as flotation or direct fusion of concentrates) was not going to prosper as these were not so simple and in general, reported low recoveries. Additionally, for environmental reasons, the introduction of cyanide leaching was left on one side. Therefore, the project had to improve a technique that at the beginning, was considered should be avoided. Contrary to the traditional method of open circuit, drum amalgamation is much safer for the environment.

In this case, only a relatively small portion of high grade concentrate was amalgamated. With a careful operation, it is possible to minimize the inevitable loss of atomized mercury in the tailings (see sub-title 5.5.1.4.).

Amalgamation drums are widely accepted because they are highly efficient and the work required is low in comparison with manual amalgamation. Additionally, the drums avoid direct contact of mercury with the skin, and losses from atomization can be reduced to less than 1% of the mercury used. However, there are sulfurous concentrates (especially sulfides of arsenic, antimony and bismuth) from primary mines that make amalgamation difficult even using a drum.

Ascending current hydraulic separators (Hydro separator or Elutriator)

Ascending current hydraulic separators (elutriators) were introduced, to separate amalgam from free mercury and sands after the amalgamation process. The recovery of amalgam and free mercury is generally better using the traditional method with pans and the capacity is several times higher [a].

Retorts

Diffusion of the use of retorts appeared to be the solution to mercury contamination by small mining. This is not true, because, as mentioned above, when this is used in an open circuit, emissions can be much higher than burning amalgam in the open air. Apart from this, there is considerable difficulty in promoting its use.

In some parts of Bolivia, there are already some rustic form of retort (for example, some are made from old carbide lamps), so that they were not completely unknown. However, miners have an aversion to their use for several reasons (see sub-title 5.5.5.1.).

Despite these obstacles, the project was able – sustained by a strong campaign on the health risks from burning amalgam in the open air – to promote the use of the retort to a certain degree. Three different sizes of retorts were developed and optimized with 300g, 1kg, and 3kg capacities

[a] It has been shown that with some material containing heavy accompanying minerals (arsenopyrite, casiterite etc.), it is necessary to substantially increase the ascending flow to lift these minerals and expel them. Fine amalgam and mercury is also lost in the process. In these cases, mechanical pans have produced better results.

respectively; these are currently produced by local workshops (see Photo 41)[a]. Of approximately 60 retorts sold, about 70% are still being used; considering the difficulties in their acceptance mentioned above, this is a relative success [b].

Table 27 shows the previous processes and the changes made in several primary mines in Bolivia. Annex 1 shows several flow sheets of improved plants.

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a Due to their local manufacture, the prices of the retorts are low: US$40 for a small retort, US$50 for a medium size and US$90 for the large retort. Adequate gas burners are also produced at a low price. Due to their frequent use (heating and cooling), the retorts do not have a long life. Depending on care and handling, the crucibles in particular are inclined to deform and must be replaced from time to time (after 30 or 50 uses). The more mechanized mines have their own workshops (including lathes) and manufacture their own replacements.

b Several large retorts have been sold to mechanized alluvial cooperatives. In these cases, the retorts are used daily and significantly reduce the mercury emissions. With just one large retort used by a cooperative located on the river K'aka, over 300 kg of gold were recovered in one year (life of the crucible: one month). The quantities of mercury recovered by retorts in primary mining (average grinding capacity is 15 t/d) are generally small. About 2 kg of amalgam are burnt per week and mercury recovery is about 50 kg per year.

TABLE 27

SUMMARY OF EQUIPMENT AND PREVIOUS PROCESSES, AND CHANGES MADE BY MEDMIN IN SEVERAL PRIMARY GOLD MINES IN BOLIVIA (1996/97)

Mine/Cooperative	La Suerte		Yani		25 de Julio		Libertad		15 de Agosto		10 de Febrero		Virgen del rosario		Huayna Sunchulli		Cotapata		Fortaleza de S. Vicente		Zongo		Unión Ideal		Copacabana**		Ingenio Fortuna**		Ingenio Pallaya**	
EQUIPMENT/MACHINERY																														
Crushers	X	X	X	X	X	X	X	X		X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Ball mills	X	X	X	X	X	X	X	X		X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Chilean Mills	X				X								X		X								X							
Rocker grinders									X		X																			
Stone mortars					X				X																					
Rustic sluice boxes (cobbles)			X		X		X						X		X		X		X		X		X		X		X		X	
Sluice boxes with carpet				X		X		X		X		X		X		X						X		X		X		X		
Trommel (at mill outlet)	X			X		X	X	X		X		X		X	X	X	X	X	X			X		X		X		X		X
Spiral classifier	X	X																		X										
Hydraulic classifier		X								X								X		X	X	X								X
Pan (for pre-concentrate)									X		X																			
Jig		X								X								X		X	X	X				X				X
Concentrating table	X	X	X	X														X	X	X										X
Amalgamated sheets	X		X		X																X		X				X		X	
Spiral				X														X						X		X		X		
Amalgamation drum	X	X		X		X				X		X		X				X	X	X	X	X		X		X		X		X
Amalgam separating pan	X		X		X		X	X	X				X		X	X	X		X		X		X		X		X		X	
Amalgam hydro-separator		X		X		X				X		X		X				X		X		X		X		X		X		X
Retort	X	X		X		X		X		X		X		X		X		X		X		X		X		X		X		X
PROCESS																														
Crushing	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Grinding	X	X		X		X	X	X		X	X	X		X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Grinding with mercury – open circuit	X		X		X				X				X		X				X		X		X				X		X	
Grinding circuit with concentrate		X		X		X		X										X		X						X				X
Sheet amalgamation	X				X																X		X				X		X	
Gravity conc. Rustic sluices			X		X		X						X		X		X		X		X		X		X		X		X	
Gravity conc. With improved sluices				X		X		X		X		X		X		X						X		X		X		X		
Gravity conc. With jigs		X								X								X		X	X	X				X				X
Gravity conc. With tables	X	X	X	X														X	X	X										X
Gravity conc. With spirals				X														X		X				X		X		X		
Other gravity concs.																			X*											
Manual amalgamation of concs.			X		X		X	X			X		X		X	X	X						X		X		X		X	
Mechanized amalgamation of concs.	X	X		X		X				X		X		X				X	X	X	X	X		X		X		X		X
Amalgamation with Toloka					X				X																					
Burning in open air			X		X		X		X				X		X		X		X		X		X		X		X		X	
Burning with retort	X	X		X		X		X		X		X	X	X		X		X		X		X		X		X		X		X
Systematic recovery of gold sulfides		X		X		(X)				(X)		(X)		(X)		(X)		X		X		X		X		X		X		X
Systematic storage of coarse tailings	X	X		X		(X)	X	X		(X)				X		X				X								X		X
	OLD PROCESS			NEW PROCESS			*KNELSON			(x)PARCIAL			**EXECUTING																	

7.2. Brazil: "Mercury Contamination from Gold Mining in the Tapajós and Madeira River Basins, Brazilian Amazonia"

7.2.1. Presentation of the Project

The European Community finances a Technical Assistance Program in the Brazilian Amazonia with the following objectives:

- Diagnose the contamination effects caused by gold mining
- Study and develop mechanisms to mitigate these effects

The project is composed of two parts:

- Diagnosis of the environmental impact (establish laboratories for mercury analysis and intoxication of the surrounding mining population and, the terrestrial and aquatic flora and fauna.
- Development and application of clean technological alternatives to achieve mining without environmental impacts, or at least minimized impacts.

Gold mining has existed for centuries in the Brazilian Amazonia, principally on an artisan level, generally using simple and mobile techniques with minimum investment costs. These conditions have induced contingents of Brazilians to migrate to the Amazonia in search of the precious metal, some as a means of living and others to make fortune. This phenomenon had major intensity at the beginning of the '80 s when the price of gold rose. It is estimated that today there are close to 100,000 "garimpeiros" (small miners) in Brazil, established in this vast region. The number is variable due to seasonal fluctuations (a large part of Amazonia cannot be worked during the rainy season) and also because of the "gold rushes" that increase strongly – in a short period – in the number of persons dedicated to this activity.

This massive and uncontrolled activity, although it has provided work and sustention for hundreds of thousands of Brazilians, has inevitably caused, and continues to cause aggressions to the environment as also mercury contamination in different forms (liquid and gas), muddying of he rivers and the destruction of the Amazonian landscape. The European communications media, shows the "garimpeiro" as a savage animal that with his greed for gold, destroys Amazonia and, with it the last indigenous people of the region.

On the other hand, over the last few years in Brazil, a different image of the problem has been formed and shown, as in the recent past there were frequent conflicts between informal mining (garimpagem) and formal mining (medium and large), the Brazilian government has made intents to eliminate informal mining activities. Finally, this sector has achieved the general respect it deserves, because the garimpagem became an escape valve for the social problem represented by thousands of jobless and homeless persons in the country, in addition to the gold production they generate, estimated at 50 tons per year which has a vitalizing effect on the local and national economy, a fact that cannot be ignored or underestimated.

Many towns and communities in the Amazonia such as, Santarem, Itaituba, etc., depend in great measure on this important economic activity and, many industrial companies in the developed Southern Brazil; sell their machinery and commodity production to a large sector of the informal miners. It is estimated that between 1 and 2 million persons depend directly or indirectly on the garimpagem.

Although sympathizers with large mining resist accepting this reality, they are aware of the enormous number of deposits in Amazonia that are not adequate for large scale mining and can only be worked by the garimpagem method where sometimes the garimpeiros result more exploited than the deposit itself.

For years the large mining companies have been exploring the Tapajos area without having discovered a deposit of any magnitude. An understanding of the importance of the garimpagem and the impossibility of substituting it, has changed the attitude of the government and state policies, which originally tried to repress these activities, then adopted an attitude of “let it pass”, until finally adopting the policy of development and control of this type of mining. This new policy, together with legal and physical aspects and environmental protection, acquires a most important role. Not only the government institutions and the affected population, but also the garimpeiros, start to acquire consciousness of the environmental problems, which makes it important to reinforce this attitude with projects such as ours.

It would be an error, even though the title of the project “Mercury Project” appears to suggest it, concentrate efforts only on the application of clean technologies related to the use of mercury.

Such a complex theme as the environmental impact produced by informal gold mining, can only be solved in an integral manner, as the mercury emissions, the destruction of the landscape and the muddying of the rivers, are a partial expressions of the fundamental problem: the visible negligence of this sector – during decades – of the total absence of technical assistance and rational development.

The change of the monetary symbol from Cruzeiro to Real, due to its relation to the US dollar, has resulted in an increase of almost 100% in operating costs, which means that many operations are about to close down with the foreseeable social consequences for the area.

Due to the above considerations, any project directed towards the environmental problem, should commence first by providing the necessary technical assistance to the garimpeiro to allow him to overcome this crisis and subsequently confront the environmental impact problems in a parallel form. The total abandon on the part of the government has created an atmosphere of a lack of confidence by the garimpeiros that is difficult to overcome, consequently the strategy of the present Project in its first phase will consist in recovering their confidence, by starting work closely with a work team focusing their problems in an integral form (from exploration and production to beneficiation and the final gold product).

The present chapter analyses the essential problems of informal mining in this region, suggesting solutions and describing actions taken and to be taken.

7.2.1.1.Work area

The Tapajos gold region is encrusted right in the Brazilian Amazons in the state of Pará. There are thousands of operations dispersed in the area, the majority of which work with the monitor-gravel pump-sluice (caixa) system in elluvial and alluvial deposits. Few mines have heavy equipment (tractors, back hoes, etc.).

The monitor-gravel pump-sluice operations are extremely mobile and move with the work front following the richer parts of the deposit. There are few existing primary mine operations in the zone; it is estimated that these will increase considerably in the near future due to the apparent potential of the zone.

The scope of the project will only cover alluvial and elluvial mining, as it is actually the most important activity. A future phase should consider including the other type of mining in its plan of technical assistance. The environmental impact of a primary deposit operation where mercury is used in the grinding stage, may be several time the contamination produced by alluvial mining.

Before executing the first technical phase of the Project in May 1995, the work area had not yet been defined due mainly to political difficulties. During a series of meetings with the DNPM (Department of National Mineral Production), the AMOT (Association of Gold Miners of Tapajos) and SEICOM (Secretariat of Industry, Commerce and Mining) of the state of Pará. After comparing technical history and logistics of the different alternatives available, finally the garimpo area of Piririma was selected by consensus as the pilot area.

The selection of this area and of the work group was based on the following criteria:

- An operation typical of the zone
- Access facilities (air and river)
- Prior work executed by universities and other related institutions (DNPM, CETEM, universities etc.)
- The technology employed in the Piririma area, having been catalogued at a higher level in relation to the common Amazonia garimpos, served the project to outline a strategy of qualitative, progressive and successive advances for Piririma in particular, and for the garimpagem in general.

The proprietor of the Piririma garimpo is a notable personality in the garimpagem field: ex President of the Association of Garimpeiro Syndicates of the Brazilian Amazonia, and he counted also with the select and experienced human group in gold production.

7.2.1.2. Organizations involved

- **The European Community (CE)**

  The CE finances the project and ICON (IC Consultants, London) is the executing entity, with the support of Projekt-Consult GmbH from Germany responsible for the technical part of the project.

- **National Department of Mineral Production (DNPM)**
  The DNPM is the federal authority for mining in Brazil, the most important counterpart for the project on the technical side.
- **Secretariat for Industry, Commerce and Mining (SEICOM)**
  SEICOM is the state mining authority for the state of Pará
- **Secretariat for Science, Technology and the Environment (SECTAM)**
  SECTAM is the state authority for the environment in Pará
- **Association of Gold Miners in Tapajos (AMOT)**
  It is the local federation of garimpo (concessions) owners
- **Municipality of Itaituba**
  The municipality of Itaituba is linked to the Project activities through its Secretariat for Mining and the Environment.
- **Center of Mining Technology (CETEM)**
  CETM is the federal mining research institute domiciled in Rio de Janeiro.

7.2.2. Alluvial Mining: integrated changes and solutions

Starting from the fact, that for the Brazilian garimpeiros, the environment and possible measures are a luxury, and that it is at a low level in the scale of priorities, the Project made tried to develop a technical package to find solutions. The objective was to satisfy the most urgent necessities of the target group and introduce the environmental concepts of Brazilian mining legislation.

During this procedure it was not only necessary to modify the individual steps in the production process, but also to aspire if possible to an integral and complete improvement of the beneficiation and production cycle.

In regards to the above mentioned strategy, the Project's technical work had to start with an analysis of the problems, both from the technical and economic view point and the environmental aspect.

The most important mining problems of the garimpeiros were the following:

- The preparation of new production fronts, that in many cases have a very low content and do not justify their exploitation; thus, from work that has taken up to three weeks to prepare, no results are obtained;
- Deficient production planning due to the lack of reliable information; frequently, future production areas have been covered by dumps and tailings;

- Insufficient gold recovery in the traditional sluice boxes (particularly fine gold).

As a consequence of the above, serious environmental problems arise that require immediate action to remediate the situation:

- Unnecessary destruction of soils and vegetation whilst preparing production areas
- Bad use of reserves due to deficient production and gold recovery planning
- High metallic mercury losses due to use in sluices (open circuit amalgamation). In addition, mercury vapor is emitted during amalgam distillation
- River muddying
- Stagnant residual waters that become mosquito breeding grounds that transmit tropical diseases (such as anopheles)

A package was developed to face these problems composed of the following individual solutions: A simple drilling technique to prospect new production areas and a statistical evaluation of drilling results (see Photo 54); production planning, including refilling of areas exploited (see Photo 55); improved sluice boxes; an additional upgrading step for pre-concentrates; controlled amalgamation of concentrates (in closed circuit); amalgam distillation in retorts.

The following table shows a series of individual techniques replacing traditional techniques, the repercussions of these innovations in technical and economic aspects, and also the results obtained in the environment (Table 28).

TABLE 28

TECHNOLOGICAL CHANGES IN THE MERCURY PROJECT

TECHNIQUE	TRADITIONAL METHOD	ENVIRONMENTAL IMPACT	OPTIMIZED METHOD	EFFECT ON ENVIRONMENT
Prospection	Garimpeiros locate new exploration area without geologic data, cut trees, remove soil, open large pits (in 2/3 weeks work) to verify quality of gold gravels. Depending on results, continue work or abandon site.	• Unnecessary tree felling. • Artificial lagoons that later breed mosquitoes (Malaria).	Manual drilling obtain samples for analysis after pan concentrate, counting gold particles of each size range, gold content estimated in area drilled and determine if production is viable.	• Block out areas for production with reduced environmental impact. • Vegetation and soil remain intact
Sluice boxes (concentration)	Garimpeiros use rustic sluices: to improve fine gold recovery they add mercury to sluice or directly to the ground, to amalgamate in open circuit.	• Mercury emissions with fine gold and amalgam losses.	Improved sluices help recover fine gold without use of mercury in this stage.	• Liquid mercury and amalgam emissions to the environment in pre-concentrate stage (these are the major part of mercury emissions) are eliminated.
Amalgamation	Amalgamation of gravity pre-concentrates in the sluices in rustic fashion with large quantity of concentrates and mercury in open water flow.	• Mercury emissions with fine gold and amalgam losses.	An enrichment stage with small additional sluice (cubrinha) allows production of small volume of high grade concentrate, that is amalgamated later in closed process (bucket).	• Liquid mercury and amalgam emissions to the environment in amalgamation stage reduced to minimum: amalgamation in bucket with a small quantity of mercury that remains inside, can be thrown into clay hole.
Gold-mercury Separation	Garimpeiros burnt amalgam in open air. In majority of cases the process was done close to or in miners homes.	• Mercury vapor Emissions • Intoxication of garimpeiros and their Families with mercury	Use of retorts allows recover mercury in a closed process for future use.	• Mercury vapor emissions are reduced almost totally.
Land filling, Water decanting	Garimpeiros generally throw tailings to rivers.	• Muddying of rivers • Change river courses • Residual lagoons	Production plan based on new prospection permits more economic work, also fill pits and decant water before re-use.	• Reduced fine & coarse solids to rivers. • Land is almost • restored.

The improved method

Utilize a cheap system, this was the basic principle used for working on improved sluice boxes (“caixas”), they were well known and for this reason had a high possibility of diffusion. Because of the special conditions of the forest, the lack of infrastructure, the frequent mobility of the operations, other sophisticated mechanical equipment was not selected. Additionally, in conversations held with the miners, they clearly expressed that neither would they accept another costly solution that was complicated or required energy.

The point of departure at the “garimpagem” washing installations was once again the low recovery of fine gold in their traditional sluices that work with high wooden riffles mounted on carpeted floors. These riffles produce high turbulence causing high gold loss. The good experiences obtained with sluices without riffles or railings in primary mining (see Chapter 5.4.2.1.2.), have been the basis for experimenting with low turbulence sluices. By working closely with the garimpeiros, experiments were carried out on the floors of the sluice boxes with different types of carpets, sometimes combined with expanded metal.

The comparative tests between improved and traditional sluice boxes were only possible with a parallel installation that permitted simultaneous tests with the same feed material (see Photo 29). As the nature and quality of the feed material is intrinsic and difficult to influence, the parameters for the optimization of the sluice boxes were: width, length, inclination, type of floor lining and the number of these, and the intervals between washing. First, the results of the parallel comparative tests between improved and traditional sluice boxes were evaluated. In order to eliminate feed distribution errors, duplicate analyses were performed, crossing in the twin installations, the lining materials and their inclinations. The vertical zigzag installation brakes the pulp velocity and also, the collision of the pulp at each turn helps to clean off the clay coating on the stones.

As sample taking in a sluicing system fed by a pump is almost impossible during the operation, the tailings were accumulated in an old gulley and subsequently evaluated by systematically drilling this material. The assays of the samples and the statistical handling of the results gave an average value for the tailings. The production obtained in the gullies and the assays of the tailings, allowed the corresponding metallurgical balance to be made. By this means, it was possible to demonstrate that the improved sluice boxes lined only with carpet (Multiouro liso de Sommer, Sao Paulo), recovered more than 90% of the gold [a]. The grain size of the gold was quite fine (65% < 250μm, 32% < 125μm). However, the reduced content of heavy accompanying minerals (<1 kg of black sand per m3), favored high recovery.

A small sluice (called cobrinha, see Photo 30) was used to enrich the concentrates. With this operation, the quantity of concentrate was reduced from about 50 kg to 5 or 7 kg (this is normally carried out every two days), re-cycling the material two or three times with very low gold loss [b].

This reduced volume of concentrate was later amalgamated in a simple bucket with the minimum necessary amount if mercury. The material is easy to amalgamate and required very little contact time and smooth action, with minimum mercury losses in the tailings. The amalgam separated from the black sand with a pan, was then burnt in a Brazilian made retort.

It was demonstrated, that with improved sluice boxes, which were amply accepted by the garimpeiros, fine alluvial gold can be recovered efficiently with recurring to the use of mercury in an open circuit.

As a result of the favorable results and the minimum changes required for the conversion from the old system, this was rapidly diffused in the region even before a formal diffusion campaign was initiated.

Work for the future

For various reasons, the project had only one year of field technical work. This period, only permitted certain types of mining problems in the region to be attacked.

Apart from river bed and beach operations, there are two other types of operations with slightly different problems, such as working in elevated terraces or elluvial-saprolite deposits; or even more different, operations in primary mines. It was not possible to develop and apply solutions for these

a Based on these results, the same types of carpets were used in some dredges working in the River Caroni in Venezuela, with excellent results.

b The use of the cobrinha is nothing new to the garimpeiros. Especially to the old ones who remember the decade of the ’60s when the use of mercury was not common (especially as it was difficult to obtain and very expensive, and their operations were purely gravity (caixa – cobrinha –pan).

cases. Due to the depletion in river deposits, miners are looking for and incur more and more into elluvial and primary deposits. In these types of deposits, the use of mercury in open circuit (elluvial deposits and elevated terraces “mountains”: the use of mercury “in situ” and in the caixas; primary deposits: in hammer mills, in “jackpot” type amalgamators and amalgamated sheets) is generalized, and with excessive mercury losses. There is an urgent necessity to dedicate efforts to this new problem in the area.

Finally, it should be stressed that the success of the project depends above all on the personal dynamism with which these techniques have been diffused. The diffusion, in major part was carried out without external support and only by copying proven and successful solutions. In the special case of prospection techniques, a group of independent consultants (formed by ex members of the garimpeiro work team) has been formed, that evaluates drilling results for other garimpeiros and interested companies. This should be proof that the “win-win-options” as solutions to environmental problems can be implanted voluntarily by the miners –also informal- that are open to innovations.

7.3. Ecuador: Project for Mining without Contamination (PMSC) Collective studies on environmental impact.

7.3.1. Project presentation

Small mining in Ecuador, the majority of which is gold mining, is composed of artisan miners, partnerships, cooperatives and mining companies that are dedicated to ore production and beneficiation involve directly or indirectly about 100,000 persons.

From April 1993, the CENDA Foundation (112) advised by the consulting firm Projekt-Consult GmbH and financed by the “Swiss Agency for Development and Cooperation” (SDC), executes a project “Mining without Contamination” (PMSC); that is currently in its second phase of operation until 1999.

This project is of a pilot nature and is a pioneer in two aspects: it is the first environmental project for the mining sector financed by SDC, and is the first mining project in Ecuador directed towards minimizing the practice of environmental contamination by the small gold mining activity.

The project seeks to achieve its objective by applying a strategy of equilibrium between economy and ecology, through technical assistance for the miners, creating a consciousness in the population and environmental control in coordination with the authorities.

ILLUSTRATION 13

LOCATION OF THE ZARUMA/PORTOVELO REGION

The project region (Zaruma-Portovelo) and its environmental problem

Zaruma and Portovelo, two communities that form the region with the major mining tradition in Ecuador, are located in the El Oro province to the southwest of Ecuador. The region is in the western foothills of the Andean mountain chain at an altitude of between 600 and 1,600 meters above sea level. Hydrographically, it is in the basin of the rivers Puyango-Tumbez that after crossing the frontier with Peru flow into the Pacific Ocean.

This region is characterized by its environmental (113), mining (114), technical ((115), social (116), and legal complications; a zone in which, if corrective measures are not taken, could affect important economic and social sectors in southern Ecuador and northern Peru (117) in the immediate future. Examples are: The use of highly contaminated water for irrigation and human consumption in the semi-desert region in the Ecuador/Peru frontier zone, and contamination of the tributaries and sea waters used by the shrimp industry on the Ecuadorian Pacific coast.

The project group target

In accordance with the social-economic organization (116), the persons dedicated to mining can be grouped as follows:

- **Artisan miners**: Those that work gold vein mines (informal) and those that lease beneficiation plants to mill their ore. They control the amalgamation process and recover amalgamated gold.
- **More or less organized miners**: Grouped into companies, partnerships or associations de facto or legal. These groups are generally dedicated to vein mines and ore beneficiation. They are economically more solid (the majority of these groups are legalized, but there are also some informal groups).
- **Owners of ore beneficiation plants**: These are a group that offer the artisan miner their treatment services gratuitously in exchange for the mill tailings which they subsequently cyanide and recover their milling costs and profit (a great majority of the owners are informal).

- **Organized mining companies**: These are few in the zone and they work with adequate technology for production and ore beneficiation (these operate legally).

Environmental contamination is produced mainly by the treatment plants. The proprietors of these installations (groups 2,3 and 4), are consequently the principle target groups. The project via ECO+ is directed at them. In a parallel manner and due to the mercury contamination, the project also focuses on the artisan miners (group 1) using consciousness measures and demanding of the installations proprietors, adequate areas for amalgamation.

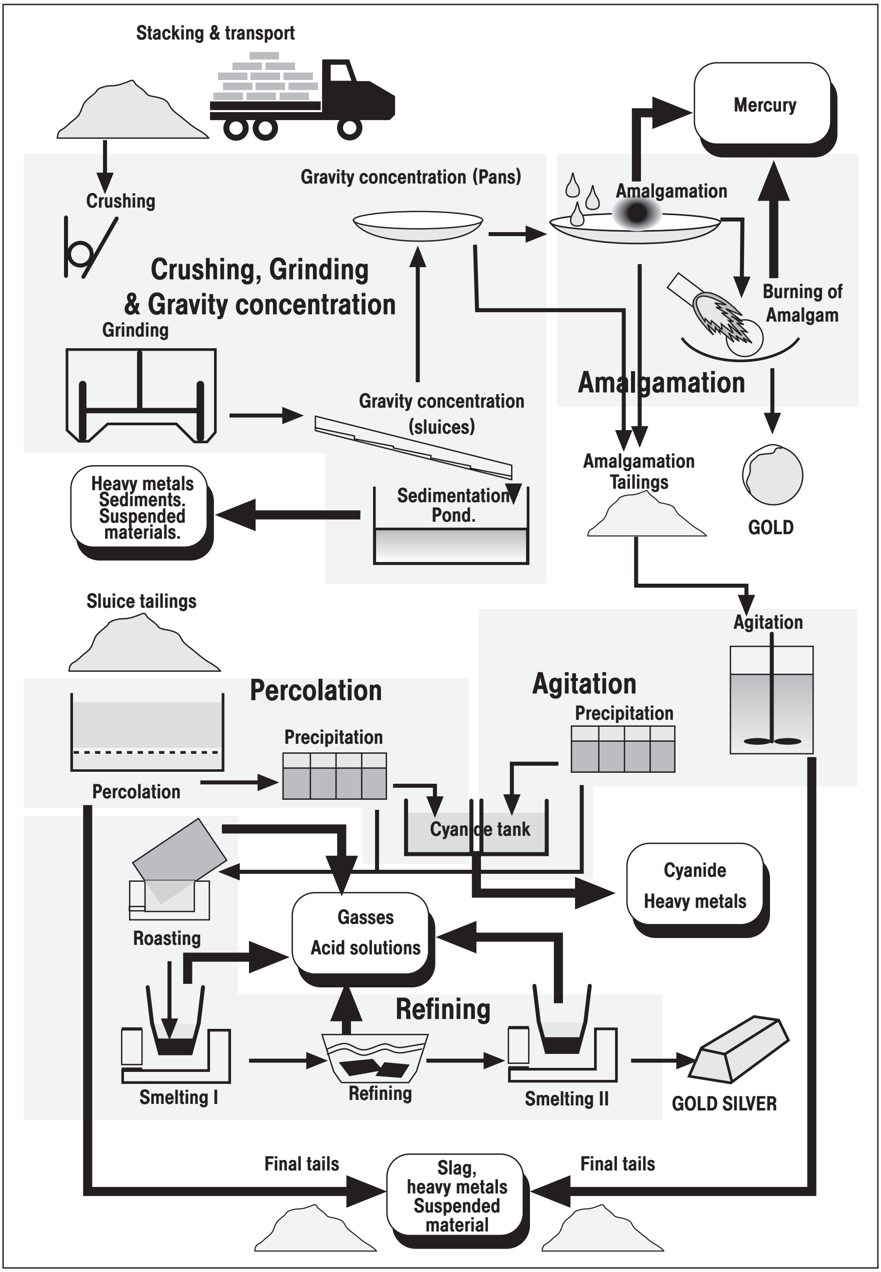
Production levels and contamination

The ore beneficiation process in the region, consists generally of the following phases:

- Crushing and grinding
- Gravity concentration in sluices
- Concentrate amalgamation
- Tailing cyaniding by percolation or agitation
- Smelting and refining.

ILLUSTRATION 14

GENERAL FLOW SHEET OF BENEFICIATION PLANTS IN THE ZARUMA/PORTOVELO REGION



The installations are characterized by different combinations of the models shown, this permits classifying the installations according to their flow sheets. A total of nine different combinations (or flow sheets) were identified. All fall into the generalized diagram in Illustration 14 and differ only by the absence or presence of one or another component (118, 119).

The principle gold and residue production parameters are summarized in Table 29.

TABLE 29

METALLURGICAL AND ENVIRONMENTAL PARAMETERS

GRINDING AND GRAVITY CONCENTRATION PROCESS	
Number of grinding unit	150 (estimated)
Tons per day per day per grinding unit	10
Tons processed per day (grinding)	1500
Gold recovered per ton	10 g/t
Daily gold production	15 kg.
Annual gold production	4000 kg
CYANIDE PROCESSING	
Tons cyanided per month	40000
Gold recovered per ton of sand	5-6 g/t
Gold production per month	200 kg.
Gold production per year	2400 kg.
ENVIRONMENTAL RESIDUES	
Tailings production (in the form of suspended solids, sediments & ponds) 48000 t/yr	
Heavy metal sulfides in tailings	35000 t/yr.
Mercury	7000 kg/yr
Cyanide	6000 t/yr

Fields of action

Social

Community participation in the change processes is of vital importance for their sustainability, so that in order to achieve social integration, complementary activities consisting of measures to create confidence, community organization, objective information on the true situation, environmental sensibility, involvement of health professionals, use of communications media, etc. These activities are directed towards:

- Groups not involved (local authorities, leaders, ecology groups) or indirectly involved (women, children) with mining, with the objective that they assume leadership roles over a medium or long term period for the protection of their environment and their health. *(Examples of activities: Ecological competitions and prizes, Child dining hall program, Goldsmithery program, Diffusion of information material (monthly publications, videos, exhibitions, seminars, radio campaigns), joint actions with the Ministry of Health etc.*
- The miners, so that it is they that improve technical-mining and health conditions in their places of work.

(Examples of activities: Occupational health programs jointly with other ONG's and OIT. Diffusion of safety manuals, Diffusion of the monthly publication "Boletin Minero", Radio programs etc.)

Technical-environmental

Activities in the technical field promote changes in environmental management by applying and diffusing environmental techniques adapted to local conditions, training and legal-administrative incentives (Plan ECO+; sub-title 7.3.2.). Additionally, an element of control and environmental audit was included (complying with the environmental management plan).

(Examples of activities: Plan ECO+ collective studies of environmental impact and collective plan for environmental management; application of techniques for the mitigation of mercury emissions, heavy metals, solids in suspension, cyanide, smelting and refining gasses, dust, noise, etc; feasibility study of post- processing and cyanided sand decontamination (120); space planning and creation of green areas; etc.).

Institutional

Activities in the institutional field are directed to the inside and outside of the project. In the interior of the project, profound reinforcement of the national counterpart is sought. Externally, increase existing cooperation on a formal and informal level by the interchange of experience bi and multilaterally, achieving project reinforcement by other institutions. By obtaining cooperation from government entities (NEM, DINAMI, DINAPA, MSP, MOP, municipalities etc.) and international institutions (World Bank, OPS, OIT, etc.); in an effort to support the creation of a viable form of environmental control and management (environmental administration) that is applicable to small mining, and at the same time receive the legal support for its application (Obligation and audit component). Cooperation with other similar and/or complementary projects has the final objective of interchanging experiences and unite efforts to achieve common objectives.

(Examples of activities: Cooperation with MEDMIN and PRODEMINCA projects; Agreements with OIT, MEM, MOP, universities, etc; Creation of the Commission for Environmental Administration of the local Municipalities; Cooperation with the Chambers of Mines, APROPLASMIN, etc; Participation in International Seminars organized by the World Bank , European Community, ONUDI etc; Creation and coordination with the "Mercury Network"[a] on the Internet; etc).

7.3.2. The central axis of the project: Plan ECO+

Legal situation with regards to environmental impact studies in Ecuador

According to the current mining and environmental legislation in Ecuador (121), every natural or legal person dedicated to mining activities must be authorized by his mining title (exploration, production and beneficiation concession) or an operating permit granted by DINAMI (The National Mining Directorate). The granting of this title or permit signifies for the miner, the obligation to present a study on environmental impact and environmental management plan, revised and approved by the Undersecretary for Environmental Protection through DINAPA (National Directorate for Environmental Protection).

The mining-environmental legislation in Ecuador does not differentiate between small, medium or large scale mining. Thus, environmental protection is focused principally on the need to introduce adequate environmental management for medium and large mining, as in some of its aspects it is of difficult application to small mining. In practice, the environmental impact studies are not presented by the majority of small miners due to its elevated cost.

a The "Red Mercurio – Mercury Network", an internet discussion space, has the objective: to interchange information on the use and effects of mercury related to gold mining, diffuse the results of research and projects, join efforts, avoid duplicities and optimize resources. The address is: http://www.geocities.com/rainforest/8985/mercurio.html

Because of this, many miners in the past have not been able to leave their informal status. This on the other hand, is the principle obstacle for their development. The investment required for a mining venture is high; not only for medium or large mining, but also for small mining, taking into consideration the social-economic situation of the micro operators.

As mining is a high risk economic activity, it is understandable that operators try to minimize their investment. If, added to the geologic and economic risks there are political and legal risks, as in the case of informal mining, it is obvious that the miners wish to legalize their operations. Over a medium and long time period (sometimes also a short period), legalization costs (patents, royalties etc.) are less than the cost of remaining informal.

Thus, the necessary “hook” in order to offer a “win-win” option to the miners, was found in their desire to become legal and their necessity to present an environmental impact study (122).

The ECO+ Plan: an innovative incentive for the application of environmental measures.

The counterparts of the Mining without Contamination Project (CEDA Foundation and Projekt-Consult GmbH) developed the concept of the PLAN ECO+ (Collective Studies on Environmental Impact and Collective Plans for Environmental Management for Mining) in 1994 (123, 124, 125,); with the central idea of:

Mine workings of similar technical characteristics, within similar environmental characteristics, have the same environmental impacts, and as such, the mitigation measures to be applied are similar.

In this manner, a collective environmental impact study with a collective environmental management plan can be representative of an environmental reference framework for a large number of installations in the area.

By means of a mechanism for “affiliation to the PLAN ECO+”, the environmental measures anticipated in the Collective Study can be individualized and applied through a mutual agreement between miners, the project and the competent authorities. In this manner, the strategy is based on a tri-partite cooperation between the Ministry of Energy and Mines, the miners and the national counterpart of the project.

AsR, ECO+ commit to:

- **The CENDA Foundation–Mining without Contamination Project**
  - To carry out collective studies for mining areas with similar technical and environmental characteristics.
  - To present and obtain approval of the studies and plans for collective environmental management that can be executed by the small miners.
  - Develop a mechanism or tool for the control and follow-up of the environmental management plan.
- **The Government**
  - Through a Ministerial agreement, will authorize the CENDA-PMSC Foundation to execute the ECO+ plans in the zone.
  - To receive, analyze and, finally approve the studies and plans for the programmed environmental management.
  - Support legally and administratively the follow-up and control for the application and compliance with collective environmental management plans.
- **The miners**
  - Affiliate themselves to the ECO+ Plan through the subscription of environmental investment agreements.
  - To invest the amount of money that an environmental study would have cost (cost of private consultants) in the application of environmental measures (environmental management plan) in their own installations.
  - To comply with, individually and collectively, the recommendations of the environmental management plan.

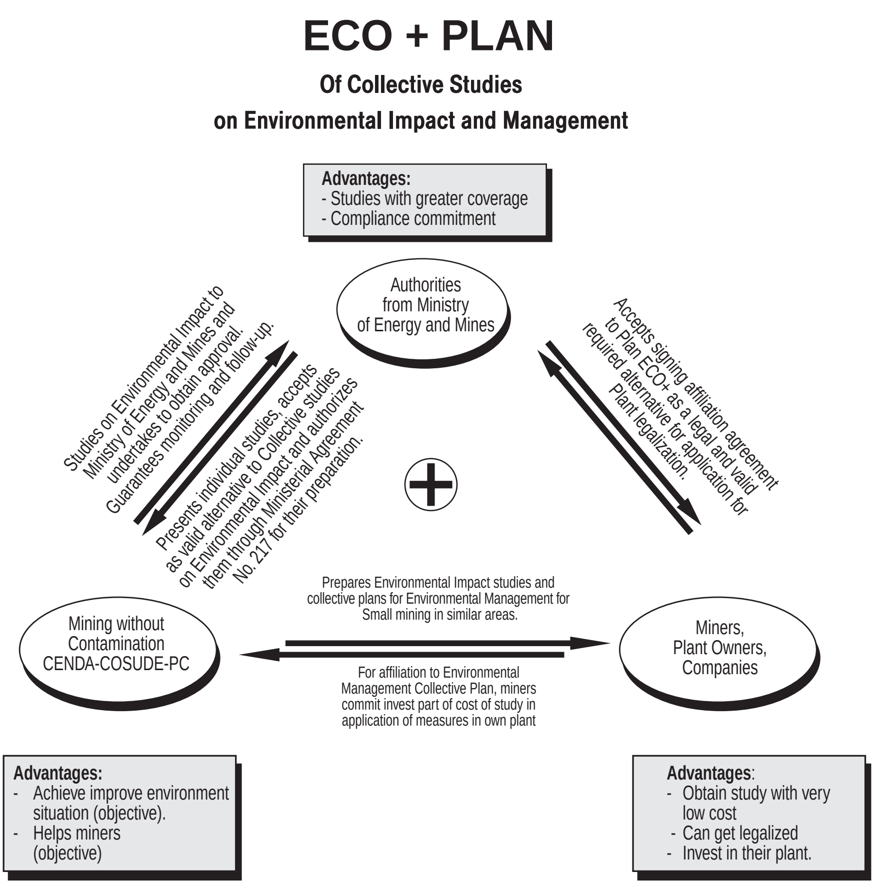
The incentive for the miners is that they are offered an affiliation to the ECO+ Plan as a legally valid alternative on presentation of the individual environmental impact study. The advantages consist of, the saving of the cost of contracting an EIAPMA study, and avoid the procedures involved in the presentation and approval of the same by the authorities in Quito. An additional obligation for the miner, apart from the normal compliance with the environmental management plan, is to formalize an economic obligation guaranteeing the application of environmental measures (Agreement of Environmental Investment, backed by a performance guarantee issued by a bank).

The ECO+ PLAN was proposed and accepted by the Ministry of Energy and Mines in Ecuador; which, through Ministerial Agreement No. 217, of August 31, 1994, authorized the CENDA-PMSC Foundation to effect collective environmental impact studies in the mining region of Portovelo/ Zaruma (126).

Thus, the project commenced towards the end of 1994, with the preparation of the first collective study of environmental impact on the grinding and ore beneficiation plants located in the valley of the river Calera, and named ECO-Calera as a "pilot" operation.

ILLUSTRATION 15

INSTITUTIONAL INTER-ACTIVE SCHEME OF THE ECO+PLAN



7.3.3. Application of Plan ECO+

The ECO-Calera study

The sub-region of the river Calera/Salado was selected for a pilot study. The river Calera plain covers an area of 13 km^2 and has about 50 mine installations (milling and cyanide plants), spaced along the length of the river, from the union with the river Amarillo to the river Salado.

At the initiation of the first collective environmental impact study, the methodological structure for collective studies was started together with the design of the tools for their subsequent application, as no similar or comparable projects were known (127, 128, 129). At the time the work was carried out by the project team (an interdisciplinary team of 11 professionals divided between plant, consultants, national and international personnel) (48, 130, 1131, 132, 133, 134, 135, 136, 137, 138, 139 and 140) that allowed "ECO-Calera"(141, 142) as the project was named, to count with the following components:

- Diagnosis of the environmental situation of the river Calera
- Evaluation of environmental impacts
- Environmental management plan
- Monitoring and environmental administration plan.

Due to the pilot nature of the study and the application methodology, the preparation of all the documents required to obtain the definitive approval of the Authorities, required two years work. At the same time, ECO-Calera was made known amongst the communities and miners involved; this received a very positive answer.

The tables in annex 2, show in a condensed form , the results of the environmental diagnosis and the environmental management plan (143).

Application scheme

In order that the present study, approved by the competent authorities of the Ministry of Energy and Mines, be valid for a miner (as a legally valid alternative to an individual environmental impact study), it has to be in strict compliance with the Ministerial Agreement No. 217; that is, the miner must sign an Environment Investment Agreement with the CENDA-Mining without Contamination Project.

Once the Environmental Investment Agreement has been signed and protocolized, the miner is subject to compliance with the dispositions of the Ecuadorian Mining Law with respect to environmental protection, with a double commitment:

- The commitment contemplated in the law; with mining, health, municipal and other authorities, to apply the provided mitigation measures in the environmental management plan which is irrevocable in the same manner as those in a contracted individual environmental impact study presented by the author.
- The commitment, sustained by the Agreement with the CENDA-PMSC Foundation for the application of the environmental measures of the Environmental Management Plan, in his mine workings. The agreement contemplates the delivery of a performance bond for the environmental measures.

Once the agreements with the miners have been signed, the “individualization” of the collective study commences, in other words, the definition of those environmental measures in the environmental management plan that each miner has to apply. In order to facilitate application, the Collective Environmental Management Plan (Macro Plan), has been designed in a modular form:

- An analysis of all the flow sheets applied in the region, permitted the establishment of process phases that are common to several installations.
- As each of these phases has an environmental impact (e.g. amalgamation produces mercury emissions), all the plants that use this module in their process, will have to apply the corresponding mitigation measures. (In the case of mercury: Amalgamation is a closed process in amalgamation drums; the use of retorts for burning amalgam, the installation of filters for NOx gasses [see Photo 53], and others).

The individual environmental management plan (Plan micro) for each plant consists in a brief analysis on:

- The process phases (modules) used in the flow sheet and,
- which of the environmental measures and adjustments (144, 145, 146 and 147) provided for in the Macro Plan are applicable in the installation and which are not relevant..

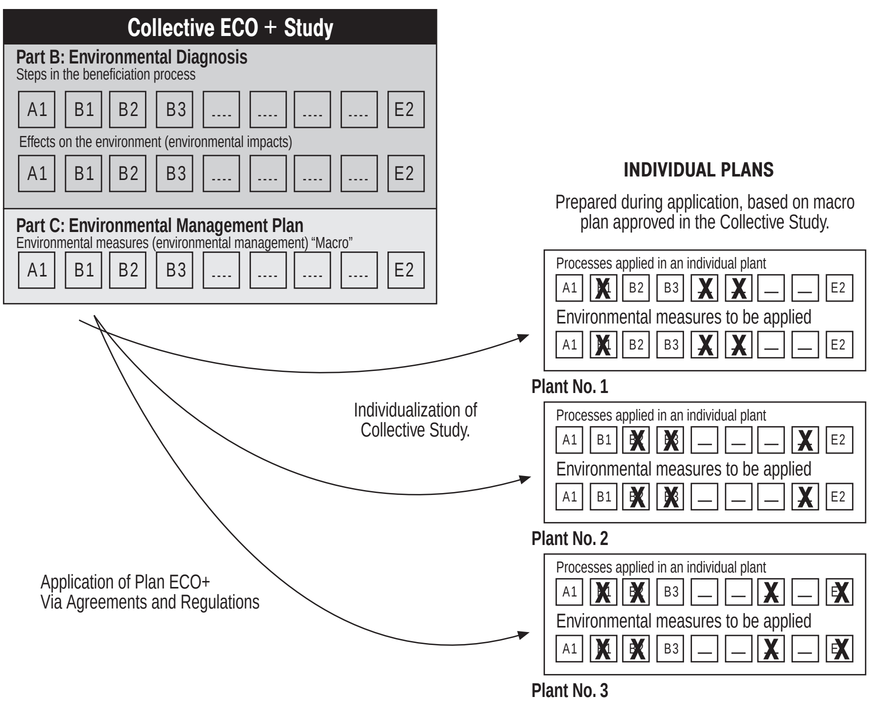
In a certain manner, the Micro Plan consists of a check list (148). Also in the micro plan (PMA-individual), time periods are established for the application of each measure.

In the case of no fulfillment of the commitments acquired by the miner, the following sanctions may be applied:

- In the case of no fulfillment of the Environmental Management Plan, the authorities from the Ministries of Mines, Health and the Municipalities, will impose the sanctions provided in the Laws of the Republic and Municipal Ordinances that refer to environmental protection.
- In the case of no compliance of the commitment with the CENDA-PMSC Foundation, the miner will lose the economic guarantee delivered, “guarantee of true compliance with the environmental measures”, this same may be used for the application of environmental measures on the part of the project.

ILLUSTRATION 16

INDIVIDUALITY SCHEME OF THE ENVIRONMENTAL MANAGEMENT PLAN



Practical application

In view of the increasing pressure on the part of the community in favor of environmentally clean mining, and the pressure from the authorities to legalize the mining sector, the proprietors of beneficiation installations commenced organizing themselves during 1996 and formed the “Association of Plant and Mill Proprietors”, APROPLASMIN with the objective of jointly obtaining their operating permits. This circumstance fitted perfectly with the intentions of the project (and was provoked to a certain degree), as through APROPLASMIN it was possible to count on a counterpart organization for the application of Plan ECO+.

Thus, during the second semester of 1996, parallel to the approval of the study by the competent authorities and as a result of an open dialog with APROPLASMIN and the DINAMI regional office (responsible for granting operating permits), the signing of an Cooperation Agreement between the parties involved was achieved.. The commitments are, that: 1.- DINAMI will provide maximum facilities to the proprietors of installations affiliated to Plan ECO+ to legalize their operations; 2.- The Miners Association will include the demands for environmental measures in their statutes, and 3.- The CENDA-PMSC Foundation will give preference to members of APROPLASMIN in the affiliation process for ECO+, and at the same time undertake the role of environmental vigilance for the installations.

Once the agreement between CENDA and APROPLASMIN was signed and the final approval of the ECO-Calera study was received from DINAPA, the practical application phase commenced in December 1996; in other words, the reception of affiliation applications for Plan ECO+ (river Calera/Salado). The acceptance on the part of the miners in this phase surpassed all expectations of the project:

> *During the whole period of study preparation and of the affiliation mechanisms, the thought was that the affiliation as such would be a much more difficult process requiring arduous work to convince each one of the proprietors of the advantages of being affiliated to Plan ECO+.*
> *In practice, the majority of proprietors almost immediately approached the project offices to present their applications.*

In this way, about 75% of the installations had presented their affiliation by the end of December and by March 1997, 85% of the installations in the Calera sector were affiliated to Plan ECO+.

During the affiliation process that consists of the following steps,

- Presentation of the application
- Verification of the application by the project technical staff
- Payment of the affiliation quota by the miner
- Presentation of the required documents by the miner
- Presentation of the performance bond by the miner
- Signing of the agreement between CENDA Foundation and the miner

Certain inconveniences arose, particularly with regards to the performance bond for which initially, a letter from a bank was required. As the banking system is not sufficiently prepared to offer a dynamic service to the client, the bank requirements for the issuance of guarantees were so exaggerated that the project was obliged to accept draft notes registered with the properties registrar.

Once the agreements were signed, the stage defining “micro plans for environmental management” commenced as from March 1997. In technical visits to each of the installations, the environmental measures to be applied based on the “Macro Plan” were established by mutual agreement with the proprietors. Additionally, with the objective of providing a clear vision for the miner, detailed platting with all the changes required was carried out. At the same time, a series of technical conferences were held to instruct the miners on the application of the environmental measures.

An important factor for the credibility of the program was, precise compliance on the part of the authorities from the Ministry of Energy and Mining with their commitments, and DINAMI commenced the proceedings of the applications for the operating permits. By the end of July ’97, the first 26 mining titles were delivered!

7.3.4. Reproduction of the Plan ECO+ in other regions

The fact that the pilot area “river Calera/Salado” did not cover the entire Zaruma-Portovelo region, initially provoked a bad feeling amongst the proprietors associated to APROPLASMIN that are located outside of this sector. They considered affiliation in the Calera sector as being unfair treatment and requested that they be taken into account in the same manner. In several urgent meetings in January and February 1997, the most adequate manner of involving them was searched for. It was made clear at the meetings, that the objective of the project is not the preparation of environmental impact as a subsidy to the mining sector, but rather the development of new models and concepts, that in the future can fortify the mining sector and benefit the environmental situation for the population in general.

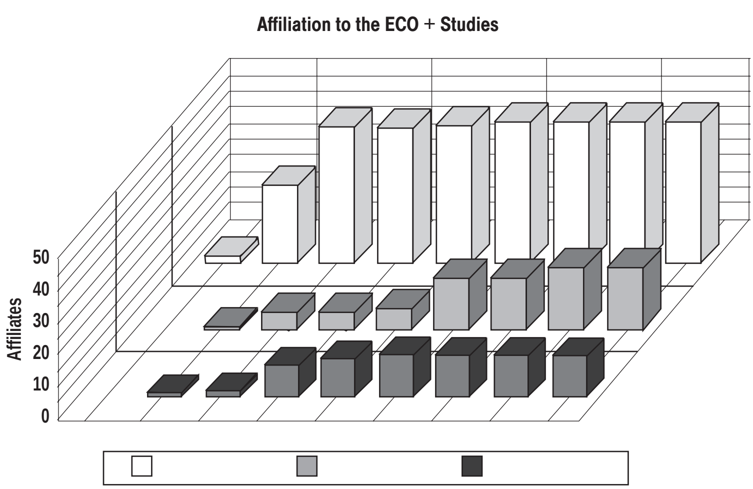
This argument permitted the miners to accept an auto-financing scheme for future collective studies and their application, distributing their costs amongst the beneficiaries.

The theoretical framework of Plan ECO+, permitted establishing two other study areas in the Zaruma/Portovelo region that complied with the "… similar environmental characteristics …" requirement, these are the river Amarillo plains and the upper plains of the Zaruma and Portovelo counties.

Thus, 38 applications were presented by the proprietors of installations located in the ECO-Amarillo and ECO-Alto areas by the end of June, each one voluntarily committing to pay between US$500 and US$1,500 affiliation fees. The reception of these funds permits the execution of two other environmental impact collective studies that will be called, "ECO-Amarillo" and "ECO-Alto". With these two ECO studies, it is hoped that the majority of installations in the region will become involved in the regional environmental management Plan.

ILLUSTRATION 17

STATISTICS OF AFFILIATIONS TO THE PLAN ECO DURING THE PERIOD DECEMBER 1996 TO FEBRUARY 1997.



The process of applying the ECO+ plans in the Zaruma/Portovelo region by the end of 1997 (after almost 4 years of project work), has reached a certain level of auto-dynamism. At meetings called by the affiliates of the ECO+ plan with mining and health authorities, the miners started to demand that the same pressure be exerted on all those not disposed to work in an environmental manner.

7.3.5. Sustainability and self-administration of the Plan ECO+

The program, originally conceived as incentive and tool for the diffusion and application of environmental measures, has become a complex system of inter-action among different individual actors and institutions.

A pillar of sustainability of the ECO+ Plan (149) is the **auto-financing of future studies on the part of the beneficiaries**. The calculation of the affiliation amount, covers not only the study preparation costs, but also a reserve for future follow-up.

The second pillar of sustainability consists of the **involvement of local institutions in environmental monitoring and consequently, in environmental administration**: so that in the future, the local institutions will slowly begin to intervene in environmental matters in their region. For this purpose, the creation of an inter-institutional commission (Commission for Environmental Administration –COGEAM) on a local level has been considered, composed of representatives from the municipalities, mining authorities, health authorities and representatives of the civil population. The recent creation of departments for the environment (DEMA) in two of the four municipalities in the region, can be considered as a first step towards this end.

The third pillar should be environmental conscience created in the population in general through sensibility programs and environmental education. The main “hook” is the health theme that is intimately connected to family welfare. The community can – and it has been experienced on several occasions – play an important role in pressuring the authorities and the miners, to adopt certain attitudes. Within the community, it is principally the women, children and juveniles, a target group of major priority for the creation of pressure groups, and for the conversion of environmental conscience into environmental motivation. The application and adjustment of transverse themes (such as “gender”) is therefore, a job of great importance in the search for the sustainability of the project.

7.4 Developments in Environmental Management of Small and Medium Scale Gold and Diamond Mining Industry of Guyana

1.7.4.1 Introduction

Guyana lies on the northeast corner of South America. It is bounded by the Atlantic Ocean in the north, Venezuela to the northwest, Suriname to the east and Brazil in the south and southwest. It lies between 1 to 9o north latitude and 57 to 62o west longitude, and has an area of 215,000 square kilometers. The capital city is Georgetown. The country obtained independence from Britain in May 1966 changing its name from British Guiana to Guyana. The population is estimated to be about 800,000, more than 90% of whom live on the coastal plains. The population has been impacted by significant migration - it is estimated that another 800,000 persons of Guyanese descent dwell in North America and a significant number reside in Europe.

Historically, sugar, rice and bauxite production dominated the economy, accounting for a large share of export earnings. With the introduction of large scale open pit production at Omai Gold Mine in 1993 and improved production by local small and medium scale operators, gold production plays an important role in the economy, with export earnings that exceed that generated for rice, sugar and bauxite. Local small and medium scale operators produce about 27% of the declared gold production and all of the diamonds won in Guyana. Declared gold production from small and medium scale miners accounted for % of export earnings Bauxite production is on a large scale but production has declined sharply in recent years.

Gold and diamond mining take place in the interior away from the coast, mainly in the northern, western and central parts of the country where generally infrastructure is not well developed. Therefore, river and air transport are important, and transportation costs are generally high. The ease with which mining equipment can be transported is therefore important, particularly for small and artisanal operations.

Geologically, Guyana forms part of the Precambrian Guiana Shield of South America. Two distinct regions, termed the Northern Province and the Southern Province have been recognized. The Southern Province consists of dominantly Archean rocks of the Proto Kanuku Group which have been subjected to Proterozoic phases of deformation. Early Proterozoic sediments, volcanics and granites, of equivalent age to rocks of the Northern Province also occur. A rift valley, the Takutu graben, separates the Northern and Southern Provinces. It is infilled by Jurassic-Cretaceous sediments and volcanics. The Northern Province consists of the granite-greenstone association of the Barama-Mazaruni Supergroup and the granitic-gneissic association classified as the Bartica Assemblage. Both assemblages are intruded by Younger Granites of Proterozoic age. The Northern Province is unconformably overlain in the southwest by the Roraima Group represented by terrigenous sediments of Proterozoic age. Much of the alluvial gold production in Guyana comes from deposits resulting from the weathering of rocks of Northern Province. While the primary source of the diamond in Guyana remains unresolved, they are regarded as secondary deposits recycled from the Roraima Group. Coastal areas of the country are covered by Tertiary Sands and Clay deposits.

The first recorded instance of gold mining in British Guiana was in 1720, but no extensive operations were carried out until 1884. The mining laws were enacted in 1880 and alluvial diamonds were discovered in 1887. The highest annual declared production of gold was 455,918 ounces in 2001of which Omai Gold Mine produced 354,069 ounces (78%) and local small and medium scale operators produced 101,849 ounces (22%). Declared gold production for small (and medium scale) producers peaked at 138,528 ounces in 1893. Declared diamond production began to increase from 1991 and successively peaked in 2001, 2003 and 2004 at 179,463, 248,437 and 412,537 metric carats respectively largely due to the introduction of Brazilian cutterhead river dredging technology and increasing use of Lavador (Brazilian jig) in land dredging. The highest declared production before that time was 214,474 carats in 1923 when artisanal methods were used. Gold has been produced by surface and underground mining (mainly surface mining) while diamonds have been mined by surface methods.

2.7.4.2 Practices in Small and Medium Scale Gold and Diamond Mining in Guyana

Small and medium scale gold and diamond mining operations constitute the great majority of mining operations in Guyana. These operations earn significant foreign exchange (7.5% of national export earnings in 2002) and provide employment for approximately 10,000 miners who are mainly Guyanese. Additional employment is generated through services for mining operations provided at traditional "Landing Places" near to mining operations, in mining communities, and based on the coast. Notably, mining provides major support to the air, road and river transport services, and is the basis of the local jewellery industry which primarily manufactures gold and diamond pieces.

The concept of medium scale mining was introduced in 1991 with the promulgation of the Mining Act 1989. The Mining Act 1989 distinguishes small and medium scale mining by the size of the concession, with small-scale mining conducted on Claims and medium-scale mining on areas held under medium-scale Permits. Only Guyanese can hold title to Claims and medium-scale Permit areas, but Guyanese Claim Licence and Prospecting and Mining Permit holders may form partnerships with foreign investors. Small and medium scale mining in Guyana mainly consists of gold and diamond mining operations by local producers. However, foreigners, mainly Brazilians, have traditionally been involved in small-scale mining in Guyana, and they are presently involved in medium scale mining as well. Throughout the history of small (and medium) scale mining in Guyana, Brazilian miners have made a signal contribution to technological advancement, resulting in increased production capacity and production of diamonds and gold.

Small and medium scale gold and diamond mining in Guyana are done by non-mechanized (artisanal), semi-mechanized and mechanized methods. Alluvial and eluvial deposits are generally worked obviating the need for blasting, crushing or grinding. Where eluvial deposits are worked, the zone of surface enrichment is treated as an alluvial deposit. In some instances, quartz veins are worked with hand crushing or the application of powered stamp mills. Artisanal methods are confined to small-scale operations, whereas semi-mechanized and mechanized practices are employed by small and medium-scale operators. Operations are land or river based with land based operations predominant over the last decade. Mining and processing methods have evolved over the 140 odd years of gold and diamond production. It is noteworthy that the sluice box with improvements in riffles and matting, and the battel (gold pan) are still the principal equipment and amalgamation is the main method used for recovering gold.

The ubiquitous sluice box is essentially an open ended elongated wooden or metal box with a sloping channel fitted with some form of crude or refined riffling and/or matting on the floor to collect the concentrate. Sluice boxes are of low capital cost, require low operating costs and are simple to construct with wood from the surrounding forest or from galvanized drums. They can be made to varying sizes to accommodate the different volumes of slurry that are being processed and to enhance their mobility. The gold or diamond bearing heavy minerals pre-concentrate is trapped on the matting at the bottom of the sluice box. The pre-concentrate from the sluice box is recovered by washing the mats in water and collecting the concentrate in a container. This is further upgraded using a battel or multiple sieves are used to recover diamonds in a process called “hand jigging” where jigging and rotary movements are combined to apply both centrifugal and gravitational forces to concentrate the diamonds at the bottom/centre of the sieve. The concentrate from the battel is amalgamated with mercury followed by burning of the amalgam to recover the gold.

Miners initially worked shallow land deposits for gold and diamonds by hand using simple portable tools and equipment such as shovels (criminels) for excavating the overburden and pay gravel, small, sluice boxes called “toms,” “battels,” and sieves for diamond recovery. The “tom” incorporated a perforated drum, which screened the slurry before it was passed into the sluice. Only the pay gravel was processed by “washing” through the sluice or “tom.” This work has been extensive, and with geological exploration, it forms the basis for current small and medium scale gold and diamond mining operations which typically employ limited prospecting.

After shallow land deposits were exhausted around 1945, the first attempt to exploit deep riverbed diamond-bearing gravel deposits was made in 1947 by Brazilian miners using primitive diving equipment. Use of a diving helmet and air supplied by means of a hand-operated compressor allowed the miner to work underwater for hours, sending gravel to the surface in sacks filled using a short handled shovel. Diamonds were recovered from the gravel by “hand jigging.” This advancement soon spread to many parts of British Guiana and was used to exploit both gold and diamonds. This was a slow process only suitable for working rich deposits and consequently, it soon fell into disuse.

Mechanization was first introduced as early as 1901 when a bucket dredge was tried in the Barama River in 1901 by the British Guiana Dredging Syndicate. It was transferred in 1904 to Gilt River, a tributary of Omai River.

In both areas the operation was not successful enough to sustain the work. Other bucket dredges were installed in the Potaro District from 1951 but these operations ceased after 1958 due to engineering, planning and management problems.

A semi mechanized form of river mining known as suction (gravel pump) dredging was introduced in 1958 and its use became common in the 1960's. This allowed small scale miners to work previously inaccessible deposits on the beds of the deeper rivers and creeks and to substantially increase their production capacity. The introduction of the suction dredge was marked by increases in declared diamond production in the 1960's.

The suction dredge consists of a mechanical centrifugal gravel pump installed on a floating raft or "pontoon" attached to airtight suction pipe with the intake end on the riverbed. Suction dredges were initially operated in conjunction with divers who manipulated the intake pipe on the riverbed, but subsequently this was done by means of a winch, obviating the need for a diver and making the process fully mechanized. The mechanized river suction dredge was called the "diver-less dredge." Introduction of the "diver-less dredge" led to the mining of riverbanks where the banks were undermined and allowed to collapse. As the riverbeds became depleted riverbank mining became increasingly widespread.

Dredge capacity progressively increased from an intake pipe diameter of 4 to 14 inches (9 – 36 cm). Processing of the gravel was done by correspondingly larger sluices to cater for the larger throughput of slurry, followed by amalgamation for gold and sieving for diamond recovery. When riverbed deposits are worked, relatively little turbidity results, but sandy tailings mounds pile up on the riverbed often extending above the water level. However, when clayey riverbanks are worked with the "diver-less dredge" much turbidity results from the tailings, in addition to the tailings mounds.

Due to the exhaustion of high-grade riverbed gold and diamond deposits, the use of river suction dredges declined, paving the way for the introduction of semi mechanized "land dredging" in the early 1990's. The operations are called "dredging" because like the river suction dredge, they employ centrifugal gravel pumps to uplift the slurry and deliver it to the sluice box via airtight pipes. Hydraulic mining or hydraulicking using pressurized water jets operated by miners is employed to excavate and disintegrate gold and diamond bearing ore and overburden material.

Overburden and ore material washed away from the pit face flows into a sump at the lowest part of the pit where a miner uses a gravel pump, usually with an suction intake pipe 3 to 6 inches (8 to 15 cm) in diameter, to deliver the slurry without prior screening to the sluice box. In some instances, miners put mercury into the sluice box and directly on the pit floor below the face that is being mined in the belief that this will increase gold recovery.

The overburden waste consists of loose clays and sands while the pay-gravel usually consists of unconsolidated sands, gravels and lesser clays. Typically, ore and overburden from “land dredging” operations contain more clays than riverbed deposits. Because hydraulicking does not discriminate between overburden and ore, both are mined and processed giving rise to the generation of a large amount of tailings with high clay content. When discharged into streams these tailings cause dense turbidity (muddy) plumes with a strong visual impact which are transported downstream and sometimes persist in the streams.

To enhance its mobility to poorly accessible working grounds, the typical “land dredge” and sluice box assembly is much smaller than the average river suction dredge. Accordingly, the cost of a typical “land dredge’ is less. The number of “dredging” units increased tremendously compared to the heyday of the river suction dredge, so that the cumulative production capacity of the small and medium scale operations grew significantly in the 1990’s. Around 1996 Lavador jigs were introduced by Brazilian miners for recovering diamonds in the Mazaruni and Takuba Rivers. This technology was adopted by all diamond producers and it has allowed previous tailings from diamond mining areas to be reworked profitably. A sluice box is usually incorporated before the Lavador to recover associated gold.

Mechanized small and medium scale gold and diamond mining operations that utilize heavy earth moving equipment are generally better capitalized than “land dredging” operations. They are therefore better “organized” in the sense of having (a range of) equipment in place to facilitate the operations. Several methods are used in these operations, incorporating the use of earth moving equipment - excavators, back hoes, bulldozers and loaders, together with the regular hydraulic jets, gravel pumps, sluice boxes and Lavador jigs. In addition, for surface or underground mining of primary ore, usually quartz veins, hammer mills and amalgam plates are used for gold recovery. In a few cases, explosives are used in the extraction of the ore. For enhanced gold and diamond recovery wash plants may be added with vibrating screens, and transverse jets to disintegrate the feed material and wash it into the underlying sluice box. A hopper may be incorporated to collect and slurry the ore feed material and feed it into the sluice box.

Essentially, overburden and ore are excavated separately and moved by heavy-duty mechanical equipment – bulldozers, excavators, backhoes and loaders. This allows for the removal of overburden so that only ore is processed. Since the overburden is not processed, a lot less tailings waste is generated and discarded. In some operations, mechanical stripping and removal of overburden is incorporated into the "land dredging" type of operation for gold and diamond mining. The exposed ore is excavated by hydraulic jets and piped to the sluice boxes by gravel pumps so that only the ore is processed.

Except where hydraulicking is used, ore is mined and stockpiled. The ore is slurried and processed by passing the slurry directly through sluice boxes without screening or indirectly, via wash plants fitted with vibrating screens. In some operations, the ore is stockpiled on sloping ground. From the stockpile, the ore is disintegrated and slurried by hydraulic jets and fed directly into "ground sluices" which are extended down the natural slope of the land. In some operations, hoppers are used. Where primary ore, usually auriferous quartz veins, is mined in surface or underground operations, a hammer mill and amalgam plates are used to recover gold.

Another form of mechanized diamond mining, cutterhead river dredging, was introduced by Brazilian miners in the 1990's to exploit river based diamond deposits. As its name implies, the cutterhead dredge, a "diver-less dredge," cuts indurated overburden and ore material and uses a centrifugal pump to lift the gravel through airtight pipes to be processed on the barge. The cutter head dredge has the advantage over the river suction dredge of being able to break and excavate hard cemented material so that indurated gravels and previously inaccessible underlying gravels can be worked, whereas the suction dredge can only work unconsolidated material. The ore is processed by a sluice box for gold recovery, and the sluice box tailings are screened via a trommel and fed to a Lavador jig for diamond recovery. Like the river suction dredge the cutterhead dredge leaves sand mounds on the riverbed.

In recent times complaints about mining are being made, due to land degradation mainly from small and medium scale hydraulicking operations for gold and diamonds, and degradation of waterways, mainly from hydraulicking operations and to a lesser extent, from mechanized land based operations and cutterhead river dredging. The issue of tailings management has thus become critical to the continued sustainability of the small and medium scale mining gold and diamond industry.

Before the introduction of the river suction dredge, there was a lot less mining operations. These were small river or land based operations where only the ore was processed, resulting in modest requirements for tailings disposal. The widespread adoption of river suction dredging resulted in river degradation through the deposition of sandy tailings mounds. Turbidity was less marked and readily subsided since the ore generally did not contain much clay. In contrast, due to river bank suction dredging and subsequently, "land dredging," with the excavation and processing of the ore and overburden, the amount of tailings generated by each mining operation and by the mining industry as a whole increased significantly.

At most of these operations, tailings management plans and practices are inadequate and hence much of the fine particles from the discarded tailings end up in the creeks, streams and rivers causing siltation and turbidity. Prolonged contamination by turbidity reportedly leads to depletion in the fish stocks, which form a significant part of the diet of the communities. Tailings deposited on land sometimes results in the formation of swamps where trees die, and swamps and mined out pits provide breeding grounds for the malaria-bearing mosquito. Except for natural revegetation, no revegetation is practiced. The use of mercury from the inception of gold mining has resulted in mercury being discharged into waterways and on land, both directly in the amalgamated tailings and indirectly from vapour from burning amalgam to recover gold. The discharge of mercury into the environment leads to the hazard of the formation of methyl mercury in the water and its incorporation into the food chain. Methyl mercury bio-accumulates in the food chain, particularly in carnivorous fish that are regularly eaten by local residents. Mercury vapour is inhaled by miners when burning amalgam without using a retort, which is a common practice.

3.7.4.3 Guyana Geology and Mines Commission: Regulatory Agency for Mining

Mining in Guyana is regulated through the Guyana Geology and Mines Commission (GGMC). The overall functions of the Commission are: to promote interest in mining, mineral exploration, development of mineral potential and the supply and sale of minerals and mineral products; to participate in and advise on the economical exploitation, beneficiation, utilization and marketing of the mineral resources of Guyana; to explore for mineral resources on lands using all techniques including geology, geochemistry, geophysics and other remote sensing methods; to exploit the said mineral resources, when discovered, using all available mining techniques including surface and underground mining; to undertake research into the optimum methods of exploring for, exploiting and utilizing minerals and mineral products of Guyana; and to carry out activities that are necessary for the exercise of its functions.

The GGMC evolved as a development of several successive state agencies established to regulate mining and ensure maximum utilization of mineral resources. The Department of Mines was founded around 1863 coinciding with the starting of the first attempts at mining auriferous quartz veins. The Geological Survey was established in 1867 to initiate geological investigation. The Institute of Mines and Forests (are you sure of the name?) was incorporated in 1890 for the protection and development of the mining and forest industries. In 1901 the Lands and Mines Department was formed, and was solely responsible for forest, geological and Aboriginal affairs. The Geological Surveys section was closed during the period 1929 – 1933. In 1943, the Geological Survey became an independent Department and its expansion began during the 1950's. The training of local personnel as mining Engineers and Geologists began after 1947. Up until 1963, the work of the Survey was limited to the documentation of the geology of the country as a foundation for mineral exploration. In 1963, with the production of a coloured geological map, the emphasis shifted to mineral investigation.

In 1971 the Mines Division of the Lands and Mines Department was amalgamated with the Geological Survey to form the Geological Survey and Mines Department. In 1973, there was drastic cut in Central Government's current and capital expenditure and this affected the

Department's exploration program and mining administration. In 1976, it was proposed that the Department should be transformed into a Commission that would be financed by revenues from the Mining Industry. Consequently, the Guyana Geology and Mines Commission (GGMC) was established in August 1979 after the passing of the Guyana Geology and Mines Commission Act 1979.

From its inception, the Commission immediately embarked on a substantial and vigorous programme of promoting investment and exploration in the mining sector in Guyana, with emphasis on the gold mining sector, since gold prices were relatively high at that time. The promotion of mineral development was sustained, and its success was marked by the realization of world class historic large scale gold mining operations at Omai Gold Mines from 1992, and additional development of significant geological resources so that at the end of 1997 more than thirteen prospects each with geological resources of more than 200,000 ounces of gold had been identified.

Several of these prospects are at various stages of feasibility evaluation and application for Mining Licence (large scale) or Mining Permit (medium scale), and medium scale mining of diamonds and associated gold was initiated in 2003 at one operation which is set to recover diamonds by heavy mineral separation. Active exploration is continuing for alluvial, eluvial and primary gold and diamond deposits, and base metal deposits. This is complemented by regional geochemical surveys and promotion of the development of bauxite, silica sand and kaolin for export that is being undertaken by the Commission.

The Mining Act 1989 was promulgated in 1991 and it formally introduced the concept of mining on a small, medium and large scale. In particular, medium scale mining was introduced to provide Guyanese miners and investors the opportunity to acquire larger prospecting and mining properties with longer tenure than small scale claim licences.

The overall mandate of the Guyana Geology and Mines Commission for promoting interest in mineral development also includes responsibility for sound environmental management in mining. The Mining Act 1989 contains general provisions that can be used to address environmental management in mining. More specific provisions are incorporated in the draft Mining Environmental Regulations that are soon to be enacted.

In the 1980's, the Commission began to take proactive interest in environmental protection, working closely with the Mining Industry association, Guyana Gold and Diamond Miners' Association (GGDMA) and the Guyana Agency for Health Sciences Education, Environment and Food Policy, GAHEF the national agency that was at that time responsible for environmental protection. The Environmental Protection Act was promulgated in 1996 and the Environmental Protection Agency was established in the same year under the Act. In October 1997 the Commission and the Environmental Protection Agency signed a Memorandum of Understanding (MOU) to formalize and govern collaboration and coordination between the two Agencies. The MOU outlined the environmental management functions, roles, responsibilities of each Agency and specified areas where close inter-Agency collaboration is required.

The Environmental Division was established in September 1998 as an outgrowth of the Environmental Unit in the Mines Division, to spearhead sound environmental management in the mining industry, which is a significant contributor to the national economy. The Environmental Division substantiates the principle of 'Sustainable development' based on good environmental stewardship during the exploration and mining phases and at the closure of mining operations. Such stewardship encompasses all sectors of the Mining Industry – large, medium and small scale, and stresses economic, social and environmental sustainability.

Environmental Division has four functions: environmental research; compliance monitoring; occupational health and safety; and collaboration with national and international agencies in areas related to mining and the environment. Environmental research consists of field surveys, effects and impacts assessment and effects monitoring. Monitoring involves systematic sampling at field monitoring stations and sampling at problem areas and incorporates education and awareness for miners. Responsibility for occupational health extends to the large, medium and small scale mining sectors and the operations of the Commission's office and field activities, and includes the provision of advice to the Commission Collaboration with national and international agencies is done through participation in common programmes, projects, field visits, and surveys and sharing of data and information..

The vision of Environmental Division in this transition period is to build human capacity for environmental management of the mining sector based on sound scientific principles and information. The Commission and the Division are being assisted by the CIDA funded Guyana Environmental Capacity Development (Mining) Project – GENCAPD. An important area of assistance is in the development of Guidelines Checklists, Codes of Practice and Protocols for environmental monitoring and regulation to be used by the Mining Industry and the Commission.

7.4.4. Guyana Environmental Capacity Development Mining Project (GENCAPD-Mining)

7.4.4.1. Presentation of the Project

7.4.4.1.1. Project Background

As noted earlier, from its inception, the Commission took active interest in environmental issues and management in mining and worked closely with the Mining Industry association, Guyana Gold and Diamond Miners' Association (GGDMA) and GAHEF, the national Agency was at that time responsible for environmental management. Collaboration continues with the Environmental Protection Agency. Collaboration with the Environmental Protection Agency (EPA) was strengthened by the signing of a Memorandum of Understanding between EPA and the Commission in October 1997.

There were several initiatives for developing a legal framework for environmental management in mining in Guyana, while simultaneously developing and analyzing information and data on the environmental and social impacts of mining and suitable mitigation methods. These initiatives took into consideration the changes, developments and growth that were occurring in the Mining Industry, particularly with respect to the newly established medium scale mining sector, and the challenges that they posed. It was acknowledged that environmental management must be in accord with Agenda 21 of the United Nations Conference on Environment and Development held in Rio in 1992, and demonstrably subscribe to the principle of Sustainable Development and the Precautionary Principle. Further, the environmental management capacity of the country and the Mining Sector was severely tested by the Omai incident in 1995 when about 2.9 million cubic metres of cyanide bearing effluent from Omai Gold Mine was accidentally released into the Essequibo River via the Omai River after the tailings dam was breached.

The Guyana Environmental Capacity Development (Mining) Project, GENCAPD, was conceived and implemented to provide technical assistance to Mining and Environmental Management Agencies and Associations to address the challenges of environmental management in mining by building capacity for environmental management. GENCAPD Project was to address the need for developing a full array of skills required to effectively assess the actual scope and nature of environmental degradation caused by mining operations.

The Canadian Government, through the Canadian International Development Agency (CIDA), approved the GENCAPD Project and chose the Canada Centre for Mineral and Energy Technology (CANMET), an Agency of Natural Resources Canada, as the project executive agency. With the establishment of Field Office in the GGMC compound, and the development and approval of the Project Implementation Plan, the GENCAPD Project officially started work in Guyana in March 1999. Initially, the expected duration of the project was 4 years, with a budget of CND$3.8 million. The project was extended by two years.

The principal beneficiaries of GENCAPD are the Guyana Geology and Mines Commission, the Guyana Gold and Diamond Miners' Association (GGDMA), and the Environmental Protection Agency (EPA).

7.4.4.1.2. Project Stakeholders

Guyana Geology and Mines Commission is the primary partner, and the Guyana Gold and Diamond Miners' Association and Environmental Protection Agency are the other main partners. The Institute of Applied Sciences and Technology (IAST) which is responsible for advancing science and technology in Guyana and the University of Guyana (UG), the sole institution of tertiary education in Guyana also participate. The Ministry of Health and the Ministry of Amerindian Affairs have participated in the implementation of several GENCAPD activities. Canada Centre for Mineral and Energy Technology (CANMET), the Executing Agency on behalf of CIDA, is responsible for implementing the project in Guyana.

7.4.4.1.3. Focus of Project Activities

The Goal of GENCAPD Project is to strengthen environmental management capacities in the Mining Sector in Guyana. Its purpose is to strengthen the technical and managerial capacity of key mining sector institutions.

A series of Outcomes and Outputs were identified by the main stakeholders as the expected sustainable results of the project (table 1). To achieve the Outputs and Outcomes of the project, a series of activities were developed, with the main Stakeholders, that are divided into three areas: Policy & Regulation (including the development of Environmental Regulations Codes of Practice, and Guidelines), Institutional Development (for building monitoring and inspection capabilities) and Industry Practices (to develop, demonstrate and promote more efficient and environmentally sound recovery practices). Activities were planned and implemented to promote sustainability by skills transfer, Guyanese participation and ownership by the participating institutions during the planning and delivery stages.

Among the intended Outcomes are a functional Environmental Division within GGMC (supported by Standards and Regulations appropriate for Guyanese conditions); capacity developed in GGMC for the collection, analysis, and management of environmental management data; improved capability in EPA to effectively coordinate and regulate the environmental management of the mining sector; and in GGDMA – strengthened capacity to meet industry needs for appropriate technologies and systems for environmental management, being also financially beneficial. Project outputs will include Operational Guidelines, appropriate Environmental Policies, Regulations and Standards in place, enhanced skills for professional and other staff of participating Agencies and Association, awareness programs, practical demonstrations, and improved management and consultation procedures amongst Mining Sector and Environmental agencies.

7.4.4.1.4. Project Organization and Management

GENCAPD Project is adaptive, responding to the needs of Stakeholders within the scope and activities of the project. To achieve this, GENCAPD Field Manager, who is the local representative of CANMET, the project Executing Agency, works closely with the major stakeholder, GGMC, with the participation of GGDMA and EPA, to regularly review and modify ongoing and coming activities. This review is made on the basis of experience gained in the implementation of the project, results achieved and evolving circumstances. Modifications are then proposed and reviewed at the bi-annual GENCAPD Project Steering Committee (PSC) meeting where the Work Plan, past and coming activities and achievements are reviewed and decisions are taken by consensus. The PSC approves the annual Work Plan and budget. The PSC comprises representatives of the Presidential Secretariat, GGMC, GGDMA, EPA, Ministry of Finance, CIDA's offices in Ottawa and Guyana, CANMET and GENCAPD Field Office. It is jointly chaired by the representative of the Presidential Secretariat of Guyana and the representative of CIDA's office in Ottawa.

Monthly Meetings of representatives of all of the main Stakeholders held to plan activities in greater detail and assign responsibility for their implementation. GENCAPD Field Manager works closely with stakeholder institutions and association in the implementation of activities and facilitates the necessary support through the provision of technical assistance through CANMET or consultancy services, training manuals, equipment or financial support for approved project activities. Development of sustainability of skills and environmental capacity and ownership are key elements GENCAPD Field Manager meets every week with GGMC management to maximize the interaction between CANMET and GGMC and the efficiency of the implementation of the activities. A Multi-Stakeholders' Advisory Committee (MAC) also meets depending of the need to discuss more technical matters and give appropriate direction. All stakeholders participate in this forum. Other experts and government functionaries can also be invited depending of the need, as determined by the chairman of the committee, GGMC Commissioner.

Table 1: Summary of the GENCAPD Project: Goal, purpose outcomes and outputs	
GOAL	
Strengthen environmental management capacities in the mining sector of Guyana	
PURPOSE	
Strengthen the technical and managerial capacity of key mining sector institutions	
OUTCOMES:	
GGMC	• Functional Environmental Division staffed with suitably skilled professional personnel; and • Capacity to competently collect, manage and analyze data on environmental management
EPA	• Increased capability to effectively coordinate and regulate the environmental management of the mining sector
GGDMA	• Strengthened capacity to meet industry needs for appropriate technologies and systems for environmental management, being also financially beneficial.
UG	• Increased educational programming for environmentally sound mining and environmental management and sustainability. • Reduced overseas studies.
IAST	• Building confidence in IAST protocol for Guyanese institutions to have their laboratory work done in Guyana rather than in the US or Canada.
OUTPUT:	
GGMC	• Increased technical knowledge and practical skills of GGMC personnel in the area of environmental management systems and technologies; • Establishment and implementation of appropriate environmental policies, regulations and standards for the mining industry; • Production of operational guidelines and awareness program for the miners; • Creation of capacities for the preparation and review of Environmental Impact Assessments (EIA's); • Establishment and application of systems and processes for environmental monitoring, data collection, data management and analysis.
EPA	• Establishment of environmental standards and regulations for the mining industry (in conjunction with GGMC) adapted to the reality of Guyanese conditions; • Adoption of improved management and consultation procedures amongst environmental and mining sector agencies; • Acquirements of in-house capacity to review mining sector-specific EIA's.
GGDMA	• Dissemination of technical advice and service through the miners and adoption of more environmental friendly practices; • Better recovery of the ore exploited by the small-scale miners.
UG	• Introduction of a Graduate and under graduate program of environmentally sound mining and environmental management education. • Possibility for stakeholders' staff to be attached on a part-time basis while working for their respective institutions.
IAST	• Increased technical knowledge and practical skills of IAST personnel in the area of environmental laboratory analysis. • Rigorous protocols for IAST.

7.4.4.2. Integrated Field Surveys

7.4.4.2.1. Environmental Assessment in Hinterland Guyana: A study of selected Mining and Non-mining localities

Introduction

Turbidity and mercury contamination were identified by stakeholders as key issues resulting from small and medium-scale gold mining. Therefore, an environmental assessment (Hydro-sedimentological and Fishery Surveys) was conducted in the Potaro, Kurupung, Middle Mazaruni, Barima Upper Essequibo, and Kamarang Rivers of Guyana from 2001 - 2003 to study the effects of turbidity, caused by suspended sediments, and the occurrence of mercury in the fishes, river waters and sediments, riverbanks and mine faces. All field surveys included stakeholders' participation at all levels.

The research project was divided into distinct phases. First an Orientation Survey was completed in February 2001 in the Potaro River. The primary objective was to provide direct guidance and information for a follow-up comprehensive survey, and to narrow the parameters to be studied that relate to the environmental impacts of mining. Based on the conclusion of the Orientation Study, the second project was initiated in March 2002. This latter survey was systematic, and it covered the Potaro River; Kurupung River; the middle section of the Mazaruni River and the Isseneru River - a right tributary to Mazaruni near the Isseneru Village;Barima River in northwest Guyana (from Five Star through Arakaka to Koriabo) upper Kamarang River in western Guyana; and Gunns Strip in Upper Essequibo in southernmost Guyana. The aim of both the Orientation and Comprehensive Environmental Surveys was to provide data, information and insights for the definition of policy positions, the refining of limits for mining environmental regulations, and the establishment of monitoring programmes.

Orientation survey of 2001

Survey Area

Sedimentological and water quality variables were sampled in the Potaro River between Amatuk Falls and the Tiger River. Nine transects were established in this segment of the Potaro River. To investigate the potential contribution of the major tributaries (the Mahdia, Kuribrong, Konawak and Tiger Rivers) on the Potaro River, transects were positioned upstream and downstream from those specific rivers. The Fishery Survey area extended along the Potaro River from Downstream Amatuk Falls to the mouth of the Tiger River. This section of the river was divided into three basins identified as the Mahdia (between Amatuk and Pakatuk Falls, at Kangaruma); Konawak (between Aurituk and Tumatumari Falls) and Tiger (downstream of Tumatumari Falls to Potaro River mouth). The three basins reflect the influence of the catchments of these relatively large drainages where mining activities were taking place. The presence of falls between each basin restricts fish from travelling from one area to another.

Methodology

Fieldwork in Potaro consisted of the establishment of several transects, with equally spaced sampling stations, across the width of the Potaro River. Water samples were taken at each station at the surface, at one metre depth and at 50% and 90% of the total depth of the water column for Total Suspended Solids (TSS) at all transects; three depths were sampled for stations less than 4 m deep. Samples were also collected from the channel stations for subsequent nephelometric turbidity readings. Unfiltered water samples were collected for subsequent mercury analysis at all transects, channel stations and depths using certified bottles. Filtered water samples were also collected using a hand-held vacuum pump with disposable and sterilized 0.2 _m filters. For velocity and temperature measurements, readings were taken at 20% and 80% of the water column depth, using a SD-30 Sensordata current meter at all transects, stations and depth. For fish sampling non-selective gillnets, 10m long x 2m depth with mesh size of 5cm, were used to catch the fish. Captured fishes were identified by species, and morphomertic and biological data such as gender, total length, weight, stomach content and maturity stage of gonads were collected. Muscle and liver samples were taken from each fish and kept in certified mercury-free bottles and preserved in an icebox containing dry ice.

Laboratory analysis for total suspended solids included measurement by filtration and weighing. Nuclepore filters (47 mm diameter) were dry-weighted at GGMC's chemical laboratory. Pore size filters used were 0.45, 1.0 and 5.0 _m. In the field laboratory, samples were passed through the pre-weighed filters using a low manifold vacuum pump. Back in Georgetown, TSS from the individual filters was dried for 24 hours at 65°C. The filters were weighed again on a precision scale to 100 _g. Total mercury analysis of fish samples was done at Flett Research Inc in Manitoba (Canada).

Numerical analysis in the hydro-sedimentological survey involved computation of the average flow rate of the entire transect by adding each of the computed cross-section flows. Sediment transport, expressed in tonnes per day, was calculated for each of the cross-sectional areas by multiplying the average flow at each cross section by average vertical TSS values. Sediment transport across all sections was totalled to provide a measurement of sediment transport across each transect. For the fishery survey, simple mathematical and statistical data treatment was followed. A condition index (K=WxL3) was calculated using Bolger and Connolly (1989) methods, where W refers to weight and L refers to length of fishes. The central tendency of the mercury concentration in fish muscles was estimated by calculation of simple arithmetic mean. The dispersion of the data from the mean was calculated using a simple standard deviation equation. Where applicable a simple equation of a best fitting curve was determined using the least square method.

For hydro-sedimentological samples, Quality control of the mercury analysis was tested using field duplicate samples, repeat laboratory analysis, testing preservatives (HCl) for Hg, and sampling non-spiked surface water triplicate samples and analysing them on time (in one week). The reliability of the mercury analysis in fish tissue samples was checked using replicate analysis as prepared by the laboratory.

Results

Results have shown that there is considerable sediment transport and deposition in the Potaro River, linked to mining activities. Mahdia and Konawak Rivers contributed to increased sediment load to the Potaro River. For instance, from Amatuk Falls to above Mahdia River where there is no mining activity, less than 50 tonnes per day of sediments are discharged by the Potaro River. Below Mahdia River, the daily sediment load in the Potaro River increased from 50 tonnes to 380 tonnes. The Mahdia River, with the most mining activity, was the greatest contributor of sediment to the Potaro River, with a daily sediment transport rate of approximately 330 tonnes. From below Mahdia River to upstream of Konawak River, 60% of the sediment load settles to the riverbed, representing roughly 230 tonnes per day. From a water quality perspective, levels of Total Suspended Solids

(TSS) from below Amatuk Falls to upstream of the Mahdia River generally fall within the most stringent limits for TSS in Bolivia, and within limits for Yukon and French Guiana. TSS is greatly increased below Mahdia River to relatively high levels of 55-85 mg/L, exceeding limits set for selected regional countries and Yukon. From downstream of Mahdia River TSS levels fall steadily to the Konawak River, then increase slightly to Tiger River. However, TSS levels in the entire length of the Potaro River studied are within limits set for streams with unspecified usage in Jamaica and Suriname.

Total mercury analysis of unfiltered water samples from channel stations indicates the presence of mid-depth and subsurface mercury plumes, and that the reworking of bottom sediments results in the creation of a secondary, deeper plume of mercury. The two (? largest) mid-depth plumes occurred below Amatuk Falls and above Mahdia River, in the area unaffected by mining at the time of the survey, and recorded the highest mercury levels of 3694 ng/L and 1700 ng/L respectively. From below Amatuk Falls, mercury levels in the water fell progressively downstream to above the Tiger River confluence, where three dredges were working in the Potaro River. The highest mercury level in the water downstream of the Konawak River confluence was 500ng/L, while the highest value above the Tiger River confluence was 1700ng/L. Only for Kuribrong and Konawak Rivers were there higher levels of mercury downstream of river confluences than upstream of them. For all samples Methyl-mercury was < 1% of total mercury content.

The study showed that while suspended sediment load and Total Suspended Solids are directly related to mining activities, the highest values of total mercury content in the unfiltered water column occurs upstream from known mining activity. TSS values exceed the most stringent limits set by selected regional countries and the Yukon, but throughout the study area, TSS values are within limits for streams for unspecified use in Suriname and Jamaica. It is evident that reworking and re-suspension of bottom sediments causes an increase in mercury in the water column that gives rise to a deeper, secondary mercury plume.

The Fish Survey indicated mercury bio-accumulation by a factor of 3.6 from non-carnivorous to carnivorous fish. All the non-carnivorous fish had mercury levels in muscle tissue that were below the safety guideline level of 0.5 mg/g of methyl mercury set by the World Health Organization (WHO), 1991, for all fish except predatory fish, while 57% of all species of carnivorous fish had mercury levels greater than 0.5 mg/g, indicating a certain level of mercury contamination. The highest value of 3.7 mg/g of Hg was obtained in lau-lau fish (Brachyplatystoma vaillanti). A regression coefficient of .75 was observed from methyl mercury (MeHg) – Total Hg dispersion in fish flesh. Methyl mercury (MeHg) is the organic specie of total mercury, which is recognized as the toxic form bio-accumulated by humans. Its proportion to total mercury can vary geographically; but for the fishes caught from the Potaro River, MeHg represents 98% of the total Hg (T-Hg) in fish-flesh. This high proportion is prevalent in both carnivorous and non-carnivorous species.

This suggested that there is no need for routine analysis of MeHg in fish flesh in future surveys and that T-Hg is an adequate indicator of MeHg. Results for total mercury for liver and flesh samples were plotted as muscle/liver ration on weight and length. Most of the calculated values for smaller fishes showed high variability. This resulted from practical difficulties in sampling the liver of small fish. This apparently led to the inclusion of other internal organs of small fish. The effect of this practice was to dilute the mercury content in liver by introducing non-mercury accumulating organs. This observation helped to conclude that any systematic future survey should be limited to the analysis of fish muscle.

Comprehensive Survey of 2002

Survey Area

Based on the conclusion of the orientation survey, a systematic and more voluminous study was initiated that extended from December 2001 to end of April 2002 for fish sampling, while the Comprehensive Hydro-sedimentological Survey was initiated in March 2002 in the Potaro river in the same location as the orientation survey except that sampling work was more detailed. During this period, in addition to the Potaro River, the Fishery Survey was extended to Mazaruni and Kurupung Rivers. The sampling sites were Tumatumari, Kurupung and Isseneru Villages where fish plays an important role in the Amerindian diet.

In November 2002, a Hydro-sedimentological Survey was completed in the Barima River in NW Guyana. Water, river sediment, bank and mine face samples were collected from the Barima river, from near Five star and Arakaka localities all the way down to Koriabo – an Amerindian settlement below Arakaka River. In January 2003, two areas thought to represent pristine areas, where mining activities have not taken place in recent decades, were targeted for data validation by sampling fish, water, riverbed sediment, alluvial and eluvial material from riverbanks. These areas are Gunns Strip in Upper Essequibo, located in southernmost Guyana and Upper Kamarang River near Paruima Village located in western Guyana. In July 2003, additional fish flesh samples were collected by GGMC Environmental Division staff in Barima River near Koriabo Village. This whole effort was intended to give a general picture of the level of mercury contamination in districts where important mining activities are taking place and provide a comparison with non-mining areas.

Methodology

Fieldwork procedures for Hydro-sedimentological Surveys were done in the same manner as that of the 2001 Orientation Survey. The Comprehensive Survey was extended in its scope to include sampling of riverbanks and mine faces. Grab samples from riverbanks and mine faces were taken at one (1) meter intervals to a depth of 5 meters. Mercury analysis was conducted on water, riverbed sediments and on samples derived from riverbanks and mine faces using the same procedures as in the Orientation Survey. Mercury Speciation analysis was conducted on riverbed and suspended solid samples and on samples derived from mine faces in order to provide independent measurements of the source of mercury in the environment. This work was done by Frontier Geosciences laboratory in USA. The speciation of mercury included the determination of free Hg, amalgam Hg, water-soluble Hg, acid soluble Hg, humic associated Hg and non-humic Hg. Variable pressure scanning electron microscope (VP-SEM) equipped with energy-dispersive spectrometer (EDS) was used to analyze filtered suspended particulate matter in water samples collected from Potaro river for eighteen elements.

In the Fishery Survey a list of 20 most common species consumed by the population within each village was established and an amount of 25 fishes per specie was targeted from each area for total mercury analysis in fish muscles only. Fieldwork procedures were done in the same pattern as that of the Orientation Survey of February 2001. The samples were analyzed for total mercury in the same laboratory (Flett Research Inc) by the same method used in 2001. Data were analyzed using the same procedures of graphical and numerical methods as in the orientation survey. Some 29 duplicate fish flesh samples were also analyzed at the Frontier Geosciences

Laboratory in USA for quality control at the end of 2002. The comparison between the two laboratories shows strikingly consistent and similar results except for high Hg values where in Flett Research Laboratory results tend to be slightly lower.

Results

TSS: From a water quality perspective, levels of Total Suspended Solids (TSS) are below 10mg/L in all mining areas (Potaro, Kurupung-Mazaruni and Barima) in sections of rivers where there is no influx of particulates from mining activities. In rivers of mining areas where there is direct entry of suspended solids (such as Arakaka and Mahdia), the TSS values are way above 1000mg/L reaching as high 3000mg/L at times. In pristine areas TSS values are always below 10mg/L. Upper Kamarang River has notably very clear water with turbidity less than 5mg/L. In Upper Essequibo near Gunns Strip, turbidity is below 10mg/L but was considered to be a bit high for a non-mining locality. This relatively higher value is due to the contribution of erosion, since elevation increases towards the south in the Upper Essequibo catchment area. During the wet season turbidity increases significantly in all areas due to erosion of riverbanks by heavy rain and storm water. Unlike the Orientation survey of 2001, the Comprehensive Survey showed higher content of Hg in the section of the Potaro River affected by known mining activities.

Mercury Concentration: Whether the samples were taken from pristine or mining areas, the behavior of mercury in the water column was the same, showing a peak concentration at sub-surface depth. Sediment samples selected based on their mineralogical and geochemical compositions and spatial relationship with anthropogenic activities (mine faces), were analyzed for total mercury by sequential extraction tests. The results indicate that higher Hg concentrations were measured in the fine (<63µm) sediment fractions, representing the silt and clay fractions. There is also an overall increase in mercury concentrations in the silty and clayey fractions of river sediments. Whether in land or river sediments, mercury concentration is positively correlated with particle size in that as the median particle size decreases, the total Hg concentration increases.

In riverbed sediments, mercury is found to be strongly associated with sections of the rivers where the mud fraction predominates. Although no mercury enrichment per unit mud weight was measured in riverbed sediments from mining areas, the mud fraction containing mercury was more abundant downstream from mining creeks than upstream and in pristine areas. On riverbanks, and on land away from riverbanks, no significant difference exists in total mercury concentration both in pristine and in mining areas. However in riverbed sediments of mining areas total Hg concentrations were always found to be higher than those in pristine areas. The Hg content in sediments of Upper Essequibo, near Gunns Strip was found to be higher than that at Upper Kamarang near Paruima (both locations are considered to be pristine).

Mercury Speciation: Mercury speciation tests of Frontier Geosciences Laboratory indicate that organo-complexed mercury (humic associated mercury) is the predominant mercury fraction in the samples derived from riverbed sediments, riverbanks and mine faces. The sum of all species of mercury averages 97% of the total mercury results reported by Flett Research laboratory, indicating data validation. On riverbanks and mine faces, the organo-complexed mercury is located in the top part (in the first two meters) of the section.

Mineralogical Analysis: Filtered suspended particulates in the water samples analyzed by a variable-pressure scanning electron microscope to obtain semi-quantitative X-ray microanalysis of eighteen elements from individual particles, indicate the dominant presence of Al-Si fraction. The sediment samples, as determined by X-ray powder diffraction analysis and scanning electron microscope examinations, are composed predominantly of quartz, kaolinite and gibbsite.

Fishery Survey: A total of 1152 fishes belonging to 34 groups were captured. Triplicate samples of muscle tissue were taken from all fishes. Overall, fish lengths exhibit a wide range of values. For carnivorous fishes mode lengths varied from 25 to 90 cm. Non-carnivorous fishes are generally smaller, mode lengths spread between 15 to 90cm, skewed under 45cm. The frequency distribution of carnivorous fishes shows an index that varies from 0.6 to 1.8 according to the species. For the non-carnivorous fishes, the indexes are generally higher, 0.8 – 2.1 indicating a higher weight condition in comparison to the proportionality of length

As expected, in mining areas, the carnivorous fishes show the highest Hg values, which reflect a relative contamination. Nearly 70-79% of carnivorous fishes exceed the concentration of mercury in muscle of the level of 0.5mg/g, recommended by the World Health Organization (WHO). The highest levels are found in the fishes from Mazaruni River. About 8-14% of the omnivorous fishes show concentrations higher than the WHO limit while only 0-3% of the herbivorous fishes exceeds the 0.5mg/g limit. In a Latin American context, total mercury content in fish samples of Guyana reveal a situation comparable to several rivers of the region such as in Brazil, Bolivia and Venezuela for carnivorous and non-carnivorous fishes (Barbosa et al. 1999, Carmouze et.al. 2001). Most carnivorous fishes concentrate mercury at levels exceeding the WHO limit while non-carnivorous fishes satisfy the criteria.

Within Guyana the level of mercury contamination in fish varies geographically. In mining areas, the highest values were found in the Mazaruni averaging about 1.1mg/g and 0.3mg/g for carnivorous and non-carnivorous fishes respectively. The second highest values of Hg in muscle tissues for the carnivorous and non-carnivorous fishes respectively were from Kurupung River. Of the areas studied, the fishes in Potaro River are the least contaminated averaging 0.79mg/g and 0.23mg/g respectively by trophic level. For non-mining areas, carnivorous fishes in Upper Essequibo depicted slightly higher than 0.5mg/g Hg, while the non-carnivorous fishes showed less than 0.2mg/g Hg; both carnivorous and non-carnivorous fishes of Upper Kamarang fishes showed less than 0.1mg/g Hg. The year-to-year variation of Hg concentration by species is less obvious. No significant differences were observed in the temporal distribution of the level of contamination in fish tissues collected from the Potaro River between year 2001 and year 2002.

The magnitude of mercury bioaccumulation throughout the trophic levels of non-carnivorous and carnivorous fishes is estimated to be 4.1 to 3.2 times according to the rivers surveyed. The bioaccumulation of Hg observed in non-carnivorous (omnivorous and herbivorous) fishes depicts smaller values, which do not exceed 1.8. Study of length and weight of fish against mercury concentration in muscle tissues shows no defined relationship between these variables. Values are scattered and determination coefficients (r2) are very low. This pattern of non-correlation was observed for selected carnivorous fishes most frequently eaten by local population

Conclusion: In conclusion, abundant mud fractions found on riverbed sediments, downstream from mining creeks, are associated with the disturbance and removal of land sediments by land dredging activity. Since mercury is present in the land, hydraulicking (without the use of tailings impoundments) causes the mud faction to end up in the rivers where it settles to the riverbed. On the riverbed mercury is made available to the aquatic biotope and incorporated in the food chain all the way to the carnivorous fish.

The results clearly show that mining area communities could be more exposed to high mercury content in fish flesh than pristine (non-mining) communities. This is due to the hydraulicking of fine sediments located in the upper part of overburden. Apart from anthropogenic activities such as land dredging for gold and diamond mining causing large amounts of fine particulates to enter the in rivers, heavy rain and storms also cause the erosion of the riverbanks and contribute significantly to the sediment load of the rivers of pristine and mining areas in Guyana.

In summary, the observations from the Fishery Surveys were very conclusive. The level of mercury measured in most of the carnivorous fishes exceeds the concentration of 0.5mg/g recommended by WHO. The magnitude of the mercury bioaccumulation throughout the trophic level is estimated to be 3 to 4 times. No relationship was found between the concentration of mercury in fish tissues and the length and weight of carnivorous fishes. The practice of consuming the carnivorous fishes as a major protein source should be replaced by an alternative source from non-carnivorous fishes. It is obvious that frequent human consumption of carnivorous fishes of the study areas can pose a hazard resulting in overt physiological symptoms and in the most severe cases causing serious damage over time.

7.4.4.2.2. Health Assessment in Hinterland Guyana: A Study of Selected Mining and Non-mining Communities

Introduction

During the period May-August, 2002, GENCAPD and GGMC collaborated with the Ministry of Health to conduct a survey to determine the impact of mining on health in mining communities. Further, additional work was done in September 2002, January 2003 and February 2003. There are many factors in these mining supported communities that either exists in the environment that are created or exacerbated as a result of mining. Thus, the study aimed to identify these factors using the following objectives: 1) To assess the incidence of selected diseases and conditions namely, malaria, typhoid, mercury (Hg) poisoning, and dengue; 2) To identify the existing behavioural practices, environmental and social conditions that contribute to these diseases and 3) To determine the effects of mining on the behavioural practices, social, and environmental conditions.

Survey Area

Kamwatta (“Eyelash”), and Arakaka, Region 1, in the Barima River, Kurupung and Isseneru, Region 7, in the Middle Mazaruni River, Mahdia, and Tumatumari, Region 8, Potaro River were the communities studied. Mining communities in Regions 1, 7, and 8 of Guyana, were selected because of concentrated mining activities currently being undertaken. These communities with the exception of Eyelash are permanent settlements, with the residents to a large extent being Amerindians, but include Afro-Guyanese and Indo-Guyanese who have moved to these areas over 20 years ago and have assimilated into the culture of the indigenous people. In addition three non-mining Amerindian communities in Regions7 (Paruima village), Region 8 (Micobie village) and Region 9 (Gunns Strip) were selected and hair samples were taken from the residents for comparative purposes.

Methodology

With the assistance of the GGMC, the communities were sensitised. A team of medical doctors and other health professionals from the Ministry of Health collected the quantitative and qualitative data. The physicians and health educators worked mainly from the health facility or from temporary accommodations where no facility existed. A consent form was applied since blood and hair samples were taken from respondents. A general questionnaire was administered to the residents whose mean average age was 33.6 years. A total of 246 persons were interviewed from the six mining communities. In addition, 49 residents of the three non-mining communities were interviewed and hair samples were taken.

Two venous blood samples were taken under sterile conditions from each participant. One sample, a non-clotting specimen for blood culture for Widal testing and dengue antibody determination. Dengue testing was done using Pan Bio’s Rapid Immuno-chromatography test. Diagnosis of typhoid fever was facilitated by the Widal test and confirmed by the isolation of Salmonella typhi in blood cultures. The hair samples for exposure to mercury poisoning were taken using guidelines provided by a GENCAPD liaison laboratory (Flett Research Inc) in Canada where the samples were also sent for testing. The environmental health specialist walked around the community to observe the environmental conditions and associated behavioural practices and collected water samples from some mining communities, which were sent to the Food and Drug Department for bacteriological and chemical analyses.

Results

Sixty percent (60%) of the sample was either Amerindian or persons of mixed descent and in all of the communities, except for Eyelash, there are over 90% Guyanese. In Eyelash, 40.9% of the population are Brazilians. The population in these areas are predominantly male between the ages of 18 and 44, except in Isseneru where there are twice as many females (66.7%) as males (33.3%). On an average, in each community over 50% of persons in the study were either married or in common law relationships. Again, in Isseneru, 66.7% of the community were either married or living in common law relationships. All communities recalled that mass smearing was done while over 50% of persons reported use of mosquito nets but Eyelash recorded lower percentages.

All Residents of mining communities dumped garbage and refuse indiscriminately; pit latrines were either poorly designed or non-existent. Flies were evident in large quantities due to these poor sanitary conditions; the water tests confirmed high faecal coliform count and e. coli making it unfit for drinking and domestic purposes. All the six communities appear to have some common diseases and environmental conditions. For example, review of the health records and new testing showed that malaria, diarrhoeal diseases (dengue fever and typhoid-like diseases) and scabies are among the most common health problems.

The study had identified that there are several behaviours as well as social and environmental factors associated with mining that affect the health of persons living in or within in close proximity to mining communities. Among the major issues are gender imbalance, limited attention to personal prevention practices, unhygienic and unsanitary environmental conditions, inadequate basic infrastructure, limited support services and legal mechanisms, and improper mining practices. In all mining communities, similar conditions existed that enhanced the breeding of mosquitoes, which could aid in the transmission of malaria.

These conditions include stagnant pools, slow-flowing streams, and large metal containers with aquatic vegetation are breeding sites for mosquitoes. In all cases, contamination of water supply sources whether stored (storm/rain) or fresh surface water (rivers/creeks/ponds) possibly occurred as a result of indiscriminate disposal of faeces (poor latrines facilities), which are washed into the natural water sources during the rainy season In addition, droppings of birds and wild animals that frequent such localities also contaminate the water source. In the case of stored water supply, the contamination occurs through droppings of birds, and small animals, such as rats, and snakes.

Chemical analysis, which was done on the water derived from some of the above sources described, again it was observed that the level of some heavy metals such as lead was unacceptable for domestic purposes. In addition, the indiscriminate disposal of rubbish (tins, bottles, old tyres, old drums and reservoirs), also result in the breeding of Aedes aegypti mosquitoes, could lead to the transmission of dengue.

A total of one hundred and eight persons (108) were interviewed from eight (8) mining and non-mining communities in Regions 1, 7, 8 and 9 along with hair sampling. Most of the mining communities confirmed the use of Hg in the mining industry for recovering gold. The mean hair Hg content of these residents was 11.595 mg/g (standard deviation 10.01 mg/g). Mean hair Hg levels was significantly higher among residents of Gunns Strip (24.770 mg/g) than those from Paruima (2.158 mg/g), Tumatumari (8.749 mg/g), Mahdia (5.255 mg/g), Eyelash (6.444 mg/g) and Kurupung (6.385 mg/g). There was no significant difference between the mean hair Hg content of villagers from Gunns Strip with those from Isseneru (18.229 mg/g) and Micobie (21.326 mg/g). Hair Hg levels were significantly higher among Amerindian residents (14.141 mg/g) than among persons of other ethnicities (Afro-Guyanese 4.304 mg/g, Indo-Guyanese 11.190 mg/g, Mixed 5.569 mg/g). Long-term residents were more likely to have higher mean Hg levels than persons who have been in the community for less than 1 year. Persons whose primary source of protein was fish (14.436 mg/g) also have significantly higher levels of Hg than those who consumed non-fish protein (chicken 6.496 mg/g).

.In conclusion, all communities' residents depict relatively higher Hg levels that exceed the background concentration normally found in hairs samples (1-2 mg/g) as determined by WHO. However, non-mining communities like Gunns Strip, Isseneru residentsIsseneru and Micobie residents appeared to have a high level of hair Hg content, above the WHO safety limit (10mg/g), but this is attributable to the consistent fish-based diet rather than occupational hazards. In general community members and miners, in mining areas, have demonstrated unacceptable social and behavioral practices, which impact on environmental health conditions negatively. Therefore, it becomes a necessity to raise public awareness and greater understanding of those factors that affect health and well being and work collectively to reduce health risks.

7.4.4.3 Status of Project Activities

Nearly all documentations of policy and regulatory aspects is now in place.

- Six Codes of Practices have been developed, namely: Mercury Use Code of Practice, Tailings Dam Code of Practice, Waste Management and Disposal Code of Practice. Effluent Management Code of Practice, Contingency and Response Plan Code of Practice and Reclamation Code of Practice.
- Draft Mining Environmental Regulations delivered to the Attorney General's Chambers for final drafting and submission to parliament for assent.
- Mining Environmental Guidelines prepared, for enforcing the new Mining Environmental Regulations, which reflect sound management practices.
- Guidelines for the preparation of EIA and CEIA prepared and several Workshop training courses given to stakeholders.
- The GGMC database has now been strengthened with staff given the necessary training in environmental monitoring and data archiving. Staff is now capable of conducting field surveys independently with the production of acceptable quality reports.

Four weather stations were installed to help environmental research such as the correlation of precipitation and sediment load in rivers around Mining Districts. The precipitation data can also be used to estimate runoff, and this information can be used in the engineered design and construction of tailing ponds and for properly developing water management programmes.

The findings of the field Environmental Surveys have helped in the establishment of interim limits for Total Suspended Solids (TSS) in mine tailings effluent discharge. Mine liquid effluent TSS limits were set for the dry season at 30mg/l; 45mg/l and 60mg/l for grab samples, composite samples and monthly average respectively. For the wet season TSS limits were set at 50, 75 and 100 mg/l respectively. These limits will be reduced progressively as the industry moves from the now largely hydraulicking to more mechanized dry mining methods.

In addition to turbidity, the impact of the use of mercury in gold mining is an area of concern. Concerns stem from the impact of mercury in the environment, and in particular the contamination of fish, as well as the risk of mercury poisoning that miners face when amalgam is burnt in the open to recover gold. The use of mercury retorts will protect the health of miners and by recovering the mercury in the amalgam, reduce the amount of mercury put into the environment by gold mining In addition, the draft mining environmental regulations stipulate that the use of a retort will be mandatory, and GGMC will have to approve retorts.

In order to facilitate the use of mercury retorts by miners, a project to manufacture and test simple retorts was initiated by GGMC Environmental Division in 2001 using the design of The Mining Programme, Intermediate Technology (IT) of England. The initial result using this design was not satisfactory showing only 80% mercury recovery using wood fire. In July 2002 a follow-up programme was undertaken to modify the original IT design in order to come up with the best possible model in terms of high mercury recovery. After making different modifications and producing and testing several models of the upgraded IT retort, the most efficient retort with mercury recovery above 95% in firewood and over 97% of mercury recovery in charcoal was achieved. Following the success of the test work, 100 retorts were produced and distributed to miners, particularly Amerindian miners and to the Guyana Gold and Diamond Miners Association. Distribution of retorts took place in late 2002 and early 2003. Onsite demonstration was made to teach miners on how to use them and on how to follow safe practices. A brochure was distributed, along with the retorts, which will be a guide reference on the use of the retorts.

Field technology demonstrations for improved gold recovery were held in mining areas, spearheaded by Canadian consultants, Three demonstrations were made in total: at Kaburi and Mahdia in Region 8, and Arakaka in Region 1 in the northwest from September 1999 to 2000. The use of Nomad matting (magic matting), expanded metal riffles, angled iron riffles, varying the slope and dimensions of the sluice box increased gold recovery by at least 15% more than what was obtained from traditional sluice boxes. A diamond recovery test was conducted in

Kurupung area in Region 7 in March 2002 using tracers. The aim of the demonstration was to investigate the recovery efficiency of the Brazilian Lavador jig so as to make recommendations for improving its performance. The test showed that miners lose about 50% of the diamonds which are less or equal to 4mm grain size. Miners were advised how to improve several factors of their operation, particularly with regard to the feed rate.

In February 2002, a manual was produced on Mine Inspection to equip GGMC staff with the necessary knowledge base to deal with monitoring work in Mining Districts. Based on this manual, many GGMC Mines Officers and senior technical staff, EPA technical employees and University of Guyana academic staff received workshop training in March 2002. In addition, Mines Officers and University of Guyana staff were trained on the manual in the field. University staff were included to ensure the sustainability of the knowledge gained. The underlying principle to this approach was that once the staff gained the necessary knowledge the University will be able to hold similar training workshops for regulators or miners.

With respect to institutional development, the strengthening of the IAST laboratory; development of curriculum that addresses environmentally friendly mining practices; strengthening GGMC in data facilities and training; and increasing the capacity of EPA in promoting awareness in mining districts; and providing an Environmental Officer for Miners who works closely with GGDMA and with Miners in the field to foster environmental responsibility among miners; were addressed through various project activities.

7.4.5. Work for the Future

At its formal ending in March 31, 2004, GENCAPD project will transfer managerial responsibility to GGMC for the remaining activities. This will be done within a transition period of two to three months. Incomplete activities include the training of Amerindian Community Representatives scheduled for April 2004, conducting a pilot testing of an Awareness video produced by EPA in cooperation with Ministry of Health and GGMC, and the wrapping up of activities including the documentation of communication products.

GGMC will soon be training representatives of selected Hinterland communities impacted by small and medium scale gold and diamond mining in the following areas: Mining Act, Environmental Management, Environmental Regulations, GGMC operational practices of Mines Division, Administration of Small and Medium Scale mining, GPS Application and Use of Compass. The objective of this training is to foster better environmental management practices through ongoing monitoring, to empower communities in evaluating and responding to environmental disturbances caused by Small and Medium Scale mining and to create better understanding between miners and mining-impacted communities. Trainees will be required to work as Rangers on a part-time basis, with some degree of authority to enforce the regulations.

One key area that GGMC is urgently addressing is tailings management. Every mining operation will be required to have settling ponds or tailings impoundments to allow suspended matter to be contained via settling before being recycled or discharged into the receiving environment. GGMC is promoting recycling, but where discharges are made, the water quality has to satisfy the discharge limits for TSS.

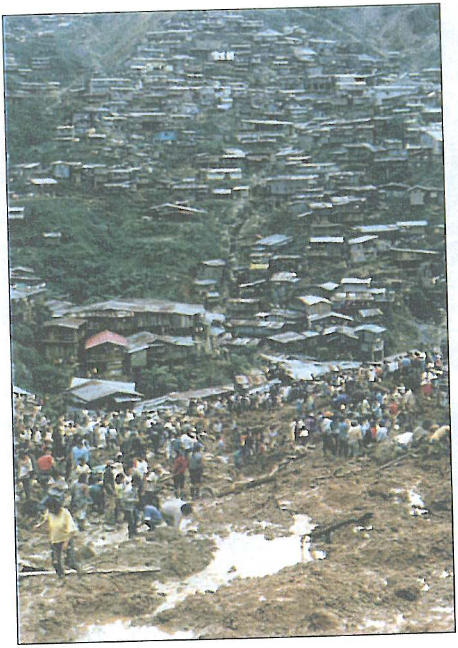
GGMC is working with miners to devise and implement designs for tailings impoundments and dams for small and medium scale operations. The challenging aspects are: determining optimum pond size that will facilitate settling; ascertaining settling rates and characteristics of different tailings solids; recycling of water; determining the life of the settling pond and attendant costs; and construction of sustainable small dams. From its headquarters in Ottawa, for a given period CANMET will provide GGMC expertise through periodic missions, and financial assistance for the implementation of activities on the ground, while GGMC will undertake and manage the experimental and research work.

GGMC in cooperation with EPA and other collaborating agencies will build its awareness programmes on the informational video on environmentally sound mining practices by small and medium operations that is being produced by EPA under GENCAPD. This video will be the basis for a series of outreach awareness exercises with miners in the field. The Environmental Division of GGMC will carry out strategic environmental surveys of important catchment areas as a foundation for cumulative environmental effect assessment and environmental effects monitoring.

With many of the policy, regulatory and inspection guidelines coming in place, GGMC will be enforcing environmental limits set for the Mining Industry. GGMC will have the three-fold task of providing guidance and technical support for small and medium scale operators to facilitate compliance; to assess and monitor compliance; and to foster sustainability and strengthening of environmental management capacity in mining. This sustainability must be achieved and maintained within GGMC and in the mining operations.

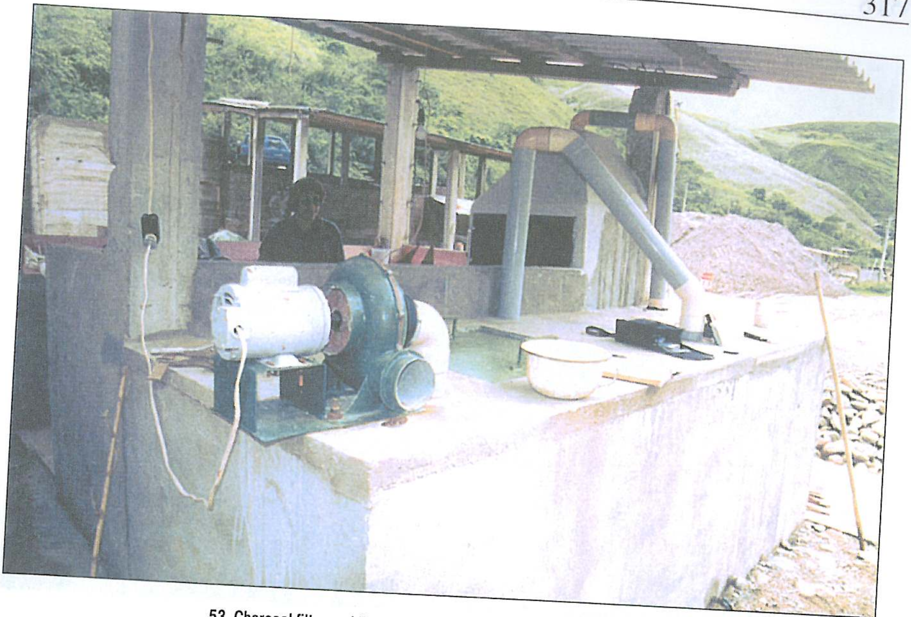
49. Woman washing for alluvial gold with a sluice (Valle de Cauca department, Colombia)

50. Children washing for alluvial gold with pans (San Jose de Yani Cooperative, Bolivia)



51. Mining camp, Nambija, Ecuador after a disastrous landslide

52. Mining camp. 15 de Agosto Cooperative, Bolivia. 5,200 mts. above sea level.



53. Charcoal filter and lime solution for NO gasses (Zaruma, Ecuador)

54. Manual drilling exploring for alluvial deposits (Tapajos, Brazil)

55. Filling a worked out pit with fresh tailings (Piririma, Tapajos, Brazil)

56. Seminar with miners (La Paz, Bolivia)

57. Demonstration of retorts (Cooperative Fatima II, Bolivia)

58. Local equipment manufacturer (SENTEC, Oruro, Bolivia)

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Annexes

ANNEX 1

Flow sheets of beneficiation plants In small primary gold mining Bolivia

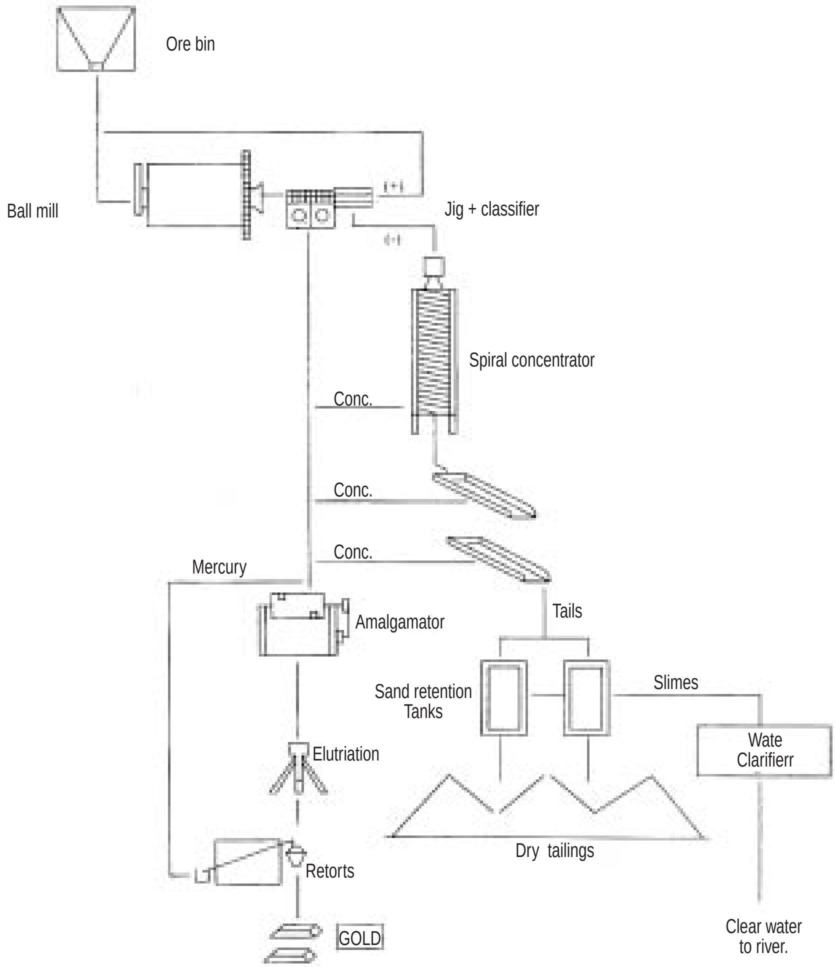
This annex shows five different flow sheets of small primary gold mining in Bolivia in the form they were installed by MEDMIN and are currently functioning. They are five typical examples out of 15 plants installed or improved by MEDMIN.

The flow sheets were designed to fit the requirements of the gold ore (not sulfide, coarse and fine gold, etc.) and also to the investment capacity of the miners.

All the flow sheets shown in this annex, use mercury to amalgamate concentrates in a controlled manner.

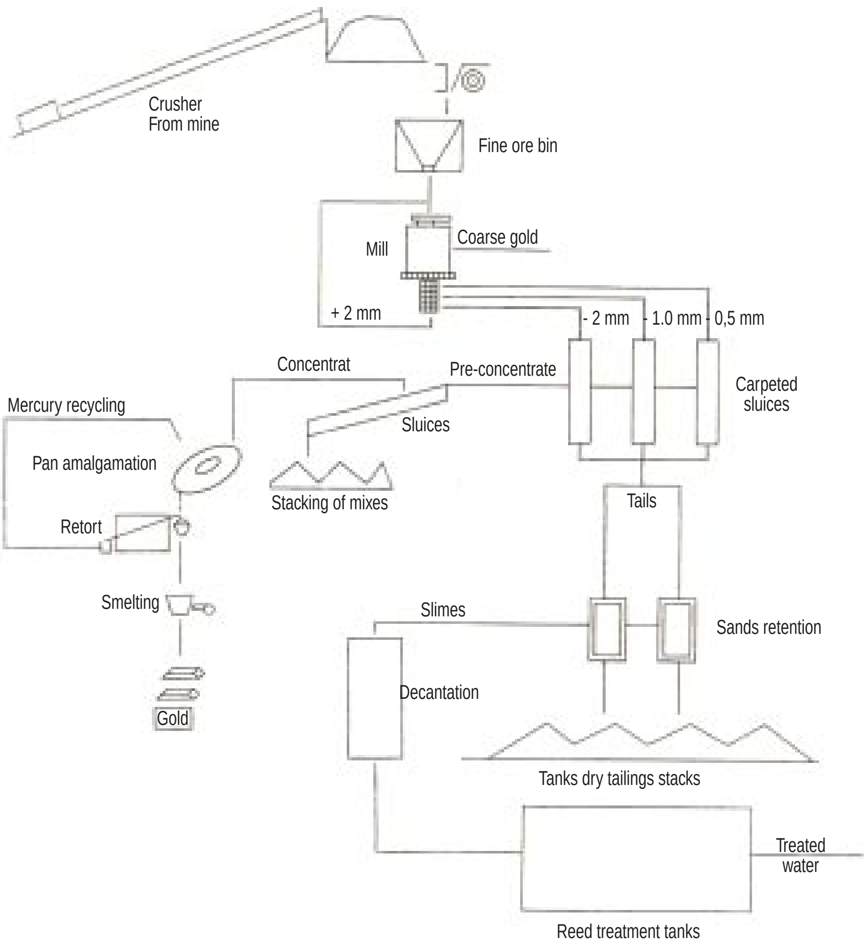
FLOW SHEET 1

COOPERATIVE "COPACABANA DE COTAPATA"



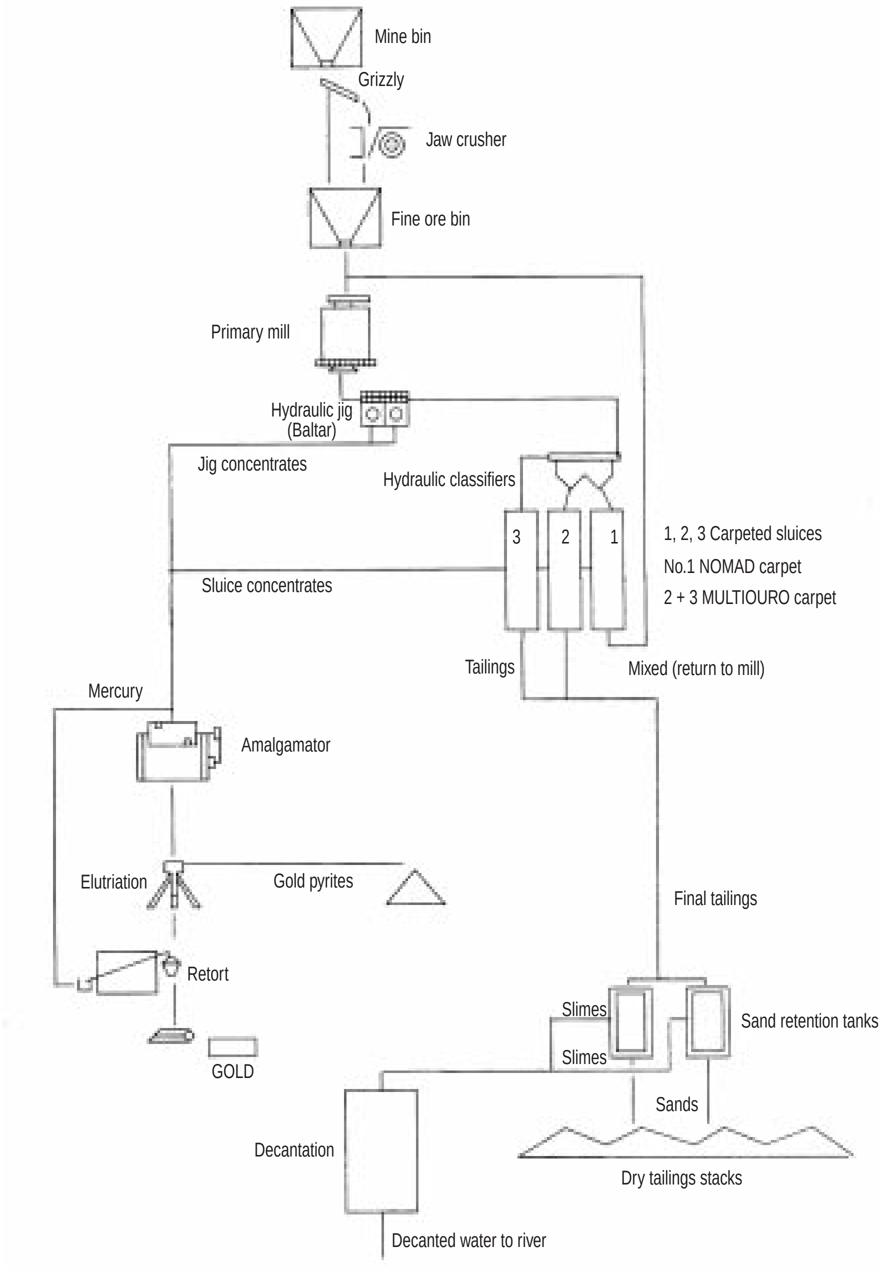
FLOW SHEET 2

COOPERATIVE "LIBERTAD"
IROCO – ORURO



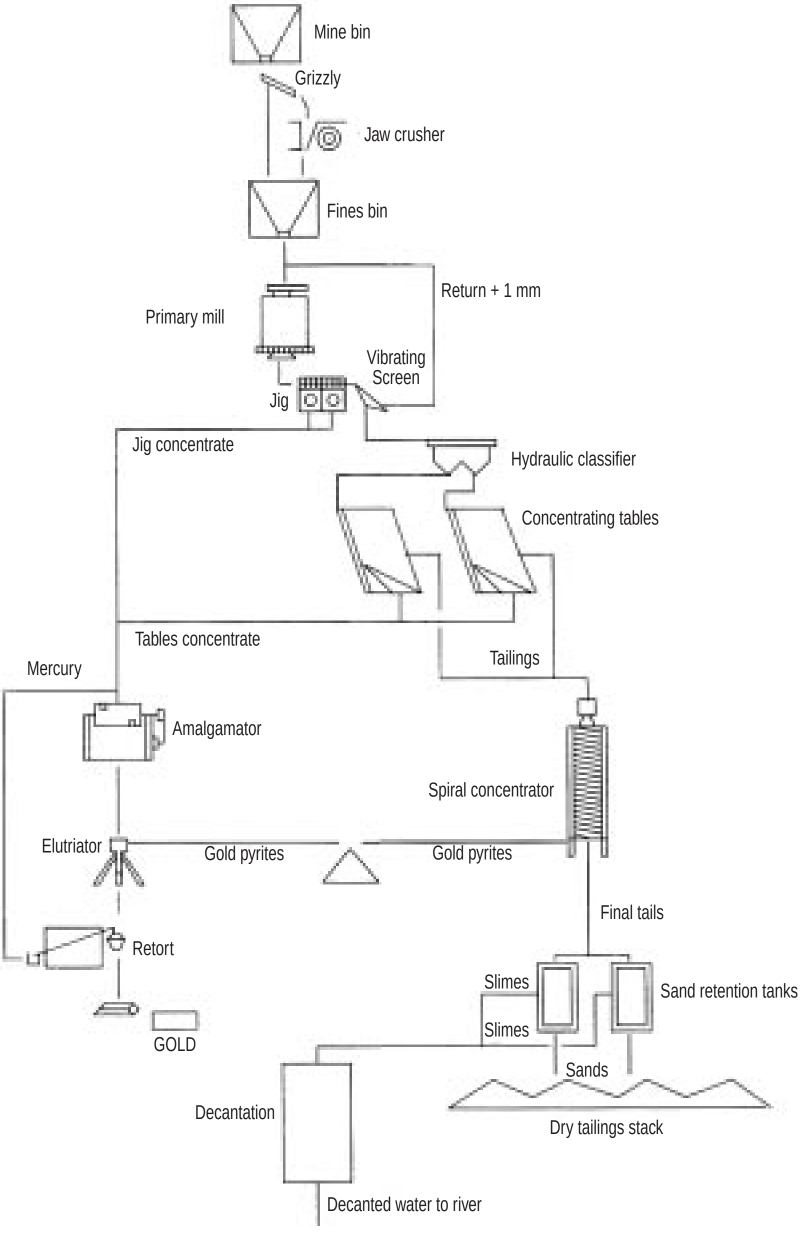
FLOW SHEET 3

COOPERATIVE "15 DE AGOSTO"



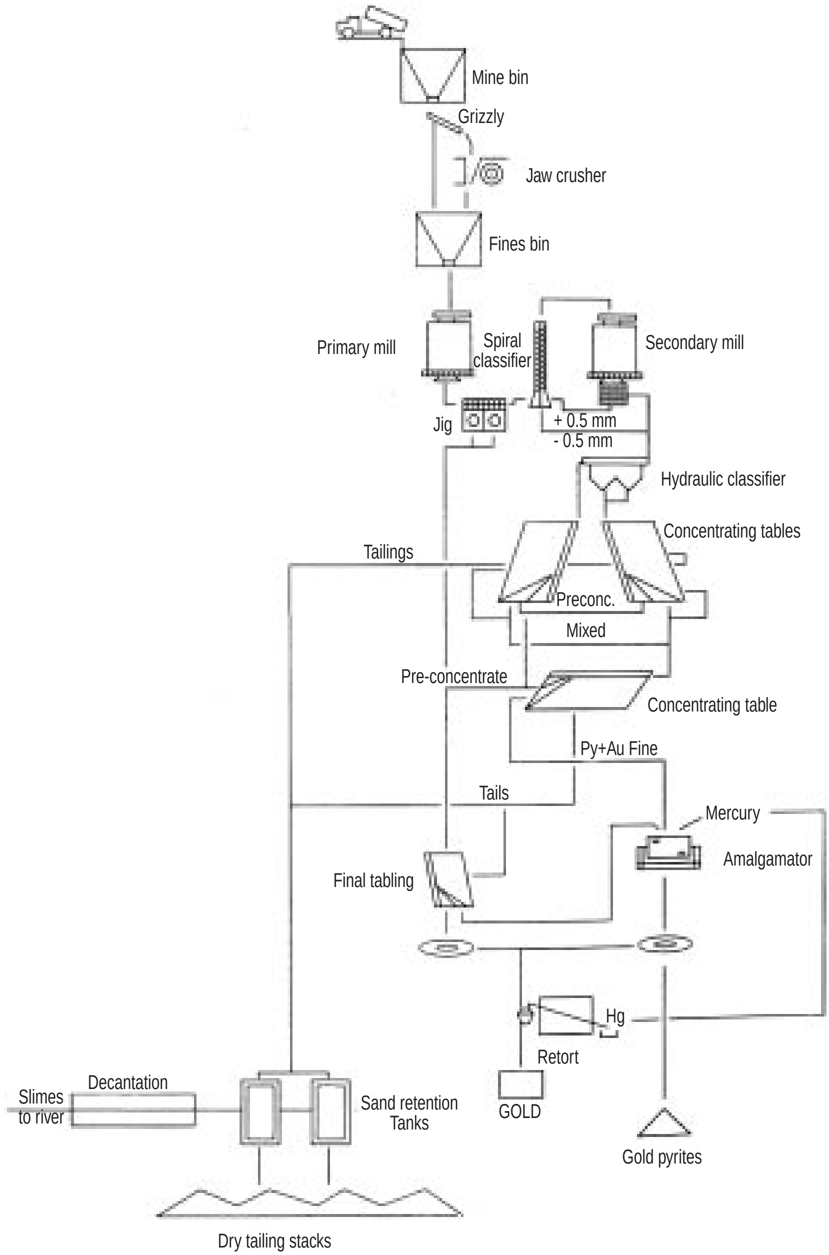
FLOW SHEET 4.

COOPERATIVE "COTAPATA"



FLOW SHEET 5

COOPERATIVE "LA SUERTE"



ANNEX 2
Summary of the Environmental Impact Study and the Collective Environmental Management Plan “Plan ECO +” in Ecuador

The following tables summarize in a very compressed form, more than 400 pages of the study mentioned in Chapter 7.3.

The environmental impacts and the environmental measures are in order of the different steps of ore beneficiation in the region (activities A to E) and their sub-processes (e.g. B1, B2, B3, etc). All the flow sheets of the installations are modifications of the generalized diagram in Illustration 14, that are characterized by the presence or absence of certain components: For example, there are installations that only offer a grinding service, others that only do cyaniding, others that apply various processes, etc. In this manner, with the flow sheet, it is possible to identify the environmental impacts and determine the applicable environmental measures.

The results of this study, and therefore the following tables, are specifically for the region and the beneficiation techniques used there. However, several of the environmental impacts are typical for small mining in general, and the environmental measures proposed for a concrete case, can at the same time be the starting point for the design of environmental measures and intervention in other regions and under other conditions.

TABLE 1

ENVIRONMENTAL IMPACTS (EFFECTS) CAUSED BY ORE BENEFICIATION IN THE STUDY ZONE

ACTIVITY	EFFECT ON THE ENVIRONMENT	IMPACT		EFFECT WITH CONSQUENCES	
		Direct	Indirect	Immediate	Long term
A. Plant installation					
A.1. Construction of mine Installations and unplanned colonizing	Biological				
	- Habitat (lairs) alteration of terrestrial and aquatic animals.	X		X	X
	- Loss of top soil	X		X	X
	Social				
	- Chaotic development, without basic structures (Public services)		X	X	X
	- Conflicts and displacement of other economic activities.	X			X
	- Prejudices tourism and recreation	X		X	X
B. Grinding (milling)					
B.1. Noise in plants	Biological				
	- Habitat alteration (la irs) terrestrial animals		X		X
	Social				
	- Effects on miner's and plant workers health	X		X	X
B.2. Discharge of tails to rivers	Physical				
	- Increase muddiness in rivers (suspended solids)	X		X	X
	- Change of physical/chemical characteristics of water and sediments of river Calero-Pindo-Puyango (increase of heavy metal content, Sulfides, mercury etc.)	X			X
	Biological				
	- Extinction of ictiofauna	X			X
	- Loss of trofic chain in high basin of river Pindo	X		X	X
	- Accumulation of mercury and heavy metals		X		X
	Social				
	- Damage to artisan fishing	X		X	X
	- Damage to agriculture in lower basin of river Pindo-Puyango (irrigation)		X		X
B.3. Emissions Mercury	Physical				
	- Increase of mercury in atmosphere	X			X
	Biological				
	- Mercury accumulation in the biota		X		X
	Social				
	- Effects on health of miners and plant workers	X		X	X

B.4. Tails accumulation From plants Physical Erosion)	Physical - Discharge of suspended solids to river (muddiness)	X		X	
	Biological - Loss of the scarce top soil	X		X	X
	Social - Change of original landscape - Prejudices agriculture in lower basin of river Pindo-Puyango (irrigation).	X X		X X	X X
B.5. Tails accumulation from plants, Chemical erosion.	Physical - Emanation of acid waters from tailings		X		X
	Biological - Damage to scarce top soil	X		X	X
	Social - Prejudices agriculture in lower basin of river Pindo-Puyango (irrigations)		X		X
C. Cyaniding					
C.1. Cyanide gas Emissions in plant	Physical - Increase of HCN content in the atmosphere	X		X	
	Social - Health effects in miners, plant workers and surrounding inhabitants.	X		X	X
C.2. Exit of used solution with gold and heavy metals .	Physical - Contamination of river Calera with heavy metals	X			X
	Biological - Death of all forms of aquatic life - Loss of trofic chain	X X		X X	
	Social - Damage to artisan fishing - Prejudices agriculture in the lower basin of the river Pindo-Puyango (irrigation)	X	X	X	X X
C.3. Accumulation of Tails and cyanides (Physical erosion)	Physical - Uncontrolled tailings discharge to river	X		X	
	Biological - Death of aquatic life - Loss of top soil	X	X	X X	X
	Social - Change of original landscape - Damage to artisan fishing - Prejudice agriculture in lower basin of the river Pindo-Puyango	X X	X	X X	X X
C.4. Accumulation of tails and cyanides (Chemical erosion)	Physical - Acid + Cyanide drainage	X		X	
	Biological - Death of aquatic life - Loss of top soil	X	X	X X	X
	Social - Change of original landscape - Damage to artisan fishing - Prejudice agriculture in lower basin of the river Pindo-Puyango (irrigation)	X X	X	X X	X X

D. Refining					
D.1. Gas and vapor Emissions during Burning.	Physical - Air contamination with heavy metals	X		X	
	Biological - Accumulation of heavy metals in the biota		X		X
	Social - Health effects on workers and population	X		X	X
D.2. Nitrous gas emission by attack on DORE with HNO3 and discharge acid solutions.	Physical - Air contamination with NO - water contamination with HN03 + Me(NO3)	X X		X X	
	Biological - Elimination of habitats terrestrial fauna - Effects on top soil	X X		X X	X X
	Social - Health effects on those directly doing this work - Health effects on local population	X X		X	X X
E. Process in general					
E.1. Exploitation of non- Contaminated Natural resources	Physical - Alteration of the waters system	X			X
	Biological - Deforestation - Alteration of terrestrial fauna habitat	X X		X X	X X
E.2. Industrial waste Management	Physical - Disorderly waste disposal	X		X	
	Biological - Source of sickness transmitted by rodents & insects		X	X	
	Social - Health effects on direct operators - Heath effects on local population	X X		X	X X

TABLE 2

OUTLINE FOR THE REGISTRATION OF INDIVIDUAL MEASURES (INDIVIDUAL PLAN FOR ENVIRONMENTAL MEASURES)

a.) Installation generalities: general detail of the mine, owners, work organization, etc., also:

Types of minerals to be treated	Gold ores (primary ore) Gold sands from grinding Ore with sulfides Ore with oxides Ore with sulfides and oxides	yes? yes? yes? yes? yes?	no? no? no? no? no?
Technical description of plant	Grinding Amalgamation Percolation cyaniding Agitation cyaniding Smelting	yes? yes? yes? yes? yes?	no? no? no? no? no?
Flow sheet	A?, B?, C?, D?, E?, F?, G?, H?, I?, Others ? (Specify)		
Plant capacity	Tons/day Tons/month		
Source of ore	Own mine Ore purchase Plant leasing	yes? yes? yes?	no? no? no?

b) Environmental measures to be applied

Measure A:
Impact: Unplanned construction
Objective of measure: Space distribution and planned industrial development
Description of measure: Municipal intervention, DINAMI and others
Applicable to plants with flow sheets: ALL

Establishment of a 5m space on the riverside as a “protected area” or forest barrier
Enforcement by municipalities (for example, application of ordinances)
Potable water for workers and local population
Establishment of schools, diners and first aid posts to guarantee health and hygiene.

Measure B1:
Impact: Noise from milling plants.
Objective of measures: Reduce or avoid hazards to workers and users.
Description of measure: Prevention and minimize noise.
Applicable for plants with flow sheets: A, B, C, D, E
Should the measure be applied in the plant: yes? no?

If positive	Quantity	Value	Notes
Acquirement of auditory protection equipment (multiple use ear flaps or throw away ear plugs).			Time period
Isolate noise sources, especially Crushers.			Individual design Time period:
Maintenance schedule for machines			Weekly maintenance Time period
Space distribution of machinery			(plants under construction)
Total			**Sucres**

Measure B2:
Impact: Tailings (pulp) discharge from grinding to river
Objective of measure: Reduce contamination by solids in suspension.
Description of measure: Control overflows (tails) from sedimentation tanks to river by using decantation tanks, filtration and flocculation.
Applicable for plants with flow sheet: A, B, C, D, E
Should the measure be applied in the plant: Yes? No?

If positive	Quantity	Value	Notes
Separate fines and coarse (e.g. Hydro-classifier)			Method to be specified Time period
Construction of separate tanks (fines and coarse)			Design to be specified, Capacity Time period
Introduction of flocculation system			Method to be specified Time period
Recirculation of clarified water to the process			Time period
Total			**Sucres**

Measure B3:
Impact: Emission of mercury gasses
Objective of measure: Reduce mercury contamination
Description of measure: Control emission of mercury gasses
Applicable to plants with flow sheet: A, B, C, D
Should the measure be applied to the plant: Yes? No?

If positive	Quantity	Value	Notes
Acquirement of retorts to burn amalgam			Min. 3 sizes Time period
Preparation of amalgamation area			Design to be specified Time period:
Installations of amalgamation drum			Capacity: Time period:
Acquirement and use of personal Protection equipment. - Masks and special filters - Gloves			Model, useful life Time period:
Total			Sucres

Measure B4:
Impact: Physical erosion of tailings
Objective of measure: Reduce river contamination by suspended solids.
Description of measure: Control physical erosion of tailings.
Applicable to plants with flow sheet: A, B, C, D, E, F, G, H
Should the measure be applied to the plant : Yes? No?

If positive	Quantity	Value	Notes
Build retention wall at riverside			Design to be specified Time period:
Plant 5m green belt at riverside			Design to be specified: Time period:
Destine a space to stack tailings			Capacity: Time period:
If space not available: sell sands			
Total			Sucres

Measure B5:
Impact: Chemical erosion of tailings.
Objective of measure: Reduce river contamination with heavy metals
Description of measure: Control chemical erosion of tailings.
Applicable to plants with flow sheets: B, C
Should the measure be applied to the plant: Yes? No?

If positive	Quantity	Value	Notes
Construction of culverts and ditches for collection and conduce drainag			Design to be specified. Time period:
Prepare pits for neutralizing			Design to be specified: Time period:
Impervious floor for tailings			(plants under construction)
Total			**Sucres**

Measure C1:
Impact: NaCN handling, HCN gas emission.
Objective of measure: Application of industrial safety equipment for personnel protection against cyanide gas emissions and contact with cyanided sands.
Applicable to plants with flow sheets: B, C, E, F, G, H, I
Should the measure be applied to the plant: Yes? No?

If positive	Quantity	Value	Notes
Instruction on cyanide dangers			Time period:
Application of program 5S			Time period:
Acquirement and use of personal protection equipment: - Special masks and filters - Gloves - Boots			Define useful life. Time period:
Prepare store room for chemical Reagents and handling packing			Individual design Time period:
Minimum equipment to be defined			Time period:
First aid kit			Contents to be defined Time period:
Total			Sucres

Measure C2.
Impact: Discharge of used cyanide solutions to the river.
Objective of measure: Reduction of contamination by suspended solids and heavy metals of the river
Description of measure: Prevention of discharge of used cyanide solutions with gold and heavy metals to the river Calero/Salado
Applicable to plants with flow sheets: B, C, E, F, G, H, I
Should measures be applied in the plant: Yes? No?

If positive	Quantity	Value	Notes
Contribution to installation and operation of collective de-intoxication plant.			Organization, adminis-tration and design to Be specified. Time period:
Individual installation of a de-intoxication System.			Design to be specified Time period:
Total			**Sucres**

Measure C3:
Impact: Physical erosion of cyanided tailings
Objective of the measure: Reduction of contamination by suspended solids and heavy metals in the river Calero/Salado
Description of the measure: Prevention of physical erosion of cyanided tailings
Applicable to plants with flow sheets: B, C, E, F, G, H, I
Should the measure be applied in the plant: Yes? No?

If positive	Quantity	Value	Notes
Construction of containing wall at river side			Design to be specified Time period:
Plant 5 m green belt at riverside			Design to be specified Time period:
Determine storage capacity for sands at the Installation site.			Time period:
Allow space for tailings			Time period:
Sign pre-contract for removal of mine discards.			Time period:
Apply collective program for tailings storage.			Program to be defined. Time period:
Total			**Sucres**

Measure C4:
Impact: Chemical erosion of cyanided tailings
Objective of measures: Reduction of contamination of river Calera/Salado with heavy metals
Applicable for plants with flow sheets: B, C, E, F, G, H, I
Should the measure be applied?: Yes? No?

If positive	Quantity	Value	Notes
Construction of impervious foundations in areas reserved for tailings			Design to be specified Time period
Construction of concrete foundations in areas reserved for loading/unloading.			Design to be specified Time period:
Collection culvert and pit for neutralizing acid drainage and cyanide solutions.			Individual design Time period:
Total			**Sucres**

Measures D1 and D2:
Impact: Gas emissions from roasting/smelting, nitrous gas emissions.
Objective of measure: Reduction of air contamination and health protection of workers and population.
Applicable to plants with flow sheets: B, C, E, F, G, H, I
Should the measure be applied to the plant?: yes? no?

If positive	Quantity	Value	Notes
Designate area for roasting/smelting			Individual design Time period:
Installation of: Furnace, bell and spray for Roasting/smelting gasses.			Individual design Time period.
Installation of extraction bells (sorbona), Filter and alkaline spray for nitrous gasses.			Individual design Time period:
Acquirement and use of industrial safety Equipment: - Gloves - Masks with filters - Goggles - Heat resistant clothes			Models, useful life.
Total			**Sucres**

Measure E1:
Impact: Exploitation of natural resources
Objective of measure:
Description of measure: Rational exploitation of natural resources and mine consumables.
Applicable to plants with flow sheets: ALL

Awareness and environmental education program
Diffusion of manuals and technical guides
Technical advise for application of new processes

Measure E2:

Impact: Industrial and domestic waste management
Objective of the measure:
Description of the measure: General cleanliness and order.
Applicable to plants with flow sheets: ALL

If positive	Quantity	Value	Notes
Application of environmental quality Program "5S"			
Space reorganization of installation			Time period
Waste recycling			
Total			Sucres

ANNEX 3

Technical norm: Use of mercury in mining

1. General

1.1. Mercury is a toxic element in all of its forms, liquid, gas (vapor) and its compounds. In mining it is used to amalgamate fine gold and separate it from other minerals.

1.2. The use of mercury should be such, that it does not affect water (subterranean and surface), nor be emitted into the air or discharged to the soil.

2. Transport and storage

Transport and storage of this element should be carried out in such a manner that it will not be lost, either in liquid or gaseous form.

2.1 It must be transported in unbreakable containers (never glass) that are hermetically sealed. The mercury should be covered by water or kerosene.

2.2 Mercury should be stored out of reach of children.

2.3 Mercury should be stored far away from food and outside the homes.

2.4 In case of spills, it should be recovered completely. Loose droplets may be sucked up with a syringe, if the quantity is considerable, the drops of mercury should be collected with a brush or by applying water to join them together and then recover. If mercury has infiltrated into the soil, this should be extracted and washed and the mercury concentrated by gravity methods (in a pan or small sluice).

Special care should be taken when the spill is in a home or other closed rooms, as mercury exposed to air slowly evaporates and contaminates the enclosed environment.

3. Use of mercury in gold amalgamation

3.1 It is forbidden to use mercury in an open circuit. This means, if material that has been put into contact with mercury, or the water used in the process can enter bodies of water or the soil.

3.1.1. It is forbidden to use mercury in ball, rod, hammer, stamp or trapiche (Chilean mill) mills.

3.1.2. It is forbidden to use mercury in sluice boxes or washers.

3.1.3. It is forbidden to use mercury in jigs, on concentrating tables, centrifuges or any type of gravity concentrating equipment.

3.1.4. It is forbidden to add mercury to crude ore (in situ, ore bins etc.).

3.1.5 It is forbidden to use amalgamation sheets or plates in open circuit.

3.2. It is an obligation to minimize the quantity of material that is put into contact with mercury.

3.2.1. Coarse gold should be separated from heavy minerals before mercury addition.

3.2.2. Concentrates should be enriched as much as possible.

3.3. An amalgamation method should be used that minimizes the creation of mercury flouring. It is prohibited to combine grinding with amalgamation.

3.3.1. Amalgamation drums should function at low revolutions to avoid mercury over- grinding.

3.3.2. The time required for amalgamation should be determined and not be surpassed.

3.3.3. Manual amalgamation should be avoided. If it is used, it should only be for small quantities of concentrate and the following recommendations should be followed:

- Use gloves
- Outside closed areas
- Good ventilation

3.4. Amalgamation tailings still contain mercury, particularly atomized (mercury flour).

   3.4.1. It is forbidden to discard mercury tailings into bodies of water or deposit them inadequately.

   3.4.2. Amalgamation tailings should be under cover (with ventilation) and impermeable floor.

   3.4.3. If mercury tailings cannot be sold as gold byproducts, they should be deposited in conditions that guarantee compliance with article 1.2.

   3.4.4. If mercury tailings are re-processed by roasting, it must be assured that appropriate filters are used to avoid mercury escaping to the atmosphere. Mercury should be recovered from the filter dust or the dust deposited in compliance with article 1.2.

   3.4.5. If mercury tailings are re-treated by other gravity, chemical or physical processes, there must be compliance with article 1.2 and the final residues deposited in appropriate manner.

3.5. The maximum amount of amalgam and free mercury must be recovered from the concentrate amalgamated. Residual mercury in amalgamation tailings must be a minimum.

3.6. The amalgam obtained must be squeezed to the maximum possible (preferably under hot water or using a press) to recover a maximum of liquid mercury not amalgamated.

3.7. The squeezed mercury should be reused in the process, after adequately cleaning it (with detergents, sodium hydroxide, dilute acids etc. or redistilled in a retort).

3.8. The separation of mercury and gold must be done in such a way, that the maximum amount of mercury utilized is recovered and that article 1.2 is complied with.

   3.8.1. It is forbidden to burn mercury in the open air, as the mercury vapor that escapes to the atmosphere cannot be re-condensed and recovered.

   3.8.2. In order to burn amalgam it is mandatory to use a mercury recuperation device; this may be:

   - A retort, which is a hermetically close crucible with a cool ing tube to recover mercury in liquid form. The retort must be an appropriate model in good condition to avoid mercury gas from escaping. The performance of the retort (hermetically closed, total mercury condensation) should be tested at regular intervals.

- A furnace to burn amalgam with a cooling and condensation system for mercury gasses. The performance of the condensation system should be tested at regular intervals.
- Other condensation or filtering system that permits mercury recovery.

3.8.3. Dissolving amalgam in nitric acid, the mercury remains in solution (liquid) in the form of mercury nitrate. It is forbidden to throw this solution into bodies of water or soil. The solution must be stored in plastic containers for the subsequent step of mercury recovery by cementation with copper or other metals.

3.9. The mercury recovered should be reused in the process after adequately cleaning (with detergents, sodium hydroxide, dilute acids etc.).