# PLANNING AND IMPLEMENTING SOLUTIONS FOR ARTISANAL GOLD MINING SITES, PREVENTING ENVIRONMENTAL IMPACTS AND REHABILITATING DEGRADED AREAS: A BRAZILIAN CASE STUDY

by

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## ABSTRACT

Artisanal small scale gold mining (ASGM) is a large source of environmental, health and safety problems in more than 70 developing countries, employing more than 15 million people, motivated by the current high price of gold and lack of better economic opportunities. Around 200,000 miners are located in Brazil with 40,000 concentrated in the Tapajos River Basin, in the Amazon. In this region, they extract gold by using rudimentary processes, causing mercury contamination, river siltation and deforestation. This thesis conducted research in the Tapajós region highlighting the strengths of some initiatives introduced by the GEF/UNDP/UNIDO Global Mercury Project from 2002 to 2008. Its training program was delivered to 4,200 artisanal miners in 141 mining sites, and it focused on disseminating 20 good mining practices. Performance indicators have shown that the conformance to standards before and after the program improved from 22 to 51%, with highest success on reduction of mercury (43%) and river siltation (37%), and improvement of sanitation (40%) in the participating sites. This study suggests the use of a heuristic approach to environmental impact assessment and ways to address those variables in intervention programs through training and education. The study also presents a successful rehabilitation initiative using simple local materials. In the participating sites 128 pits were backfilled after training and some of them revegetated. In another case study, a pilot plant to pre-concentrate gold with centrifuge followed by intensive cyanidation of the concentrate in a ball mill has demonstrated to be a fast and advantageous alternative to replace the current 20-day vat leaching or even amalgamation. This pilot study reduced cyanide consumption more than 20 times and may represent an economy of US$150,000/a in NaCN. Finally, this study analyzes 20 Brazilian regulations that affect ASGM, shows that many of them have not been effective, and suggests recommendations that would help to organize the miners and give them proper access to training, technical assistance and technology.

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## LIST OF ACRONYMS

ABNT - Brazilian Association of Technical Norms

ASGM – Artisanal and Small-Scale Gold Mining

CETEM - Mineral Technology Centre

COMTRADE – United Nations Commodity Trade Statistics

CONAMA – Brazilian National Council for the Environment

CPRM - Mineral Resources Research Company

DNPM - National Department for Mineral Production

EIA - Environmental Impact Assessment

GEF – Global Environmental Facility

GMP – Global Mercury Project

IBAMA – Brazilian Institute for the Environment and Renewable Natural Resources

IBGE – Brazilian Institute of Geography and Statistics

IBRAM - Brazilian Geological Service

INPE – National Institute of Spatial Research

ISO – International Standardization Organization

MMA – Ministry of Environment of Brazil

MME - Ministry of Mining and Energy of Brazil

PAS – Sustainable Amazon Plan

PRAD – Degraded Area Rehabilitation Plan

RIMA - Environmental Impact Assessment Report

SECTAM – Secretary of Science, Technology an Environment of the State of Para

SEMMA – Secretary of Mining and Environment of Itaituba Municipality

SISNAMA – National Environment System

SMM - Secretary of Mines and Metallurgy – Ministry of Energy and Mining

SNUC – National Protected Areas System

SPVEA - Superintendence for the Economic Plan of the Amazon

SUCAM – Superintendence of Health Campaigns - Brazilian Ministry of Health

SUDAM - Superintendence for the Development of the Amazon

UNDP – United Nations Development Programme

UNIDO – United Nations for Industrial Development Organization

USEPA – United States Environmental Protection Agency

## LIST OF SYMBOLS

g/t – grams per metric tonne

ha – hectare = 10,000 $m^2$ (roughly 1 soccer field)

$km^2$ – equal to 100 ha

L – litre (10 $cm^3$)

oz – ounce = 28.3495 g

ppb – parts per billion

ppm – parts per million (g/t)

$AgNO_3$ – Silver Nitrate, used in titration

Au – gold

$Ca(OH)_2$ – calcium hydroxide

$H_2O_2$ – Hydrogen peroxide

Hg – mercury

$Hg(CN)_2$ – mercury cyanide complex

KI – Potassium Iodide, used in titration as indicator

NaCN – Sodium cyanide

NPK – fertilizer based on Nitrogen, Phosphorus, Potassium

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Many other people deserve to be mentioned in here. Citing names is an interesting and fair expression of gratitude, but it is always associated with the risk of unintended omissions. Thanks to all of you who contributed directly and indirectly for the consecution of my objectives and goals.

## DEDICATION

I dedicate this thesis to the 15 million artisanal gold miners worldwide. Unfortunately, for the reasons mentioned in this thesis, most of them do not have access to formal education, which would open a large window of opportunities to them, including access to the many studies existing on artisanal mining. They are, however, the unique reason of such efforts.

It is hard to evaluate how much these studies as a whole have directly contributed to improve the artisanal miners' lives, but despite measurable successes and failures, the receptivity and willingness of these miners to help researchers in the field have always been a key component of the successful cases. They truly deserve our respect, admiration and gratitude.

I also dedicate my work to my family, highlighting the unconditional support I have always received from my wife and sons during the many weeks I spent away from home working with the artisanal miners in the Amazon and elsewhere.

How miners learn

I did not know, so I did not do;

I now know, so I am beginning to do

I now do, so I am beginning to teach others

## CO-AUTHORSHIP STATEMENT

Chapters 2, 3, 4, 5 and 6 of this manuscript-based thesis are related to publications in which I was the main author and the co-authors were my research supervisor and other researchers and colleagues, as listed in the APPENDIX A. In the manuscript of chapter 2, my main role involved the literature review, the design of the lists of environmental aspects and impacts and the development of formulas to estimate the significance of environmental impacts. The co-authors (Dr. Veiga and Dr. Meech) supported the concepts through their previous work with fuzzy logic, and reviewed the paper writing. In chapter 3, I coordinated the planning and implementation of the field activities, developed evaluation forms and wrote the reports. The co-author (Dr. Veiga), was the main instructor of trainers in the program and he also produced the training material. In chapter 4, I conducted the evaluations of rehabilitated areas, calculations of forest inventory, literature review and the manuscript writing. The co-author (Dr. Veiga) participated in the field work where we discussed the methods of rehabilitation and he also reviewed the paper writing. In chapter 5, as the main author I was in charge of the implementation in the field of the pilot plant for concentration and cyanidation of concentrate, and I also conducted the lab tests with cyanide. The co-author Dr Veiga oriented all the tests to be performed and analysed the results with the main author. The co-authors (Dr. Klein, Dr. Telmer, Mr Gunson and Mr. Bernaudat) discussed the technical aspects of the paper and reviewed the writing. In chapter 6, I conducted the literature review and analyzed the main policies and laws affecting ASGM in Brazil. The co-authors (Dr. Veiga, Dr. Van Zyl, Dr. Telmer, Mr. Siegel, Mr. Selder) discussed the policies and laws, provided guidance and suggestions and reviewed the preliminary drafts of the manuscript.

# CHAPTER 1 - INTRODUCTION

## 1.1 Statement of the problem

Artisanal small scale gold mining (ASGM) is a large cause of environmental damage around the world, generating water contamination, siltation and deforestation, among others. Health issues like mercury intoxication and tropical diseases such as malaria, dengue and yellow fever are also strongly associated with, and likely spread by artisanal mining.

ASGM is characterized by the use of rudimentary techniques to extract gold from any type of ore, employing a low level of mechanization and very low safety standards (Labonne and Gilman, 1999). ASGM typically employs many unskilled people, and therefore can cause a large influx of migrant workers who typically perform practices that are low productivity and have relatively high environmental impacts.

According to the United Nations Industrial Development Organization (UNIDO) about 30 million people in the world are directly involved with the extraction of more than 30 minerals and rocks in more than 70 developing countries. Considering people involved indirectly, this population can reach over 100 million people (Veiga and Baker, 2004; Telmer and Veiga, 2008, Telmer and Veiga, 2009; UNIDO, 2006). All over the world ASGM employs about 15 million people in gold extraction only, producing around 350 tonnes/a of gold, which represents around 15% of the world's total gold production (Telmer and Veiga, 2009; UNIDO, 2009).

This large and decentralized group of people are motivated by the current high price of gold, hovering around US$1,000 to 1,100/oz from Dec/2009 to April 2010 (Kitco, 2010) and the lack of better opportunities for a livelihood. A significant number of artisanal miners are located in the Amazon, and the highest concentration occurs in the Tapajos River Basin, where more than 40,000 miners extract gold by using rudimentary processes (SEMMA, 2006). ASGM sites in Brazil are locally known as "garimpos" and artisanal miners as "garimpeiros".

The ASGM activities involve a mix of social, health and environmental aspects, where causes and consequences have the same roots. A vicious circle feeds the situation and has perpetuated poverty and environmental degradation for decades. Furthermore, this is likely to continue to be the trend for the years to come, unless serious measures are immediately taken. Worldwide, environmental and health problems related to small-scale gold mining have not received high priority from governments and agencies and the problem has grown and reached proportions as never seen before. The general characteristics of the problems tend to be similar across developing countries as they all face poverty as a major social issue. Therefore, reducing or eradicating pollution caused by artisanal and small-scale miners requires a combination of coordinated actions that actually fight poverty or the cycle will continue.

ASGM is known as the second largest anthropogenic source of mercury release to the environment after coal fired power generation. It is estimated that over 1000 tonnes of Hg/a are released by ASGM worldwide (Swain et al., 2007). In 2008, Brazil produced 54 tonnes of gold, and around 6 tonnes were produced by "garimpeiros" (DNPM, 2008). A large concentration of "garimpeiros" is located in the Tapajos River basin region, producing around 3 tonnes of gold annually (SEMMA, 2006). In this process, between one to twice this amount of mercury is consumed and then released to the environment. In addition, millions of tonnes of sediments have been released into the streams. It is important to observe that most "garimpeiros" operate on an informal basis, therefore all official estimates of gold production, number of miners and mercury release can be underestimated or overestimated. According to local authorities the real gold production can be from two to three times the official number. Thousands of pits were opened in the process of exploitation of colluvial gold in the last three decades and most of these pits have never been refilled. These activities cause water siltation, deforestation and create artificial habitats for proliferation of mosquitoes, disseminating malaria and other vector transmitted diseases (Veiga and Hinton, 2002).

The environmental impacts generated by ASGM can be classified into three major groups: mercury and cyanide contamination, siltation of streams and rivers, and deforestation. In the study region, the Tapajos River Basin, it is estimated that at least 6 tonnes of mercury are released to the environment annually. Around 3 to 6 million tonnes of tailings are dumped into the tributaries of the Tapajos River and around 12,000 ha (120 $km^2$) of forest are removed along these rivers every year. Reliable estimates for total consumption of cyanide are not available, but there is no tailing treatment facility in the region. A single site considered in this study, Garimpo Ouro Roxo, consumes 30 tonnes of cyanide (NaCN) annually. No reliable estimate of the total number of mines using cyanide in the Amazon was found, but according to local authorities in the Tapajos Region alone the use of cyanide in ASGM is higher than 1000 tonnes / annum.

Worldwide, most assistance programs in artisanal mining sites have been restricted to monitoring the levels of mercury in the water, soil and biota whereas very few programs have brought techniques to the affected communities to improve gold recovery and reduce the emissions and exposure to mercury vapour (Veiga and Hinton, 2002; Hilson, 2006; Hilson and Vieira, 2007; Hilson et al., 2007),

## 1.2 Justification of the study

This study addresses the following problems:

1. The environmental impacts caused by artisanal mining activities in the Tapajos River Basin in the Brazilian Amazon (mercury contamination, water siltation and deforestation) are significant in intensity and extent.

2. The root of the environmental problems includes the low level of education of miners, lack of investment in infrastructure and misuse of resources, lack of technical assistance, and the disequilibrium between political discourse, studies, research, and practical actions in the field. Most studies developed on ASGM in the Amazon address scientific aspects, highlighting environmental problems but putting a low effort on solutions. Most of these studies have not been converted into practical actions that are scalable, affordable and compatible with the ASGM context. This study shows evidence of this, and suggests some practical solutions for some of these problems in Brazil and elsewhere, in special in chapters 3 to 6.

3. The lack of structured criteria to establish objectives and goals does not allow for effective participation of the interested parties. When planning interventions in ASGM, if the stakeholders are not involved in the problem formulation phase and the approaching method, it will be harder to get their commitment when it comes to the implementation of solutions. Most interested parties (local stakeholders) are not environmental experts, and

they have never received appropriate information about the consequences of their rudimentary practices. A participative problem formulation is a means to homogenizing knowledge (technical, environmental, etc), which facilitates the convergence of opinions towards common and obtainable goals. This study addresses this problem by proposing a structured method to conduct field intervention, as shown in chapters 2 and 3.

4. In environmental programs, the effort put on developing problem formulations and setting objectives and goals to address environmental impacts may be worthless if the system lacks mechanisms to evaluate the effectiveness of the recommended and implemented solutions. Most environmental programs in the Amazon do not have reliable mechanisms of progress evaluation, making it difficult to form clear conclusions on their effectiveness. This thesis demonstrates the use of a balance scorecard to evaluate field intervention, as shown in chapter 3.

5. Although prevention is much less expensive and more effective than rehabilitation, there are more studies and efforts addressing reclamation than prevention. As a qualitative indicator, a rapid survey of key words on Google Scholar (Google Scholar, 2008) returned around 80% of studies on “reclamation of degraded mining areas” and 20% on “prevention of degraded mining areas” in ASGM. One of the main reasons for this is that rehabilitation is triggered by the existence of  a shocking visual impact, in general a degraded landscape, which appals society, which in turns strives for eradication, and reclamation rather than prevention. This thesis shows how education and awareness are key issues to promote prevention of health and environmental problems.

6. Even though rehabilitation should take place only after all effort on prevention has been taken, it is necessary to develop practical and affordable procedures to deal with rehabilitation of degraded areas, where a prevention system was not effective or has not been initiated yet. The procedures in ASGM are either nonexistent or not easily accessible to artisanal miners. As the environmental movement worldwide is still a recent phenomenon, the dilemma goes beyond how to halt or minimize the current levels of environmental impacts. It is also necessary to change the trend of degradation to avoid future irreversible impacts, as well as to reclaim the "environmental debt" of areas that have never been reclaimed. The environmental impacts in the particular location of this study have been accumulated for the last three decades, since the first gold rush in the 1980's. In the Tapajos River Basin, it is estimated that around 300 to 600 large pits are excavated annually and left open – perhaps accumulating between 9,000 to 18,000 pits. Prevention and rehabilitation have to be performed in conjunction in order to assure effective environmental protection. This thesis illustrates this by showing methods to promote prevention and also to promote practical rehabilitation of degraded mining sites, as shown in chapter 4.

7. When studying and understanding the artisanal miner's motivation, it is clear that economic factors have higher priority than environmental issues. In the context of ASGM, not only in the Amazon Region but in the whole world, mining is strongly associated with poverty, poor education, low safety standards, and rudimentary and inefficient techniques to extract gold. Therefore, external initiatives to address environmental education in ASGM without consideration to economic improvement are generally fated to fail, as chances are that miners will not embrace them. When an environmental program is

associated with methods to improve gold recovery or reduce costs, the chances of success increase substantially. This is illustrated in this study by discussing the miners' motivation and needs, and by correlating the social economic aspects with environmental degradation.

8. Most, if not all, developing countries fail to properly enforce their environmental legislation in ASGM sites. This is result of a combination of unrealistic or lack of proper policies and regulations, lack of political will, lack of infrastructure to enforce the existing regulations and lack of incentives for miners to comply with legal requirements. This is the case of ASGM in Brazil, were studies in the Tapajos River Basin have shown that 99% of miners operate without the required environmental and mining permits. This is evidence that the existence of stringent regulations does not ensure that actions have been taken to effectively protect the environment and benefit society as a whole. This study evaluates this situation, discusses the effectiveness of the current policies and regulations affecting ASGM in Brazil, and indicates practical changes that would improve compliance.

## 1.3 Objectives and research questions

In order to propose a path for environmental programs in artisanal gold mining sites in the Brazilian Amazon region, which can be adapted to other parts of the world the main objectives and research questions of this study are:

1. **How to evaluate environmental impacts:** this study proposes heuristic and simple criteria to evaluate the environmental impacts caused by the artisanal miners, involving a practical and intuitive path to classify the relevance of each activity. This is done

according to the environmental aspects and impacts associated with such activity. The impacts are identified and estimated by magnitude, intensity, and extent. This method is practical and easily understood by the main stakeholders related to the ASGM sector. A simple evaluation method supports flexibility and allows quick adjustments of programs to optimize their progress on addressing environmental issues and mitigating problems.

2. **How to address prevention:** considering the social issues in artisanal mining and the miners' values and needs, this study recommends a strategy to convey environmental awareness campaigns and technical training as effective ways to: increase gold production, reduce production costs, promote legalization, prevent environmental degradation and improve health and sanitation.

3. **How to measure effectiveness of results:** this study proposes a set of criteria to establish measurable performance indicators for educational programs to "garimpeiros". Effectiveness of results and the accomplishment of objectives and goals are very transparent with the developed method. All investment and effort to mitigate environmental impacts have to be evaluated ultimately in terms of practical behavioral transformation in the field. The establishment of objectives and goals has to be participatory and requires strategies that involve relevant affected stakeholders.

4. **How to address rehabilitation:** any complex and costly activity would not be effective in a region with severe scarcity of basic infrastructure, low level of education and high logistic costs. Therefore, the ideal procedures to rehabilitate degraded areas in artisanal mining are not necessarily the ones with highest technical level, but the ones with highest chances of successful implementation. Aligned with this concept, this study recommends steps to go through in order to rehabilitate degraded areas that result from

artisanal gold mining activities, involving rehabilitation of soil and vegetation, protection of water streams from siltation, and reduction of mercury pollution. A mining operation called Garimpo Canaan is used as a successful case to be replicated in other locations as it has shown that revegetation can also be a viable economic diversification for artisanal miners.

5. **How to improve mineral processing:** there is no single solution for such a question, but rather a combination of steps are required to improve gold recovery, reduce costs, reduce environmental impacts and improve safety standards. An alternative method presented in this study has proved to be very effective to extract gold without using mercury, and rely on pre-concentration of material by gravity concentration followed by intensive cyanidation of the concentrate. Miners are already using cyanide in vat-leaching tanks in many locations in the Amazon. In a typical mining operation called Garimpo Ouro Roxo a pilot plant to pre-concentrate and leach gold has proved to be able to replace the current vat-leaching process, with a significant reduction of cyanide consumption, compared to the current method.

6. **How to formulate realistic policies and regulations for ASGM:** the current legal framework and its effectiveness in the ASGM sector in the Brazilian Amazon is analyzed and discussed. Despite the high environmental standards in the current regulations, the level of compliance is negligible in most locations. A more realistic approach, which includes simplification of administrative processes, implementation of awareness campaigns, educational programs and technical assistance to miners, is presented as an alternative to improve and accelerate formalization of miners. Moreover, legalization would give miners access to better infrastructure and programs such as micro credit.

The main research questions and how they contribute to the state of knowledge on ASGM are shown in Table 1-1.

Table 1-1 – The main research questions and respective contributions of this study

| Chapter | Research questions | Main contributions |
|---|---|---|
| Chapter 2 – Evaluation of environmental impacts: the use of a matrix of E.I. | • What are the most relevant activities affecting the environment in a typical ASGM site in the Amazon?<br>• How to facilitate the interaction among the stakeholders to set objectives of an intervention programs?<br>• How to align the most critical activities with the objectives and goals of an intervention program in ASGM | The matrix of E.I. puts stakeholders together to select and discuss the relevance of variables.<br>Variables to be addressed in Environmental Programs are selected based on the Degree of Belief they may cause significant Environ. Impacts |
| Chapter 3 – Intervention programs in ASGM | • What are the best practices for creating programs to address technical limitations and environmental problems caused by ASGM?<br>• How to consider the main stakeholders' motivations and needs when setting objectives of an intervention program?<br>• How to evaluate the effectiveness of interventions and implement preventive and corrective actions? | The proposed method helps the "vision, mission, objectives and goals" of different stakeholders to find a common ground<br>The effectiveness of interventions is measured through Balanced Scorecard - Performance Indicators |
| Chapter 4 – Rehabilitation of degraded areas in ASGM | • What is the extent of the impact caused by ASGM in deforestation and water contamination?<br>• What are the suitable techniques for miners to reclaim their degraded areas and mitigate environmental impacts?<br>• What are the miner's incentives to reclaim degraded areas? | The extent of damage is estimated based on gold production and grade of deposits. Techniques involve refilling old pits and revegetation. Reforestation can represent a source of revenue to miners and local fruit supply. |
| Chapter 5 – Alternative method for gold recovery without using mercury | • Why miners engage in programs addressing environmental protection?<br>• What are the alternative solutions with higher chance of assimilation by miners?<br>• Is cyanide a suitable chemical for ASGM? | Miners need to see economical advantages associated with environmental protection. A method using concentration reduce the use of chemicals and cyanide is safely destroyed after leaching gold |
| Chapter 6 – Policy and regulations for ASGM in the Brazilian Amazon | • Is mercury prohibition an effective strategy to reduce mercury pollution?<br>• How effective are the existing regulations aimed to protect the environment in ASGM sites in Brazil?<br>• Are there ways to improve the current level of effectiveness / compliance to legislation? | Mercury use in Brazil is already prohibited since 1989. It is largely used in the field. Based on field survey, the existing regulations are analyzed. Suggestions are offered to simplify the administrative process and improve compliance by miners. |

The main points of each phase of this thesis, including its deliverables, based on the problem formulation, objectives and methods developed, are presented in Table 1-2.

Table 1-2 – Problem formulation, objectives, methods and deliverables

| Phase | Main points |
|---|---|
| **I - Problem formulation (Justification of study)** | Environmental Impacts (E.I.) caused by ASGM are significant and include Hg contamination, water siltation and deforestation. Miners' formal education is low. Investments in studies versus field work are disproportional. Unclear criteria to establish objectives and goals in intervention programs. Effectiveness of interventions is low. Lack of procedures for rehabilitation. Environmental programs dissociated from economic advantages including either cost reduction or improvement of gold recovery. The current legislation is ineffective. |
| **II – Objectives (Identification of solutions)** | Establishment of criteria to address prevention of environmental impacts. Criteria for establishing objectives and goals in intervention programs. Criteria for rehabilitation of degraded areas. Criteria for evaluation of effectiveness of programs. An alternative method to improve gold recovery/ reduce use of cyanide is demonstrated. Alternatives to improve compliance to legislation are demonstrated. |
| **III – Methods (Implementation of solutions)** | Case study (GMP): development of a matrix of environmental impacts (heuristic system); proposed method for training and awareness campaign; use of Balanced Scorecard (Performance Indicators) to measure effectiveness of interventions in ASGM; training of trainers in the Tapajos River Basin. Case study (Garimpo Ouro Roxo): implementation of a pilot plant for pre-concentration of gold followed by cyanidation. Case study (Garimpo Canaan): rehabilitation of degraded areas in ASGM. Study of the current policies/ legislation affecting ASGM and proposed simplification. |
| **IV – Deliverables (expected results)** | Matrix of Environmental Impacts (E.I.) with DoB (Degree of Belief) of significance of E.I. Set of objectives and goals and performance indicators. Database for intervention. Procedure to improve gold recovery, reduce mercury and cyanide consumption, reducing cost and environmental impacts. Procedure to rehabilitate degraded areas. Guidelines to improve effectiveness of policies and regulations. Scientific publications. |

## 1.4 Significant contributions of this study

Most studies in ASGM in the Amazon address the origin of the problems and their biological and chemical consequences. The biggest challenge is yet making this accumulated knowledge actionable after the assessment phase. In this context, the best recommendations for ASGM are not necessarily those with the best technological and environmental standards, but those with the best chances to be implemented.

By exploring and understanding the miners' motivation and needs, the proposed approach takes into consideration the environmental concerns in conjunction with the technical aspects of gold processing. This aims to improve the gold recovery, which is the miners' main motivation, consequently making an environmental program attractive to them.

The proposed methods employed in this study are based on a vast literature review, on the experience from previous initiatives, above all, the UNIDO - Global Mercury Project (UNIDO, 2006), and laboratory and field experiments conducted from 2006 to 2009.

From the academic stand point, the rich literature review on the main ASGM issues and the publications generated from this thesis will be a valuable resource for others involved in ASGM. From the practical stand point, this work is intended to be a useful source of consultation and a guide for immediate and future interventions addressing legalization of mines, gold processing, environmental protection, rehabilitation of degraded areas and health and safety issues. The proposed methods are thoughtful but also purposefully simple to make them understandable and affordable by artisanal miners in locations like the Brazilian Amazon. Furthermore, the method and results of measuring the effectiveness is hoped to be a strong point in convincing potential decision makers and agencies to re-think how best to invest their resources towards practical solutions in the field. A successful case study in the Amazon will provide the best opportunity for acceptance and broad dissemination and will undoubtedly influence and change practices at other sites. This should help minimize the chaotic environmental and socio-economic situation of artisanal mining. Most of the conceptual ideas introduced in this thesis may be applied in ASGM areas elsewhere in the world, although the practical aspects of the interventions must be site specific. As an example, the reclamation methods presented in chapter 4 would apply for most neighbouring countries of Brazil, where artisanal miners use similar mining methods and work in other parts of the tropical forest.

## 1.5 Limitations of research

Although many of the methods proposed in this research can be adapted to other locations, every situation has to be considered carefully based on its particular characteristics. This study was mainly conducted in the Tapajos River Basin, in the Brazilian Amazon, and therefore the direct conclusions are valid for this area. Other parties with expertise in ASGM in different parts of the world will judge which parts of this study are transferable to other areas and which are not. Overall, the concepts apply universally but the practical implementation requires site specific considerations, depending on socio-economic aspects, political situation, environmental conditions such as whether, topography, hydrography and mineralogical characteristics.

Moreover, there was no intention to exhaust the alternatives to solve each of the main problems surrounding ASGM. The methods and solutions presented here were those that seemed to be more appropriate at the time the study was conducted, but they are not intended to be unique, neither have they covered all the miner's needs and expectations.

## 1.6 Thesis general structure

This thesis consists of 7 chapters, of which 5 (Chapters 2 to 6) are associated to manuscripts that have been published or submitted to refereed journals (list of publication in APPENDIX A). Chapter 1 gives the introductory basis of the study addressing the main objectives of this manuscript-based thesis, and chapter 7 presents the final discussion and conclusions. The general relationship among these chapters is shown in Figure 1-1.

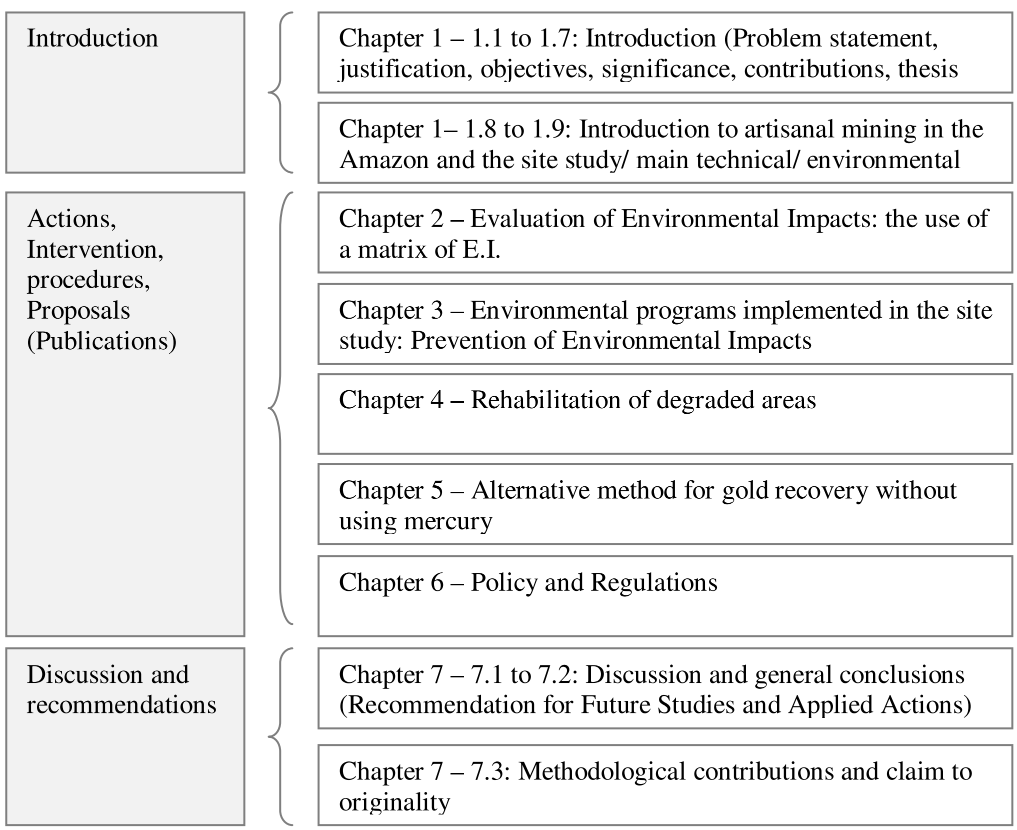


Figure 1-1 – Thesis overview

## 1.7 Summary of the chapters

### Chapter 1: Introduction

This chapter discusses the main objectives of this study and the main research questions, offering alternatives on how to evaluate environmental impacts, how to address prevention of impacts, how to measure effectiveness on intervention programs, how to address rehabilitation of degraded areas, how to improve the current process of gold recovery and ideas on how to address all these issues in policies and regulations. The main problems of ASGM are listed in here and some solutions are introduced from chapters 2 to 6.

The Tapajos River in the Brazilian Amazon is introduced as the site of study (sub-item 1.8). The main characteristics of ASGM in this region are presented, highlighting previous studies addressing mercury contamination and river siltation. As the problem is presented, the study is justified, addressing the significance of ASGM in the site of the study and lack of proper tools to deal with the magnitude of the problem.

The GEF/UNDP/UNIDO/Global Mercury Project (GMP) is highlighted as one of the most important initiatives in the area to support miners to improve their processes, technologically and environmentally. By describing the current social-economic scenario, this chapter also provides the context in which these miners work, as well as their labour structure, their level of formalization, the gender issues, their level of revenue, etc.

### Chapter 2: Evaluation of environmental impacts in the site study

After the general context of ASGM in the Amazon given in chapter 1, chapter 2 focuses on a case study (Global Mercury Project) implemented in the Tapajos River Basin, starting by presenting the proposed simple tool for the evaluation of the environmental risks posed by an artisanal small-scale gold mining site. The case study was constructed upon the ASGM of the Tapajos River, but can be adapted to other situations. A heuristic method uses a matrix to determine the relevance of risks based on the classification of activities according to the likelihood (or Degree of Belief) they may cause environmental impacts. This creates selection criteria and reduces the subjectivity of the process, allowing the establishment of a plan of action focusing the control of the most significant variables. When applied in the pilot site, the matrix revealed the variables posing higher environmental risks, which were properly addressed in a training program to promote better practices.

**Chapter 3: Environmental program implemented in the study site**

The matrix of environmental impacts presented in the previous chapter was an important tool for the UNIDO-Global Mercury Project training program, used as case study in chapter 3. Miners' main motivation is gold production and government main interest is formalization of mines. Therefore, interests had to be balanced in the same program. The main idea was to implement an environmental program associated with economic gain (gold production / cost reduction) as the miners' main motivation is economic. This is explained through an adaptation of the Maslow pyramid of human motivation (Maslow, 1943). This chapter uses the GMP as a good example of how to plan an intervention program, establishing local partnerships, establishing and sharing concepts such as vision and mission, settings realistic objectives and goals, and defining proper performance indicators to evaluate the effectiveness of an intervention program.

Among other actions, the GMP trained local trainers to multiply the training program in the communities. The program covered 4,200 people in 141 mining locations and the 20 performance indicators were evaluated before and 120 days after the training.

**Chapter 4: Rehabilitation of degraded areas**

The case study presented in the previous chapter (The GMP training program) was complemented by another case study on rehabilitation of degraded areas, presented in chapter 4. This chapter gives the general picture of deforestation in the Amazon and the importance of ASGM in this context. Deforestation in the Brazilian Amazon region was increased in the 1970s, reaching almost 1% of the forest a year in the 1990s. Mining activities also escalated after 1970s, with thousands of artisanal miners extracting gold and removing fragments of forest and surficial soil along the riverbanks and streams, not only causing deforestation but also releasing sediment and mercury into the water bodies. Thousands of pits were opened in the process of exploitation of colluvial gold in the last three decades and most of these pits have never been refilled. Following a common trend, miners abandon the sites after depletion of surficial gold deposits and migrate to new areas, without reclaiming the old mines.

The case study presented in this chapter is called Garimpo Canaan, a mining and farm that has introduced outstanding environmental practices which have made the area a reference in reclamation of open pits in the region. In this location, most old pits have been backfilled with the tailings of new excavations. In some refilled pits, naturally occurring vegetation is recomposing while others have been reforested. The main techniques used to reclaim some pits are presented, and a forest inventory was performed in areas planted with Mahogany, Teak and Neem. Variables such as diameter, heights, basal area and volumes are presented. Economic considerations are also presented, showing that reforestation can be a good long-term alternative of economic diversification for miners in the area, as the surficial gold deposits are depleting in a fast pace.

**Chapter 5: Alternative method to improve gold recovery from reprocessing tailings**

Complementing the previous sections, chapter 5 shows the implementation of a pilot plant to concentrate gold and extract gold from concentrate. Cyanide has become a common trend in many areas in the Amazon, although it has been conducted in a rudimentary fashion. The preferred methods have been heap leaching and vat-leaching. In a location called Garimpo Ouro Roxo, used as case study in this chapter, miners extract primary ore from shafts and use amalgamating copper plates. The tailings of this operation have been accumulated for the last three decades, and in the last 2 years miners started reprocessing the tailings with cyanide in vat-leaching. Each cycle usually recovers 50% of the gold and takes 20 days per tank, consuming around 3,300 kg NaCN/month. The new proposed process developed and implemented in a pilot plant in this area involves gravity concentration followed by cyanidation in a ball mill. Concentrate leaching is conducted with a PVC capsule filled with activated carbon inserted in the cyanide solution in the mill. The concentration process is yet to be improved as it has recovered around 50%. However, the cycle takes less than 24h and the leaching process recovers up to 98% of the gold in the concentrate. The main advantages of the new process include reducing the cycle from 20 days to 24 h, and reducing cyanide consumption by up to 22 times. In addition, the process may be suitable to eliminate the use of amalgamation at the site.

**Chapter 6: Policy and regulation for ASGM**

Artisanal small-scale gold mining in Brazil produces around 6 tonnes Au/annum and employs around 200,000 miners. Most of this contingent is located in the Amazon region, where miners have been extracting gold for more than 40 years. A study conducted in the Tapajos River Basin showed that around 99% of miners operate without the environmental and mining permits required by law. This is a result of a combination of unrealistic or lack of proper policies and regulations, lack of political will, lack of infrastructure to enforce the existing regulations and lack of incentives to miners to comply with legal requirements.

This chapter analyses a group of 20 laws, decrees and resolutions that affect ASGM in Brazil and points out the main idiosyncrasies of these regulations, which sometimes make no clear distinctions between large and small scale mining. As artisanal miners operate in vast and remote areas, and the government does not have proper infrastructure (personnel, vehicles, information and materials) to enforce the laws, ASGM has remained informal ever since it has initiated. There is no single solution for the environmental, health, technical and socio-economic problems associated to ASGM. However, a realistic approach should consider improving the current level of education of miners, permanence of government officials to provide technical assistance in the field, implementation of awareness programs, simplification of administrative procedures and adequate enforcement.

**Chapter 7: Discussion and General Conclusions**

Chapter 7 summarizes the main findings of this study and addresses the research questions presented in Chapter 1, which includes: 2.1) The most relevant activities affecting the environment in typical ASGM sites in the Amazon; 2.2) The interaction among the main stakeholders to set the objectives of intervention programs; 2.3) The alignment of the critical activities with the objectives of an intervention program in ASGM; 3.1) The best practices for creating programs to address environmental problems caused by ASGM; 3.2) Objectives and goals considering the stakeholders' motivations and needs; 3.3) The effectiveness of interventions and implementation of preventive and corrective actions; 4.1) The extent of the impacts caused by ASGM in deforestation and water contamination; 4.2) Suitable techniques for miners to reclaim degraded areas and mitigate environmental impacts; 4.3) The miner's incentives to reclaim degraded areas; 5.1) The miners engagement to programs addressing environmental protection; 5.2) Alternative technical solutions with higher chances of assimilation by miners; 5.3) Cyanide as a suitable chemical for ASGM; 6.1) The effectiveness of mercury prohibition to reduce mercury pollution; 6.2) The effectiveness of the existing regulations to protect the environment in the ASGM sites in Brazil; 6.3) Ways to improve the current level of effectiveness / compliance with legislation.

This chapter also highlights this thesis contribution to research and the practical implementation in the field of its recommendations. The following initiatives are claimed as original approaches to the ASGM context: 1) In chapter 2, the matrix of environmental impacts is an innovation that replaces conventional and more complexes environmental risk assessment methodologies, which would be incompatible with the ASGM reality; 2) In chapter 3, the use of Balanced Scorecard to evaluate and prove the effectiveness of an intervention program. 3) In chapter 4, some of the mine reclamation methods demonstrated are innovative, above all the use of a triple barrier of palm leaves to retain sediments in old pits. 5) In chapter 5, the pilot plant to pre-concentrate gold and leach the concentrate in a batch ball mill is also an innovation. It employs a PVC capsule with activated carbon that can extract 98% of the gold in the concentrate in less than 24 h. 6) Chapter 6 was devoted to discussing policies and legislation. Instead of the usual approach of proposing more legislation to resolve the existing problems, the author points out the reasons why the current legislation does not work on the ground, and offers alternatives to simplify the requirements.

### 1.8 Introduction to artisanal mining in the Amazon and in the site study

Despite its importance, ASGM has never received proper attention from governments and NGOs (Non-governmental Organizations) as they usually focused on large organizations and other formal sectors. The environmental problems associated with ASGM activities have grown and reached elevated proportions with apparently no trend of reduction in the years to come. This is not a Brazilian problem only, but a common characteristic of ASGM worldwide. According to Hilson (2002), if ASGM continues along its present course, problems associated with ASGM will intensify and the situation can become unmanageable. This author highlights that governments should improve environmental protection and quality of life in resident operations, which would be achieved by formalizing operations, improving environmental management and addressing the needs of individual miners.

Many studies have been conducted in the Amazon addressing the social, environmental and health impacts of the ASGM (Malm et al., 1995; Silva, 1995; Akagi et al., 1995a; Akagi et al., 1995b; Rodrigues and Maddock, 1997; Malm, 1998; Silbergeld, 1999; Silva et al., 1999; Strickland, 1999; Akagi et al., 2000; Santos et al., 2000; Harada et al., 2001; Villas Boas et al., 2001; Silbergeld, 2002; Veiga and Hinton, 2002; Hinton et al., 2003; Otchere et al., 2004; Farias et al., 2005; Telmer et al., 2006; Passos et al., 2007). The favourite approach has been the assessment of the environmental and health effects caused by ASGM, in particular the use of mercury. In many cases, the lack of indicators of the field interventions does not allow appropriate evaluation of the efficiency of the actions, when they happened. Other organizations have studied the problem of mercury generated by natural sources, erosion and deforestation and its health related problems (Lebel et al., 1996; Lebel et al., 1997; Lebel et al., 1998; Roulet et al., 1998; Roulet, 1999).

According to Hilson (2007), the problem of mercury in ASGM has been over studied and sponsored programmes that aim to educate miners about the implications of mercury have demonstrated a fixation on contamination analyses. This author mentions that ASGM suffers from "research fatigue", whereas the real problem is the lack of immediate action on the ground.

According to the Brundtland report (1987), two thirds of the world's population live in state of scarcity and do not have access to proper formal education. Artisanal miners are included in this large portion and suffer the direct consequences of their insufficient technical knowledge and better opportunities, which also compromises their understanding of the environmental impacts they may cause, among other problems.

The Brazilian Amazon is one of the most important ASGM sites in the world, considering the number of miners, gold production, mercury consumption and the overall environmental impacts derived from their activities. This region experienced one of the biggest gold rushes of the history in 1980s, when almost 1 million people were directly involved with gold mining (Feijão and Pinto, 1992; Veiga and Baker, 2004; Veiga et al., 2006). Worldwide, the number of individuals involved in ASGM activities is far larger than all the formal mining companies all together. As an example, currently the formal Brazilian mining sector employs

161,000 people (DNPM, 2008) whereas the informal artisanal mining is believed to employ at least 200,000. Even with this large contingent of informal miners operating in the Amazon for at least three decades, the government has provided little assistance to formalize and improve their working conditions.

According to Guimarães (2004), the history of ASGM in the Tapajós started in 1958 with the first “garimpo” in the region. The mining activity accelerated in the 1970’s and the discovery of Serra Pelada mine in 1979 was a landmark for the ASGM in the Amazon. In 1983, the Brazilian government created the first ASGM reserve in the Tapajós region, called “reserva garimpeira”, with area of 28,645 $km^2$.

According to Silva (2003), three main gold mining methods are used in the Tapajos region, depending on the source of gold: 1) manual method and dredges for alluvial ores; 2) hydraulic monitors and sluice boxes with carpets for colluvial ores (in the river banks) and; 3) hammer mills and amalgamating copper plates for primary ores. Cyanidation is also used but still in smaller scale when compared with mercury amalgamation. In the three methods mercury is used either to extract gold from gravity concentrates or from the whole ore. As alluvial gold has become rare and primary deposits require more sophisticated technology, in general not accessible to most artisanal miners, colluvial deposits are the main source of gold in the region. Hydraulic monitors used to mine colluvial ores cause high environmental impacts as tailings are generally disposed into the rivers.

### 1.8.1 Description of the site study: Tapajos River Basin – Itaituba – Brazil

The Tapajos region in Brazil, with around 40,000 miners, is known as one of the largest artisanal gold mining region in the world. There are more than 2000 mining sites in the 493,000 $km^2$ of the Tapajos River Basin and its sub-basins (Feijão and Pinto, 1992; Silva, 2001; Ribeiro, 2006). The United Nations Global Mercury Project (GMP) selected pilot sites of artisanal gold mining in the basin of the Crepori River, the major tributary of the Tapajos River (including the localities of São Chico, Creporizinho and Creporizão) to conduct an environmental and health assessment. These locations are an integral part of the municipality of Itaituba in the State of Para, in Brazil, with an area of 98,000 $km^{2.}$ They are located around 300 to 500 km from Itaituba City. The watershed of the Crepori river is located in the southwest region of the State of Pará, Brazil and drains an area of 13,578 $km^2$ (Ribeiro, 2006) (Figure 1-2)

By 1980, with the construction of the "Transgarimpeira" road, many mining communities were created due to the existence of this transportation route. Since then, other peaks have occurred, fluctuating according to the discovery of new gold deposits. This road was intended to serve as the main access to an area with hundreds gold mines, starting in the road Santarém-Cuiabá (BR-163) and ending in the community of Creporizão. The Transgarimpeira has 200 kilometres of extension and its maintenance is very poor, which makes it almost inaccessible during the rainy season (from November to February). The construction of the road intensified the process of degradation and deforestation as many villages were created along the road (Silva, 2001).

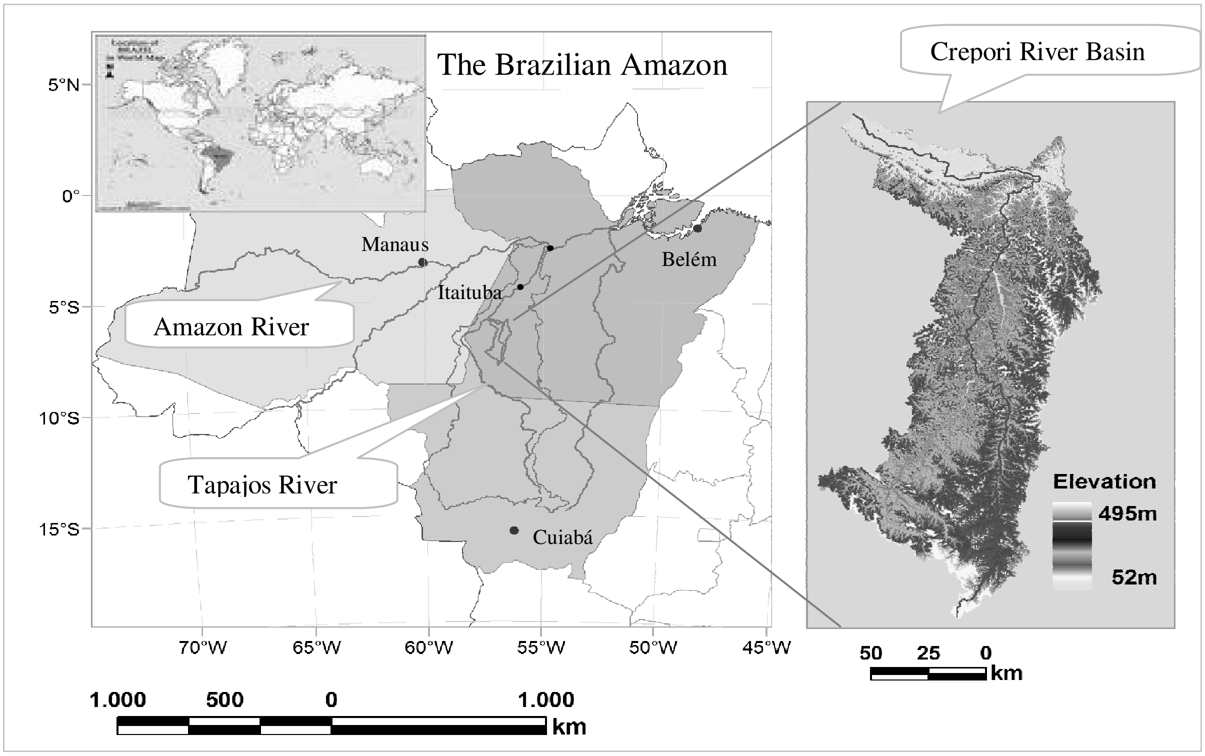


Figure 1-2 – Location of mining sites in Itaituba – Brazil (Ribeiro, 2006)

The villages of São Chico and Creporizinho have already been considered prosperous in the 1980's and 1990's when gold rich primary deposits were discovered. At that time about three tonnes of gold were produced in this area alone. The population of these villages reached 5,000 and 10,000 people respectively (Rodrigues et al., 2004). Figure 1-3 gives a general view on typical mining communities of the Amazon.


1 – General view of the City of Itaituba


2 – Main street of the Village of Creporizao


3 – Mining Community of Cabacal

4 – Mining Community of Sao Jose


5 – Overview of the Village of Creporizao

6 – Typical mining site in the Tapajos Region

Figure 1-3 – Typical gold mining communities of the Amazon

Considering that in the Tapajos River Basin most mining communities employ similar technology for extracting gold as the villages in this study, it was assumed that equivalent levels of mercury contamination, water siltation and deforestation can be found in different locations. The importance of the Tapajos River Basin has justified its choice for this study, where it is addressed the implementation of programs to mitigate environmental and health impacts of ASGM.

### 1.8.2 The use of mercury for extracting gold in the region

A common practice employed to process hard rock is the direct amalgamation of the whole ore on mercury coated copper plates, a procedure through which some mercury is lost to the environment. The plates are scratched and the amalgam collected is burnt to evaporate the mercury. The use of retorts to recover mercury vapour is still not widely disseminated or practiced.

Another common concentration process currently used by Brazilian “garimpeiros” employs sluice boxes and amalgamation of the gravity concentrate. Most recently, starting around the year 2000, some miners have used cyanidation to recover residual gold they could not recover by conventional amalgamation. Cyanide is used to reprocess mercury contaminated tailings to extract gold by heap leaching and vat-leaching. The sodium cyanide dissolves not only gold but also mercury, forming mercury cyanide, which is either more bio-available to be methylated than metallic mercury or directly bioaccumulated by the biota (Veiga and Baker, 2004, Veiga et al., 2006). This fact has been identified in different locations worldwide including the Tapajos region in Brazil. Levels of Hg in fish as high as 22 ppm have been reported (Rodrigues et al., 2004), whereas the guideline level for human consumption is 0.5 ppm total Hg (Ministry of Environment, 1999). Mercury represents a real threat as at high concentrations (above 10-20 ppm) methyl mercury is teratogenic, e.g., it may cause babies to be born with deformities or brain damages (Holt and Webb, 1986; Earth Rights International, 1999).

The usual gravity process for extracting gold from colluvial deposits consists of the use of hydraulic monitors to break the friable ore, creating a slurry which is pumped to sluice boxes, where gold is retained in carpets. The gold in the gravity concentrate is captured by mercury.

Worldwide, around 70% of the mercury used by ASGM is lost to the aquatic system due to the amalgamation of the whole ore using copper plates or grinding with mercury and around 20 to 30% of the mercury is lost to the atmosphere when amalgams are burned in open pans (Veiga et al., 2006). An additional 10% of mercury is released to the atmosphere latently as emissions from contaminated tailings (Telmer and Veiga, 2009). This is particularly true of tailings that have been treated with cyanide as this type of tailings is rich in elemental mercury. Assessments in artisanal gold mining areas have confirmed that the mercury vapour is toxic not only to miners, but also to their families and the neighbouring communities (Veiga and Baker, 2004). The amalgamation of the whole ore is responsible for the largest mercury losses. The contaminated tailings that have passed over copper plates typically are disposed of in creeks and streams, with 50 to 200 ppm Hg, are subject to the oxidation, complexation with organic matter and mercury methylation (Meech et al., 1998; Dominique et al., 2007).

Once the mercury collects fine particles of gold from concentrates or from the whole ore, miners squeeze the amalgam in order to remove excess mercury by filtration in a piece of fabric. This results in an amalgam usually with 60% Au and 40% Hg (Veiga and Hinton, 2002). Depending on the manual strength applied to squeeze the amalgam in a piece of fabric this amalgam can retain more or less mercury. When the amalgam is centrifuged it generally retains around 20% Hg (Veiga, 1997). According to Veiga and Baker (2004) when the whole ore is amalgamated, for instance using copper plates, more than 3 parts of mercury is lost for each part of gold produced, and the mercury lost generally enters the aquatic system with tailings.

When the amalgam is roasted in open air pans with a blowtorch to separate mercury from gold, mercury vapour is inhaled by miners and neighbours and accumulates in critical organs, especially the kidneys and brains. Health effects of mercury have been subject of many studies in the Amazon and worldwide (Malm et al., 1995; Malm, 1998; Harada et al., 1999; Akagi et al., 2000; Drake et al, 2001; Drasch et al., 2001; Harada et al., 2001; Hilton et al., 2003; Limbong et al., 2003; Betancourt et al., 2005; Taylor et al., 2005; Vieira, 2006). Several miners and community members of Tapajos have shown neurological symptoms of mercury toxicity from exposure to vapour (Rodrigues et al., 2004).

The use of retorts can reduce substantially the emission of Hg to the atmosphere as well as occupational exposure. It is unknown how far the mercury vapour can travel, however the use of low cost retorts can reduce up to 95% of mercury vapour emissions (Diaz, 2000). Although the use of retorts is undoubtedly an important step to recover mercury, recovered mercury usually looses part of its amalgamation properties. A thin layer of oxidation is formed by oxidation of the mercury surface by atmospheric oxygen. Mercury loses its coalescence forming thousands of droplets not useful for gold amalgamation. This phenomenon is called “flouring”. This loss of amalgamation capacity often leads miners to discard used mercury inappropriately in the environment (Veiga, 2007). However, used mercury can re-acquire its amalgamating capacity as proposed by Pantoja and Alvarez (2001), by using an electrolytic process that reduces oxidized mercury and causes dispersed Hg droplets to coalesce – also described by Hinton et al. (2003). Essentially the process uses a regular 9 or 12 volts batteries and table salt (sodium chloride) to form an electrochemical cell to clean the mercury surface – it is similar to the reaction used to produce commercially chlorine. Although this simple technology is available at low cost and prevents mercury from being discarded into the environment, it has not been disseminated enough and remains unknown to most miners in the Amazon region. This exemplifies situations where some problems require dissemination of existing technologies, rather than the development of new technologies.

In the studies addressing ASGM worldwide much emphasis has been given to mercury (Hg) contamination. At least in terms of number of studies and publicity, mercury seems to be the major environmental concern, although mercury alone is not the only factor causing health and environmental impacts. Without diminishing the relevance of mercury pollution, in places with the abundance of fresh water like the Amazon region, siltation is at least as important as mercury pollution. Mercury is directly related to the health problems whereas siltation is more directly related to environmental impacts and indirectly related to human health.

Mercury from ASGM can be transported to pristine areas hundreds of kilometres from the mine. According to Telmer et al. (2006) Hg bound to suspended sediment has around 600 and 200 times the concentration of dissolved Hg per litre of water, in impacted and unpolluted areas, respectively. Suspended sediment, thus, represents the major pathway of river-borne Hg transport. Telmer et al. (2006) found that the concentrations of Hg in suspended matter in the Tapajos River Basin were around 134 ppb and 80% of samples had Hg levels below 300 ppb. The author concluded that riverine Hg fluxes are proportional to the concentration of total suspended solids. This study suggested that the lithogenic Hg (originated from sediment) is mixed with anthropogenic mercury (discharged by the artisanal miners), resulting in higher levels of total mercury, which can be bioaccumulated by the biota. This study is corroborated by similar conclusions of Bourgoin et al. (2000).

Although artisanal miners cause direct environmental impact releasing mercury in watersheds, streams and rivers, mercury can also be mobilized by erosion of the river banks and by other anthropogenic activities such as non-mining related deforestation (Roulet et al., 1998). These findings suggest that reducing mercury only, by introducing cleaner technologies for gold recovery, does not mean that successful results will be observed in reducing levels of mercury in fish, unless siltation is also reduced. Telmer et al. (2006) showed that sediments in suspension in the Crepori River, a tributary of the Tapajos River, can be carried up to 300 km downstream, where environmental conditions for methylation may exist. This fact is evidence of the high mobility of Hg-rich sediments.

Miners have very easy access to mercury, although its use in ASGM is forbidden in Brazil without a special permit (Ministry of Environment, 1989). The artisanal miners buy mercury locally in equipment supply shops without any permit. Most mercury enters legally into the country for “dental use” (as labelled in a mercury vial bought in the village of Creporizão) and diverted to gold mining. In 2009, according to UN-COMTRADE (2009) Brazil officially imported 38.0 tonnes of metallic mercury, which trade and use is controlled by the Decree 97.634 of 1989 (Ministry of the Environment, 1989). According to this decree, mercury users have to obtain a special authorization from the Federal Environmental Agency (IBAMA). However, due to bureaucratic barriers, artisanal miners do not get such permit; neither does the Federal Agency controlling mercury use and trading provide miners with any training or information on how to use it safely. A common justification heard from some government officials is that the government cannot provide training for miners to use something that is forbidden. The result is “illegal” but very open sale within the country and uncontrolled use and pollution.

### 1.8.3 Siltation caused by ASGM

Preliminary survey in the Tapajos region indicates that the release of sediments into the streams and rivers may vary from 3,000,000 to 6,000,000 tonnes/a, considering that the average head grade of gold varies from 0.5 to 1.0 g/tonne, and 3 tonnes of gold are produced annually (SEMMA, 2006). The grain size of tailings varies from coarse (2 mm) to as fine as clay (<0.002 mm), indicating that this sediment can be carried for long distances in the rivers. Twenty pits in the Crepori region evaluated randomly showed volumes of sediments varying from 10,000 $m^3$ to 50,000 $m^3$ per pit. Generally, miners start a new pit when the dimensions reach depths above 10 m as the operation becomes more complex. This survey led to a rough estimation of 300 to 600 new large pits open every year in the Tapajos area. Most of these pits remain open, as the current practices do not properly address mechanisms of retention of sediments, and streams and rivers are the miners’ preferred destination for tailing disposal. Veiga and Hinton (2002) studied this problem and concluded that these pits have been abandoned and no effort has been made to rehabilitate open pits or to retain sediments from tailings.

In addition to the association with mercury, suspended sediments also cause reduction of sunlight in water (Melo and Huszar, 2000). Zepp et al. (1984) studied light-induced transformations of organic chemicals on the kinetics of pollutant behaviour in lakes and rivers. This study showed that the humus component of the dissolved organic matter in natural water affects aquatic photoreactions in two important ways: by attenuating sunlight and by sensitizing photoreactions. Suspended sediments affect photolysis rates through light attenuation and scattering. Algae, diatoms, and bacteria accelerate light-induced transformations of anilines and phosphorothioate insecticides, suggesting that photobiological processes may play a significant role in the breakdown of certain pollutants in aquatic environments. Hence, sediments affect sunlight that affects pollutants and the biota. Also, Sheanan and Caramaschi (2005), studying a fish population in Lake Batata, a typical Amazonian clear-water lake, concluded that the reduction of transparency in the silted area was a selective factor for fish species.

Goulding and Barthem (1997) classified the Amazonian rivers according to water characteristics. Amazon tributaries often have extensive drainage basins with a variety of different soils, and thus they have a range of different sediment loads and dissolved ion contents. Stallard and Edmond (1987) detailed the chemical analysis of tributary waters and found that alkalinity, silica and two anion concentrations ($Cl^{-} + SO_4^{-2}$) accounted for most part of the variation in major dissolved anions of their waters. These features are associated with soil weathering and chemical transport, and based on them the rivers were placed into four classes: 1) rivers that drain the most intensely weathered soils and contain high levels of iron, aluminum, low concentration of anions, and are relatively enriched in silica; 2) rivers that drain siliceous terrain, such as the Brazilian and Guyana Shields. 3) rivers that drain marine sediments or red bed, a type of sedimentary rock, with high cation concentrations, carbonates and reduced shales; these rivers show high levels of $Ca^{+2}$, $Mg^{+2}$, alkalinity and occasionally $SO_4^{-2}$ (when draining areas with shale). 4) rivers that drain massive evaporites enriched in $SO_4^{-2}$, $Ca^{+2}$, $Na^{+1}$ and $Cl^{-1}$.

Another simpler classification is based on the water surface color, and groups the rivers into the following classes (Goulding and Barthem, 1997): A) the “white water rivers” are alkaline rivers with high sediment loads, and correlate with previous classes 3 and 4; B) the “black water rivers” are those from class 1; the dark color of black water rivers is not related to geochemical processes, but rather to a heavy load of dissolved organic compounds (tannic, humic and fulvic acids). C) the “clear water rivers” are those from class 2, and the Tapajos River is classified in this group. According to Akagi et al. (1995), the turbidity of the Tapajos River is caused mainly by anthropogenic sources.

### 1.8.4 Deforestation and abandonment of mines

A common belief widely disseminated by artisanal miners in the Tapajos region is that miners do not cause deforestation. The origin of this belief comes from the comparison of mining with logging and farming activities, which leads to the false idea that, comparatively, ASGM do not cause deforestation. In fact, comparatively, farming is far more the major cause of deforestation in the Amazon (Margulis, 2003; INPE, 2007), however mining operations are conducted exactly in the most sensitive ecosystems, along the main rivers and streams.

Gold mining is in fact the main economic activity in the Tapajos region. One of the main reasons preventing deforestation to reach catastrophic proportions is the lack of suitable roads to transport logs to markets. Artisanal miners, however, depend on the forest for their local supply of wood. Mining villages are generally 100% constructed with wood extracted locally, without any legal support and control (Mathis, 2003). The areas cleared for gold mining also cause a significant impact to the forest.

Peterson and Heemskerk (2001) studied the impact of ASGM on the Surinamese Amazon forest and found that impacts on the forest cover are significant. This study estimated deforestation from gold mining and analyzed the regeneration of abandoned mining areas, comparing the coverage of abandoned mining sites of different ages with that in the original and old-growth forest. They estimated that the miners cleared between 48 and 96 $km^2$ of forest annually, and that this estimation is expected to reach between 750 to 2280 $km^2$ by 2010 (roughly the size of almost 230,000 soccer fields). They also concluded that the natural regeneration of the forest in abandoned mining sites was slower and qualitatively inferior compared to regeneration following other land uses. As the mining activities remove the original layer of organic material, the surface is covered with sand and lateritic soil, poor in macro and micronutrients necessary for the vegetation development and so regeneration takes longer.

Telmer and Stapper (2007) studied the ASGM activities in the Tapajos region based on the analysis of satellite imagery and found that the area impacted by ASGM in the riverbeds of some important tributaries of the Tapajos River can be higher than 100 ha every year.

Most of the areas identified as artisanal mine sites are usually abandoned after the easy gold extraction. Veiga and Hinton (2002) identified as the main causes for the abandonment of artisanal mining sites in the Amazon as: 1) the easily extractable ore depletion; 2) miners disorganization and transience; 3) misconceptions of the legislation and regulations; 4) financial barriers; 5) lack of support from mainstream society. The main consequences were identified as mercury contamination and environmental degradation, contamination of biota, human health impacts and degradation of socio-economic conditions.

This scenario of uncontrolled mining and abandonment of areas makes deforestation, in addition to mercury contamination and siltation of rivers, potentially the most relevant environmental aspects to be considered when studying and planning interventions in the ASGM sector in the Amazon.

Rivers siltation and riverbanks deforestation have also been highlighted as major environmental impacts in other studies, reported by the research of Bourgoin et al. (2000), Veiga and Hinton (2002), Ribeiro (2006), Telmer et al. (2006), INPE (2007), Sousa and Veiga (2009).

### 1.8.5 The Global Mercury Project

The Global Environmental Facility (GEF) and the United Nations Development Programme (UNDP) sponsored the Global Mercury Project (GMP), implemented by the United Nations Industrial Development Organization (UNIDO). This project represented a significant contribution to mitigate the impacts resulting from ASGM (Global Mercury Project, 2008). Working in six developing countries (Brazil, Indonesia, Laos, Sudan, Tanzania and

Zimbabwe), the GMP demonstrated ways of overcoming barriers to the adoption of cleaner practices, which included correct waste disposal practices, measures to prevent mercury pollution, protection of water streams, protection of miners' health, and introduction of techniques to increase gold recovery rates, consequently increasing miners' revenue (Sousa and Veiga, 2009). Launched in 2002 and operated until 2008, the GMP aimed at reducing mercury emissions through the introduction of simple technologies, education campaigns and environmental awareness.

The strategy adopted by the GMP to implement cleaner techniques and make communities aware of the dangers of mercury misuse consisted of a straightforward approach in which technical solutions were simplified, made understandable to miners and preferentially easy to be implemented locally. The terms cleaner production and pollution prevention are sometimes used interchangeably, but it is in general understood as the application of preventive environmental strategies to increase efficiency to reduce risks to human and the environment (Hilson, 2003). The curriculum of the GMP educational measures was discussed with local miners and community members to reflect their expectations and address specific problems. Local miners, community leaders or technicians were trained by experts in geology, mining, metallurgical and civil engineering, as well as by health and social workers. These locals, in return, provided training to artisanal miners, promoting dissemination of the simple ideas and procedures that, among others, emphasized the motto of the GMP ("use less mercury, produce more gold and have better health"). Prior to the intervention through training and awareness campaign, the GMP hired local consultants to conduct preliminary environmental and health assessment studies, as well as a socio-economic study in the pilot regions.

During the GMP assessment phase a series of studies were conducted aiming at evaluating the extent of mercury contamination as well to establish the magnitude of the peripheral problems. A socio-economic study was conducted to analyze the history, characteristics and dynamics of the chosen mining communities (Mathis, 2003). Another study pointed out the existing legal framework and regulation of the mining and related activities in the Amazon (Guimarães, 2004). Furthermore, an extensive analysis was done in the areas protected under the Brazilian environmental code, namely permanent preservation areas, and the impacts of the artisanal mining activities (Ribeiro, 2006). The GMP environmental and health assessment was also conducted to support the project intervention, generating data to evaluate the problems under the political, social, health and environmental contexts (Rodrigues et al., 2004).

### 1.8.6 The GMP environmental assessment study

Rodrigues et al. (2004), working for the GMP, collected 658 samples from soils, sediments and water in two Tapajos "garimpos", and found the worst scenario in a mine site called São Chico. This site witnessed a gold rush at the beginning of the 90s and about 3 tonnes/a of gold were produced up to the of the mining activities with consequently release of 6 to 9 tonnes of mercury to the environment. It was found that over 50,000 $m^2$ of soil is covered with Hg-contaminated tailings.

The mercury level in the tailings ranged from 4 to 300 ppm Hg (mg/kg), and river sediments ranged from 7 to 14 ppm Hg. This study has shown extremely high levels of mercury in soils and aquatic sediments and has demonstrated that Hg is bioavailable since fish samples have shown a high concentration of mercury in muscles. This problem is amplified by the fact that a few miners have extracted residual gold from Hg-contaminated tailings by cyanidation using heap leaching process. The sodium cyanide dissolves not only gold but also mercury, forming mercury cyanide. The residual mercury cyanide complex stays in the tailings and it is mobilized by rain water reaching the water streams. Aggravating the situation, water-soluble mercury cyanide can be either more bioavailable or easier to be biomethylated than metallic mercury. This has also been identified in the Global Mercury Project sites in Indonesia and Zimbabwe, where levels of mercury in fish are higher when mercury and cyanide are used together than when only amalgamation is applied (UNIDO, 2006). In the monitoring program in a lagoon receiving effluents from a cyanidation operation at the São Chico site, it was found an average level of Hg in 73 samples of fish of 2.53±3.91 mg Hg /kg (Rodrigues et al. 2004). This is a very high level considering the small size of the fish (18.75±14.42 cm). The average mercury level of 31 samples of carnivorous fish was 4.16±5.42 mg Hg/kg and one sample analyzed contained 21.9 mg Hg/kg. The permissible maximum level for human consumption according to the Brazilian legislation is 0.5 mg of total Hg/kg of fish (Ministry of Environment, 1999). A similar situation was found in the Talawaan River, in North Sulawesi, in Indonesia, where artisanal gold miners extract residual gold from Hg-contaminated tailings using cyanidation in agitated tanks. All tailings are released to poorly engineered ponds and easily reach the river in the rainy season (Castilhos et al., 2006). This study showed extremely high mercury levels in soils, sediments and fish, and this problem is likely exacerbated by the use of cyanidation of Hg-contaminated tailing.

### 1.8.7 The GMP health assessment study

This study has shown that the general working and living conditions at both mining sites Sao Chico and Creporizinho in the Tapajos River Basin were very basic, and the incidence of malaria, parasitosis and other diseases are very high. Several miners and community members of the Tapajos region showed neurological symptoms of mercury toxicity from exposure to vapour. Typical symptoms included tremors, poor balance, ataxia, and concentration problems. Occurrence of symptoms such as metallic taste, excessive salivation, palpitations, and paraesthesia was more significant among miners than among non-miners. Hepatomegaly, splenomegaly, and dyspepsia and arterial hypertension were about 3 to 5 times higher in miners. Levels of Hg in urine of people directly involved with amalgamation were as high as 78.5 µg Hg/g of creatinine (Rodrigues et al., 2004; UNIDO, 2006) when the normal level is supposed to be below 5 µg Hg/g creatinine (Veiga and Baker, 2004).

The main source of mercury contamination is through vapour inhalation during the amalgam burning process. Since artisanal miners do not consume fish in daily basis, the mercury levels in hair of 136 people in São Chico averaged 3.16±2.63 ppm and 1.82±1.53 ppm in 116 people in Creporizinho, in spite of the high concentrations of mercury in fish muscles (Rodrigues et al., 2004). The lessons learned from the health studies indicated that rather than avoiding eating carnivorous fish, which is an important source of protein for the communities, the focus should be on the reduction of mercury emissions.

Another study conducted by Silbergeld et al. (2002) has shown that individuals in ASGM communities in the Brazilian Amazon contaminated with mercury are more vulnerable to contract malaria. In the States of Para and Rondonia, both with extensive gold mining activities, the prevalence of malaria and API (Primary Immunodeficiency) rates are the highest in Brazil (Pan-American Health Organization, 1996). These two States have already accounted for over half of all reported cases of malaria in Brasil. This study also found that malaria is related to some conditions created by the artisanal miners as they change the environment, causing deforestation, destruction of aquatic systems and creation of pools in place of free flowing streams and rivers. This increases breeding niches for the *Anopheles* mosquito, vector of malaria. Moreover, mining activities also increases the size of dispersed settlements, as transience in mining is very high, which causes exposure to infection of individuals from other regions where malaria is uncommon. These micro environments for reproduction of mosquitoes are also enhanced by the accumulation of standing water in garbage (like tires, plastic bags and bottles) and overall poor sanitation in the mining villages.

### 1.8.8 Socio-economic aspects

The number of miners in the villages varies substantially over time and such fluctuations are a consequence of the discovery of new gold veins or the economy as a whole. When opportunities in agriculture decrease, peasants can migrate to mining activities, and vice versa. Mathis (2003) studying the mining communities of Creporizinho and São Chico reported that 51% of the “garimpeiros” had worked in agriculture before becoming artisanal miners. A simplified survey to profile the socio-economic conditions in the Tapajos region was applied by GMP/SEMMA (2006) to 376 miners in the villages of Creporizão, Creporizinho and Cabaçal. It demonstrated that these mining communities have the following characteristics, shown in Table 1-3:

Table 1-3 – Miners' general profile

| Evaluated item | Min | Max | Mean | Median |
|---|---|---|---|---|
| Age of miners (years) | 16 | 75 | 32 | 28 |
| Time in mining activity (years) | 1 | 50 | 12 | 11 |
| Family members | 1 | 15 | 4 | 5 |
| Hg consumed (g/month. miner) | 0 | 300 | 40 | 35 |
| Production (g of gold/month. miner) | 0 | 200 | 18 | 16 |
| Revenue (US$/month. miner) | 0 | 5600 | 504 | 446 |

In these areas, gold mining is the main source of revenue as agriculture and livestock raising is not yet developed in the region.

Another local survey conducted by the author showed that the local price of mercury was US$200/kg (Dec/2009) while the mean international price in the same period was around US$17.40/kg (Metalprices, 2009). Gold was sold locally at US$35/g (Dec/2009) whereas the international price was US$39/g (Kitco/2010).

About 90% of miners are male, and women are only indirectly involved in the mining activities, as cooks and clerks in the local commerce. The level of prostitution is, however, high. No child labour (age below 14) was observed in the area, and the youngest miner found was 16 years old. The level of illiteracy or very basic reading and writing is around 60%. Mathis (2003) reported levels of illiteracy close to 55% in Creporizinho and São Chico, and also that 63% of the population in these villages did not have formal documents of identification. Although "garimpeiros" in general do not establish roots into the place they work, most of them have been involved in this activity for more than 10 years in the region. The mobility of miners is very high and they move frequently from one mine site to another where they believe they will find "easier" extractable gold. Almost 70% of "garimpeiros" live away from their families and their hometowns. The most frequent migration occurs from the Brazilian Northeast States (Maranhão and Piauí) to the North (State of Pará). This causes many social disruptions, since families are left behind and women have to raise their children alone (Mathis, 2003).

According to the GMP/SEMMA survey, the average gold production is about 18 g/month per miner at the average purity of 80-85%, which corresponds to a US$ 504/month income. This is at least as twice as high the minimum legal wage in Brazil (US$250) (Ministerio da Previdencia Social, 2009), but the cost of living in mining sites area is far higher than the Brazilian average, mainly due to transportation costs. This production was estimated based on the interview of miners who took part in the survey, and it varies a lot among individuals, also influenced by personal motivation to provide underestimated or overestimated numbers.

The average gold production found in this survey is coherent with the numbers reported by Mathis (2003) when analyzing the population of Creporizinho and São Chico, typical mining communities in the Tapajós region. Mathis found that the average gold production was 17.1 g/month per miner, but at that time (2003) gold was sold locally at US$ 7.3 /g.

The number of "garimpeiros" in the Tapajós and their gold production has always been a source of debate. The number of 40,000 "garimpeiros" seems to be a consensus among the official sources (DNPM, SEMMA, Itaituba authorities) and local community leaders, however, many of those considered as "garimpeiros" are not directly involved in mining activities or not working constantly in a mine. Many “garimpeiros” eventually spend time in the villages working on commerce, transportation and overall support to “garimpos”. Serra Pelada is an extreme example of fluctuation of number of miners. Although a local cooperative (COOMIGASP) claims to have 40,000 registered members, the number of “garimpeiros” in the village is believed to be around 6,000, but less than 200 of them are involved in working on re-processing tailings or doing any mining activity. In the whole Tapajós, the number of “garimpeiros” directly involved in mining may fluctuate between 28,000 and 36,000. Using 18 g/month per miner as reference, the gold production would fluctuate from 6 to 8 tonnes/a. Yet, as a significant part of the gold is sold informally (without proper receipts), the official production (Federal Government estimate) of 3 tonnes/a is believed to be underestimated. An equivalent fluctuation in mercury consumption would be expected, which could vary between 13 and 17 tonnes/a. It is known that the use of cyanide in heap and vat leaching has intensified in the region, but no reliable estimate of cyanide consumption was found so far, but the introduction of cyanide is another factor affecting mercury consumption.

The few roads in the region are in precarious conditions and the main way of transportation is airplanes and boats, at very high costs. To exemplify, a 2 liter bottle Coca-Coca costs US$1.50 in regular markets in Itaituba city, but in some remote mining sites the price escalates to US$10.00. Despite the better average income provided by ASGM, the artisanal miners can also spend months without any production. The amount of mercury (Hg) consumed is about 40 g/month/miner, but this depends on the amount of gold they produce and the style of operation. In the Tapajos, usually the mercury lost/gold production ratio ranges from 1 to 3 since there are miners amalgamating gravity concentrates (but not using retorts) and others using copper plates to amalgamate the whole ore.

At least four different classes of miners were identified, according to their working status:

1. Owners of "garimpos": are those that occupy the land where they work, although they do not necessarily have the title to the land. In large areas of the Amazon, the farmers or anyone claiming ownership of lands does not have any formal documentation to support their claim. It is estimated that there are between 500 to 1,000 owners of "garimpos" in Tapajos region (SEMMA, 2006).

2. "Garimpeiros": miners who work for owners of "garimpos" receiving commission. Their relationship is recognized as a partnership, and the group of miners share 25% of the gross production. In general their manager receives extra 3% commission and the supervisor receives an extra 1%. These arrangements may vary between sites, but overall there is an established culture to work in partnership, and the Brazilian Labour Ministry has interpreted this as an acceptable labour relationship, according to SEMMA (2006).

3. Independent miner: these miners own basic machinery (a pump and hydraulic monitor to excavate the pit and another pump to feed the slurry in the sluice box). They do not own lands and work by permission or invasion of somebody else's lands. Most lands are public but are occupied by someone who claimed the ownership first. This generates conflicts but the situation has become much more stable when compared with the gold rushes of the 1980s and 1990s.

4. Temporarily “out-of-work” miners: those who are not currently mining but consider themselves miners, as they can resume the activity at any time. Some have not been mining for years but still keep ties with miner’s associations as they believe in future benefits and opportunities.

The understanding of this structure is crucial when addressing actions in ASGM in this region, as the mine owners are the ones with more power for encouraging and implementing new initiatives. Naturally, they can also use this same influence for boycotting new initiatives if there is conflict of interest with their objectives, which are generally economic. However, any intervention in ASGM in this area requires a good understanding of the social context and a good political relation with the local authorities, community leaders and mine owners. According to Hilson (2006, 2007), many projects aimed at improving ASGM are not successful because they fail to acknowledge the cultural, social, economic and organizational context of specific mining sites.

## 1.9 Remarks

With the increasing international price of gold (US$1,100/oz) (Kitco/2010), and while miners can make a higher revenue (US$504/month in average) than they would make in traditional activities such as agriculture and livestock, it is unlikely that the contingent of miners in the Amazon will drop dramatically in the near future. They are also very motivated by the expectation of finding some rare high grade deposits, where miners believe they can make up to US$5,000 in a month. Despite the fact that most alluvial deposits have been exploited and colluvial deposits have been reduced significantly, miners are still moving to lower grade surficial deposits, or discovering new primary deposits, and most recently, they started to reprocess tailings accumulated in the last decades.

In the Tapajos River Basin, the problems associated with ASGM will persist in the years to come. Environmental assessment studies have demonstrated the relevance of problems associated with mercury use in the mining sites, as well as the problems of siltation and deforestation. Health assessment studies have shown that malaria and mercury contamination are amongst the most important health issues to be addressed in the ASGM.

Mercury is relatively inexpensive (US$0.20/g) compared to the price of gold (US$35/g). This indicates that even in the hypothesis of mercury price to be increased 10 times, it is unlikely that this fact alone would be enough to discourage miners in using mercury to amalgamate gold. Some international NGOs defend that mercury prohibition is a good strategy to prevent miners from using mercury and consequently reducing pollution. In fact, mercury use in ASGM is already prohibited in Brazil since 1989, and it is still largely used by artisanal miners.

There are strong links between social aspects, low technological level, environmental impacts and low levels of formalization (low compliance to legal requirements). When it comes to intervention programs in “garimpos” such interrelation needs to be taken into consideration, as they have simultaneously causes and consequences. In other words, the low technological level, the low level of organization, and poor access to capital, is in part a consequence of the low level of education but also a result of miners’ illegal status. Low technological level may result in low levels of gold recovery and inefficient methods to find gold, which results in higher costs, lower profits and revenues, and higher environmental impacts per unit of gold produced, altogether negatively impacting the miners' social conditions. Low levels of education and little access to training and awareness may be translated into low or no commitment to environmental issues.

However the lack of engagement by the government cannot be separated from the causes of the problems. The government has failed in providing technical assistance to miners or enforce its existing laws, resulting in very little compliance by miners. To illustrate this, one of the questions included in the survey applied by SEMMA (2006) in the mining areas of Tapajos, asked the miners about the frequency that they had received or seen government officials (from the environmental or mining ministries) working in their areas, and the predominant answer was "never". This again reinforces the isolation of these miners, not only physically, but also with very limited access to education, technical assistance and awareness to the risks posed by their activities, above all the use of mercury and cyanide.

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# CHAPTER 2 – MATRIX OF EVALUATION OF ENVIRONMENTAL IMPACTS[1]

## 2.1 Introduction

### 2.1.1 Environmental risks associated with artisanal small-scale mining

Despite its relevance, ASGM (Artisanal and Small Scale Gold Mining) has never received proper attention from governments and non-governmental organizations (NGOs) as has been demonstrated to larger organizations and other formal sectors (in particular formal mining operations). To exemplify the relevance of ASGM, it is important to recognize that two thirds of the world's population live in state of scarcity and do not have access to proper formal education (Brundtland, 1987). This compromises the ability of this population, to understand environmental impacts caused as a result from their activities. Artisanal miners are included in this population, and suffer the direct consequences of their lack of knowledge and better opportunities.

Once a human being's basic needs are satisfied, education is the greatest asset one can possess, as this is a determinant of health, as recognized by the World Health Organization (WHO, 2010). According to Krishnamurti (1956), education is not merely acquiring knowledge, gathering and correlating facts; it is to see the significance of life as a whole. The environmental movement observed in the world in the last decades has influenced more than one third of the population with access to formal education. For those two thirds struggling to survive, concepts like environmental protection, environmental impacts, global concerns, social responsibility and citizenship represent complex words and jargon.

[1]A version of this chapter has been submitted for publication. Sousa, R.N; Veiga, M.M; Meech, J.A; Souza, A.J. A Simplified Matrix of Environmental Risks to Support an Intervention Program in Small-scale Mining

Worldwide, the formal mining sector is frequently the target of stringent environmental legislations, resulting from the pressure of society, represented by environmentalists and NGOs. However, the informal mining sector, such as artisanal small-scale gold mining (ASGM), a predominant economic activity in developing countries, is not subject to the same regulations, or when it is, governments have not enough infra-structure to enforce compliance or to provide technical assistance. Overall, the environmental impact caused by the world's poorest population is less subject to monitoring and control than the impact caused by the formal sectors. As the poorest population is concentrated in developing countries, many of these countries do not have efficient mechanisms to implement programs to mitigate and control environmental risks, or to enforce their own legislation.

In most developing countries facing environmental problems caused by ASGM, governments have adopted bureaucratic procedures to legalize these informal activities, in which an environmental risk assessment (ERA) is requested. Complex ERA studies are beyond the reality of most ASGM sites, as they are not organized or empowered enough to develop and use these elaborated tools. Although ERAs are appropriate tools for large companies, the ASGM sector requires a more simplified approach; the current scenario and trend is the non-existence of any tool at all. In order to respect different contexts and realities, the development of simple alternatives to evaluate the environmental risks posed by activities carried on by informal sectors such as ASGM is needed. These activities generally occur in poor communities in isolated locations, were people have low level of formal education and low interest or lack of resources to invest in complex monitoring systems. To create real chances of successful implementation in this area, a risk assessment tool must be simple, inexpensive and easy to apply.

### 2.1.2 The artisanal small scale gold mining sector in the Brazilian Amazon

The Brazilian Amazon is one of the most important ASGM sites in the world, considering the number of miners, gold production, mercury consumption and the overall environmental impacts derived from ASGM activities. It was chosen by the United Nations Global Mercury Project (GMP) in 2002 as one of the project's pilot site (Global Mercury Project, 2008). The GMP has demonstrated ways of overcoming barriers to the adoption of consistent practices, which include correct waste disposal practices, measures to prevent mercury pollution, protection of water streams, protection of miners' health, and introduction of techniques to increase gold recovery rates, consequently increasing miners' revenue (Sousa and Veiga, 2009).

The number of individuals estimated to be involved in ASGM activities worldwide is far greater than those employed with the formal mining sector. As an example, currently the formal Brazilian mining sector employs 161,000 people whereas the informal artisanal gold mining is believed to employ around 200,000 (DNPM, 2008). Even with this large contingent of informal miners operating in the Amazon for at least the past three decades, the government has provided little assistance to formalize and improve their working conditions.

In Brazil, following an international trend, environmental legislation has become more restrictive over time. Regulations at the Federal, State and Municipal levels address environmental criteria for companies and individuals to operate their businesses. In 1986, the Federal Environmental Council (CONAMA) established the compulsory criteria for the evaluation of environmental impacts as part of the process of licensing mining operations. Following this orientation, new mines are required to provide a plan to mitigate their environmental impacts in order to have an environmental license issued by the government authority. In the Tapajos region, where miners extract alluvial and colluvial gold, and in some cases primary quartz-vein ore, around 99.3% of miners do not attain the legal criteria to obtain the environmental license, and thus, they are illegal miners (Sousa and Veiga, 2007a). Notwithstanding, they have been mining for decades, regardless of the existent environmental legal system.

Legislation alone does not assure that artisanal miners may comply with environmental and health requirements. For example, the Brazilian decree 97507-89 does not allow the use of mercury in "garimpos" without previous license (Ministry of Environment, 1989), but amalgamation is still the preferred and simplest method to extract gold.

Artisanal gold miners live in remote areas and the Municipal, State, and Federal governments do not have the economic structure to enforce the environmental laws required to prevent or mitigate impacts, or to develop economic options that bring enhanced benefits to miners. There is no unique solution for such a scenario; however, the administrative processes and regulations need to be simplified to adequately address the government capabilities to the ASGM reality. This includes simple criteria to identify the environmental risks associated to the artisanal miners' activities, and enabling the implementation of environmental programs to address such impacts.

The proposed matrix of environmental risks presented in this study was the result of discussions between researchers and stakeholders, taking into consideration not only the directly measurable impacts, but above all, the stakeholders' perception on such impacts. The stakeholders' consultation was not only a fundamental step during the implementation of the

GMP goals; importantly, these people represented the only individuals who would assure continuity of actions after the pilot project concluded. This simple matrix has been developed for this site in particular; however, its concepts allow for its adaptation to any other ASGM site. The matrix implemented in the pilot site in Brazil is useful to determine the relevance of risks based on the classification of activities according to the likelihood (or Degree of Belief) they may cause environmental impacts. This matrix has proved to be very useful and supported actions to mitigate such environmental impacts, as presented in this study.

Some of the environmental and health problems associated with ASGM in the region are shown in Figure 2-1.

1 – Deforestation along the rivers

2 – Use of hydraulic monitors in sensitive areas

3 – Contaminated tailings disposed into the rivers

4 – Cyanide tailings disposal without treatment

5 – Amalgam of mercury burnt without protection


6 – River siltation and mercury contamination

Figure 2-1 – Environmental and health problems associated with ASGM

## 2.2 Material and methods

### 2.2.1 The environmental risk assessment process

There are at least 3 options available when considering an environmental risk assessment (ERA) tool for ASGM. Basic comparisons between these options are presented in Table 2-1.

At one extreme, there is the classical ERA model. The classical ERA refers to the process that manages the uncertainty and probability of adverse impacts and potential risks of multiple stressors on complex ecological communities, as defined by Suter II et al. (2000). All information and data are subject to interpretation and a professional judgment is required to make decisions and find solutions to manage potential risks. A second option, one that is currently employed is where no environmental assessment or tool is utilized at all. A third option, as proposed in this paper, is the heuristic matrix of environmental risks. This approach is located between the aforementioned extremes and represents an alternative tool that is not complex, inexpensive and easy to be understood by the main stakeholders. The matrix of environmental risks proposed in this study represents a more simplified alternative to attain the same objectives. When simplification is a requirement, heuristic systems can be more appropriate than the stochastic ones.

The proposed matrix of environmental risks presented in this paper was the result of discussions with local stakeholders. This matrix took into consideration not only the directly measurable impacts, but also, the stakeholders' perception of such impacts. This consultation was fundamental during the implementation of the GMP – Global Mercury Project goals, and was critical in assuring stakeholders' commitment to actions carried out in the implementation phase of the project.

The area selected for this study is located in the municipality of Itaituba, in the Tapajos River Basin, where 40,000 miners work in the extraction of colluvial and primary gold, according to SEMMA (Itaituba Environmental Agency). The Tapajos region has one of the largest concentrations of gold mines in the world, with more than 2000 mine sites and 432 landing strips (Feijao and Pinto, 1992; Silva, 2001). Specifically, the artisanal mining area known as "Garimpo Canaan" was the first area to be evaluated through the use of the matrix of environmental risks proposed in this study.

Table 2-1 – Comparison between classical ERA, simplified matrix of risks and the current practices in ASGM.

| Classical Environmental Risk Assessment (ERA), if applied to ASGM | Simplified matrix of environmental risks, if applied to ASGM | The current scenario of ASGM, in terms of using environmental risk assessment |
|---|---|---|
| Stochastic methods: requires data, sampling, calculations | Heuristic methods: based on the existent knowledge (*) | No formal control in place |
| A probabilistic process based on data and statistics | A probabilistic process based on experience | |
| Requires expert people | Requires basic understanding | |
| High costs involved for ASGM | Low costs involved | |
| Less flexible | More flexible | |
| Not every stakeholder can understand | Better chances to be understood by all the stakeholders | |
| Generates information to support a plan of action | Generates information to support a plan of action | A plan of action is possible, but may not address the key variables |
| Reduced level of subjectivity | Intermediate level of subjectivity | High level of subjectivity |

(*) Note: knowledge, in this case, is obtained from experts or traditional miners

While the current scenario is clearly the total absence of controls and the classical ERA seems to be beyond the artisanal miners' reality, a heuristic and intuitive method based on fuzzy logic seems to fulfill this gap adequately.

The Fuzzy Logic technique was created by Lotfi Zadeh (1965) and employs human analysis to provide an approximate but effective means to describe the behaviour of situations which are too complex to allow precise mathematical analysis. As mentioned by Veiga & Meech (1995), heuristic equations and fuzzy sets are suitable techniques to mimic the reasoning of an expert, conferring elasticity to the Degree of Belief on the conclusions. These linguistic terms have the same effect as complex mathematical models that usually demand high costs, large amount of data and complex software to quantify the relationship among variables. The heuristic system developed by these authors, called HgEX, aims to evaluate mercury bioaccumulation in artisanal mining sites.

It is likely that different experts in ASGM issues classifying the relevance of environmental impacts by using a simplified matrix will be led to equivalent conclusions, as the method is based on experience and intuition. There is a risk associated with this approach, as observed by Veiga & Meech (1995), as what is considered a "low" environmental impact for some people may be considered a "high" impact for others; and this may depend on the concern and reaction of a society to the technical and economic factors related to the gold mining activity.

The NEPA (USA's National Environmental Policy Act) developed in 1969, is an original tool of evaluation of environmental aspect and impact of projects (NEPA, 1969). NEPA established the need to accomplish evaluations of environmental impacts, including the accounting of the beneficial and adverse impacts, as well as the results of actions capable to affecting significantly the quality of the environment.

The evaluation of Environmental Impact can be subdivided in three principal phases: the "identification", the "estimation" and the "comparison". In the identification phase the environmental elements are defined traditionally as physical, biological and human components of an ecosystem. The identification of the environmental impacts establishes the possible consequences (impacts) of a certain number of activities (aspects). The concept of an identification matrix, nowadays broadly used to support management systems based on ISO 14001(Barrow, 1999), is a useful tool according to Leopold (1971). The matrix of impact is the correlation of two listings of a bi-dimensional matrix, looking for correlating the activities to the affected elements. Leopold's system was conceived as a guide and consists of a matrix composed of two axes: 1) Existing characteristics and conditions of the Environment; and, 2) Proposed actions which may cause environmental impact. The first axis has the following major components: physical and chemical characteristics, biological conditions, cultural factors, and ecological relationships. The second one has the following components: modification of regime, land transformation and construction, resource extraction, processing, land alteration, resource renewal, chemical treatment, and accidents.

After the identification phase it is necessary to estimate the evolution of all environmental impacts. Models are developed to estimate the magnitude of the current impacts and there are at least three known ways for this representation: simple mathematical functions, dynamic models and verbal declarations. The simple mathematical functions of the models can be heuristic equations representing the knowledge of an expert. These functions can be defined mathematically, or simply by ranks.

The linguistic expressions allow the treatment of variables in ranks, in which a group of logical statements can be algebraically represented. These logical affirmatives are later transferred to a flowchart tree, defined for a group of experts. The final phase, called the comparison phase, uses the information generated in the previous phases to identify a solution that best fits, taking into consideration the magnitude and the significance of the environmental impact.

The method adopted for the identification, evaluation and control of the environmental aspects with significant impact is based on the information gathered from the interested parties (or stakeholders), identification of pertinent legislation, numeric evaluation of the significance of the aspects and identified impacts, monitoring and control of significant environmental parameters.

### 2.2.2 The matrix of environmental risks implemented in the pilot site

Programs addressing reduction and control of environmental impacts in ASGM generally rely on the experience and expertise of the project manager or the mandate of the sponsoring agency, in order to set objectives and identify the most important variables to be controlled. This method of selecting objectives and goals, and giving relevance for different environmental impacts is valid but can be improved, by reducing its level of subjectivity, as proposed in the current study.

The matrix developed in this case study was intended to be used by the interested parties involved in artisanal gold mining in the pilot area in the Tapajos Region (the GMP management team, the local miners' association and the local government) in order to support the assessment and understanding of the environmental impacts caused by ASGM. Its main objective was to demonstrate a simple but yet efficient and measurable way to determine the most relevant environmental variables in small-scale mining sites. This heuristic method proposed a simple matrix to classify the variables according to the likelihood (or Degree of Belief) they may occur. This classification was developed to be tested in ASGM sites in the Amazon and established consistent criteria to select variables according to their significance. This reduced the subjectivity of the process and allowed the establishment of plans of action focusing on the control of the most valuables variables.

Through this matrix of evaluation, every potential impact was classified according to its intensity and extent, and the result was the level of relevance of each variable for the environment. Variables with higher likelihood to cause environmental impact should have higher priority when controls, training, awareness and any other action had to be implemented. The matrix proposed in this study uses similar concepts to HgEX (Veiga and Meech, 1995) but aims to assess the significance of all main environmental impacts, going beyond mercury.

### 2.2.3 Mining activities with potential environmental impact

There are many activities involved in the artisanal mining, and some of them with higher likelihood to cause damage to the environment than others. ASGM mining activities vary from simple panning to mining with hydraulic monitors (a process which removes large amount of soil and vegetation). Therefore, every variable (mining activity) carries a potential environmental impact. It is possible to track and evaluate each step of the mining process using the proposed matrix.

Artisanal gold miners at the study site (Tapajos River Basin in the Amazon), work with alluvial, colluvial and hard rock ores, and use various gold extraction techniques which are dependant on the type of geological deposit they mine. For the purpose of this study, the most common process was considered; where miners excavate pits of colluvial ore by using hydraulic monitors. This process concentrates gold by passing the ore slurry through sluice boxes layered with carpets. Gold is subsequently recovered from the carpet layer by amalgamation with mercury, as described by Veiga & Hinton (2002).

The main mining activities (or steps) were discussed with key interested parties (SEMMA, "Garimpo Canaan"), initially, regardless of their environmental significance. These variables are listed in Table 2-2.

Table 2-2 – List of mining activities (or variables) with potential environmental impacts

| # | Activities | # | Activities (continuation) |
|---|---|---|---|
| 1 | Surveying | 17 | Backfilling pool amalgamation |
| 2 | Vegetation removal | 18 | Backfilling old pits |
| 3 | Equipment transportation | 19 | Backfilled pit accommodation |
| 4 | Generator and motor installation | 20 | Plowing refilled pit for revegetation |
| 5 | Excavation with hydraulic monitors | 21 | Revegetation |
| 6 | Sluice box installation | 22 | Fertilization of revegetation |
| 7 | Water catchment | 23 | Fighting pests and diseases |
| 8 | Carpet washing | 24 | Infra structure (roads, bridges) |
| 9 | Mercury use | 25 | Camping construction |
| 10 | Manual amalgamation | 26 | Well excavation |
| 11 | Concentrate gathering | 27 | Garbage disposal |
| 12 | Panning pool construction | 28 | Garbage burning |
| 13 | Panning pool operation | 29 | Used oil disposal |
| 14 | Amalgam burning without retort | 30 | Latrine construction |
| 15 | Use of retort / mercury recycling | 31 | Motors and pumps maintenance |
| 16 | Mercury reactivation | | |

### 2.2.4 Environmental aspects and impacts

The term environmental aspect is defined by ISO 14001 (1999) as any element of the activities, products or services of an organization that can interact with the environment. Note: a significant environmental aspect is the one that has or can have a significant environmental impact. ISO 14001 (1999) also defines environmental impact as any modification of the environment, adverse or beneficial, that results, in the whole or partly, of the activities, products and services of an organization. For the purpose of this study, the terms environmental aspect and environmental impact were differentiated, although in some other studies terms like effect, aspect and impacts are sometimes treated as similar. For instance, the removal of vegetation involves the environmental aspect of deforestation, which may cause environmental impacts such as soil exposure, erosion and soil microbiological alteration. Environmental Impacts refer to the chemical, biological or physical alterations in the environmental, which cannot always be observed.

In general the public understands environmental impact as something necessarily negative. However, for the purpose of this study, environmental impacts are defined as any anthropogenic alteration to the natural environment. In this case, they can be classified as adverse or beneficial.

- Adverse: Impact with negative result on the environment. Example: indiscriminate use of fire to control pasture pests, generating soil exposure and alteration of soil microbiological activity.

- Beneficial: Impact with positive result to the environment. Example: a prescribed fire of a vegetation to avoid uncontrolled fires (natural or not) that may produce much higher damages.

The variables listed in Table 2-2 are associated with potential environmental aspects (Table 2-3) and impacts (Table 2-4). The main attribution of the matrix of environmental impacts is to associate these tables and evaluate the significance of each variable, based on the degree of believe that they may cause significant environmental impact. This evaluation relies on relevance factors to measure the importance of each variable, as shown as follows.

Table 2-3 – Potential environmental aspects associated with the mining activities

| # | Potential Environmental Aspects | # | Potential Environmental Aspects (cont.) |
|---|---|---|---|
| 1 | Soil compression | 8 | Mercury release |
| 2 | Soil exposure | 9 | Particulate material emission |
| 3 | Soil removal (organic material) | 10 | Sediment release |
| 4 | Water consumption | 11 | Garbage production and disposal |
| 5 | Material consumption | 12 | Used oil disposal |
| 6 | $CO_2$ emission | 13 | Use of pesticide |
| 7 | Mercury vapor emission | | |

Table 2-4 – Potential environmental impacts associated with the environmental aspects

| # | Potential Environmental Impacts | # | Potential Environmental Impacts |
|---|---|---|---|
| 1 | Soil physical alteration | 8 | Flora alteration |
| 2 | Soil chemical alteration | 9 | Fauna alteration |
| 3 | Soil microbiological alteration | 10 | Depletion of renewable resources |
| 4 | Water contamination (chemical / biological) | 11 | Noise emission |
| 5 | Water siltation | 12 | Human health alteration |
| 6 | Water, soil and fauna alteration | 13 | Green house effect |
| 7 | Air quality alteration | | |

### 2.2.5 Classification of variables using relevance factors

In order to give the sense of relevance of each variable (activity), they were classified according to different factors, chosen heuristically by key stakeholders. These factors are *public perception, extent, frequency and intensity*, and their classification varies from low, intermediate or high. Aiming to simplify the system, the classification criteria consider that each factor has the same importance when compared to one another. Four levels of relevance for each factor were considered, with different weights (0, 1, 2 or 3 points). Hence, while a factor can be of low relevance, another can be high, and vice versa.

Weights according to the relevance of the factors:

- No relevance: 0 point (or does not apply for a particular activity)
- Low relevance: 1 point
- Intermediate: 2 points
- High relevance: 3 points

- Public perception: refers to the likelihood that the general public may perceive or associate a variable with an environmental impact. It varies from low to intermediate or high.
- Extent: refers to the geographical area affected by the variable.
- Frequency: refers to the frequency that certain activity is expected to occur, generating impact.

- Intensity: refers to the intensity in which a variable is believed to impact the environment.

For example, for the variable “use of fire to remove vegetation” a hypothetical interpretation according to the selected criteria can be:

Public perception is high, since forest fires are commonly perceived by society as a serious issue. For the purpose of this study, the technical issues related to each variable are not fully explained, as the objective of this matrix is to serve as a practical and useful tool for miners to evaluate the impacts resulting of their activity.

Extent varies depending on the history of fires registered in the region, based on comparison between a current extent and historical occurrences in the region.

Frequency also depends on the current frequency of fires when compared to historical numbers in the region. For example, how often are fires expected to occur in a year/month/week?

Intensity is determined by the % of the trees individually affected, varying from superficial to total loss (when only ashes remain).

Possible final conclusion: “use of fire to remove vegetation” has high public perception (weight 3), intermediate extent (weight 2, depending on the area), low frequency (weight 1, depending on the frequency) and high intensity (weight 3, assuming hypothetically the damage is high). This information is the basis for further classification of the significance of each variable (activity), in terms of its potential to cause environmental impact.

In addition to the previous factors, three other non-quantitative factors were considered: Legislation, interested parties and detectability. As they are not quantitative, no weight was considered, but only their pertinence. If they apply to an activity, one additional point is considered; otherwise no point is added.

- Legislation: this factor adds one more point to the variable related to legal requisites. The analysis is a simple yes (1 point) or no (0 point) consideration, without taking intensity in account (this was not considered a quantitative data).

- Interested Parties: this factor adds another point in case the variable may affect directly any interested parties. The term interested party is defined by ISO 14001 (1999) as an individual or group interested or affected for the environmental performance of an organization. For this study, the main interested parties where the GMP team, the SEMMA team and Garimpo's representatives.

- Detectability: this factor adds another extra point for variables that generate detectable and traceable impacts.

As resources to implement actions are limited, the method prioritizes variables that are legal requirements, affect other parties and are detectable and traceable. Example: the "use of fire to remove vegetation" is regulated by law, affects directly neighboring areas and is easily detectable. As a result, considering one point for each factor, 3 extra points are considered for this variable.

### 2.2.6 Significance of variables (ASGM activities)

Ultimately, the objective of the matrix of impacts was to evaluate the significance of each variable in the whole environmental impact. Thus, if a hypothetical variable X was highly significant, this means that it may produce a highly significant environmental impact.

As the variables are ranked from 0 to 3 based on their relevance, a Degree of Belief in the significance of each variable is derived by summation of the relevance factors divided by the maximum number of points. According to this the significance of a variable is classified as negligible, acceptable, moderate, substantial or extreme. This classification allows the ranking of variables with higher potential of causing environmental impacts.

The maximum relevance factors summation is 15 points (Public perception (3); Extent (3); Frequency (3); Intensity (3); Legislation (1); Interested party (1) and Detectability (1)). The DoB of the significance is shown in %.

The general DoB (Degree of Belief) of the significance of each variable was given by:

$$DoB_{\text{significance}} = \frac{\sum \text{Relevance factors}}{\sum \text{of Max Relevance Factors}} * 100$$

The classification of the DoBs is interpreted in intervals of 20%, producing the following scale for levels of significance of the results:

- Negligible: 0 to 20%
- Acceptable: 21 to 40%

- Moderate: 41 to 60%
- Substantial: 61 to 80%
- Extreme: 81 to 100%

This is called linguistic defuzzification, as mentioned by Veiga & Meech (1995). Therefore, in order to evaluate the significance of a potential environmental impact of a hypothetical activity, the user of this heuristic method takes into consideration the following questions: Is the potential environmental impact of this activity perceived by community as high? Is the frequency of this activity high (comparatively with other activities in ASGM in the same area)? Are the extent (affected area) and intensity high (comparatively with other activities in the same area)? Does it affect directly interested parties, such as neighbors? Is this a legal requirement (are there laws regulating the variable)? Is such impact easily detectable (for example, visually)? These considerations will lead to the level of significance of the potential environmental impact, which varies from negligible to extreme. This evaluation procedure indicates whether the variable requires monitoring and controls in order to mitigate its potential impacts.

## 2.3 Results and discussion

A list of the main variables (main activities, processes and operations necessary to produce gold in the studied site) are listed in Table 2-5.

Table 2-5 – ASGM activities and associated environmental aspects and impacts

| | Variable (Activity) | Environmental Aspects | | | Environmental Impacts | | |
|---|---|---|---|---|---|---|---|
| | | | Direct | Indirect | | Adverse | Beneficial |
| 1 | Surveying | Soil removal | x | | Soil physical alteration | x | |
| 2 | Vegetation removal | Soil exposure | x | | Depletion of renewable resources | x | |
| 3 | Equipment transportation | Soil compression | x | | Soil physical alteration | x | |
| 4 | Generator and motor installation | $CO_2$ emission | x | | Air quality alteration | x | |
| 5 | Excavation hydraulic monitors | Soil removal | x | | Water siltation | x | |
| 6 | Sluice box installation | Soil compression | | x | Soil physical alteration | x | |
| 7 | Water supply | Use of water | x | | Depletion of non-renewable resources | x | |
| 8 | Carpet washing | Use of water | | x | Depletion of non-renewable resources | x | |
| 9 | Mercury use | Mercury use | x | | Water/ soil/ air contamination | x | |
| 10 | Manual amalgamation | Mercury release | x | | Human health alteration | x | |
| 11 | Concentrate gathering | Use of water | x | | Depletion of non-renewable resources | x | |
| 12 | Panning pool construction | Soil removal | x | | Soil physical alteration | | x |
| 13 | Panning pool operation | Mercury release | x | | Water contamination | | x |
| 14 | Amalgam burning without retort | Mercury vapour | x | | Human health alteration | x | |
| 15 | Use of retort / mercury recycling | Mercury vapour | x | | Human health alteration | | x |
| 16 | Mercury reactivation | Mercury release | | x | Human health alteration | | x |
| 17 | Backfilling amalgamation pool | Soil removal | x | | Soil physical alteration | | x |
| 18 | Backfilling old pit | Soil removal | x | | Soil physical alteration | | x |
| 19 | Backfilled pit accommodation | Soil removal | x | | Soil physical alteration | | x |
| 20 | Ploughing refilled pit for revegetation | Soil removal | x | | Soil physical alteration | | x |

Table 2-5 is meant to organize the variables and understand the kind of environmental aspects and impacts associated to them, as well to classify such aspects and impacts. Tables 2-5 and 2-6 employed the weights assigned for the method. These weights generate a final score that is converted into a linguistic term of the level of significance of the environmental impact. In the GMP pilot site in the Amazon, variables with levels of significance “substantial” or “extreme” were selected by the GMP team to be monitored and addressed in an action plan involving a training program.

Table 2-6 – Classification of activities based on the significance of potential environmental impacts

| # | Variable (activity) | Relevance Factors | | | | | | | DoB relevance (%) | Significance |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Public Perception | Frequency | Extent | Intensity | Legislation | Interested Parties | Detectability | | |
| 1 | Surveying | 2 | 1 | 3 | 2 | | | 1 | 60.0 | MODERATE |
| 2 | Vegetation removal | 3 | 1 | 2 | 3 | 1 | 1 | 1 | 80.0 | SUBSTANTIAL |
| 3 | Equipment transportation | 2 | 1 | 1 | 2 | | | 1 | 46.7 | MODERATE |
| 4 | Generator and motor installation | 2 | 1 | 2 | 3 | | | 1 | 60.0 | MODERATE |
| 5 | Excavation with hydraulic monitors | 3 | 3 | 3 | 3 | 1 | 1 | 1 | 100.0 | EXTREME |
| 6 | Sluice box installation | 2 | 1 | 2 | 3 | | | 1 | 60.0 | MODERATE |
| 7 | Water supply | 3 | 3 | 3 | 3 | 1 | 1 | 1 | 100.0 | EXTREME |
| 8 | Carpet washing | 1 | 1 | 1 | 2 | | | 1 | 40.0 | ACCEPTABLE |
| 9 | Mercury use | 3 | 2 | 2 | 3 | 1 | 1 | 1 | 86.7 | EXTREME |
| 10 | Manual amalgamation | 2 | 2 | 2 | 3 | 1 | 1 | 1 | 86.7 | EXTREME |
| 11 | Concentrate gathering | 2 | 2 | 2 | 2 | | | 1 | 60.0 | MODERATE |
| 12 | Panning pool construction | 3 | 2 | 1 | 3 | | 1 | 1 | 73.3 | SUBSTANTIAL |
| 13 | Panning pool operation | 3 | 3 | 1 | 3 | | 1 | 1 | 80.0 | SUBSTANTIAL |
| 14 | Amalgam burning without retort | 3 | 3 | 3 | 3 | 1 | 1 | 1 | 100.0 | EXTREME |
| 15 | Use of retort / mercury recycling | 3 | 3 | 3 | 3 | 1 | 1 | 1 | 100.0 | EXTREME |
| 16 | Mercury reactivation | 3 | 2 | 2 | 3 | | 1 | 1 | 80.0 | SUBSTANTIAL |
| 17 | Backfilling amalgamation pool | 3 | 3 | 3 | 3 | | 1 | 1 | 93.3 | EXTREME |
| 18 | Backfilling old pit | 3 | 3 | 3 | 3 | | 1 | 1 | 93.3 | EXTREME |
| 19 | Backfilled pit accommodation | 2 | 3 | 3 | 2 | | 1 | 1 | 80.0 | SUBSTANTIAL |
| 20 | Ploughing refilled pit revegetation | 2 | 1 | 2 | 2 | | | 1 | 53.3 | MODERATE |

Variables with level of significance “acceptable” or “moderate” were also considered but the prioritization for actions depended on the level of difficulty and costs to implement prevention and mitigation procedures.

As shown in Table 2-6., the following activities have “substantial” or “extreme” adverse environmental impact: vegetation removal, excavation with hydraulic monitors, water catchment, mercury use, manual amalgamation, amalgam burning without retort. The following activities have beneficial “substantial” or “extreme” environmental impact: use of retorts, mercury reactivation, backfilling pool for amalgamation, backfilling old pit.

Once the most significant impacts were identified, a training program addressing the most relevant items was prepared, aiming to mitigate adverse impacts and to promote beneficial impacts. The United Nations Global Mercury Project implemented in the Tapajos region trained around 4,200 artisanal miners and the program addressed not only the environmental issues pointed by this study, but also the formalization of “garimpos”, the improvement of gold production and the improvement of health and sanitation. To improve the environmental performance, the variables listed above were all included in the training program, and the mining sites were evaluated before and 120 days after the training. The general improvement of the environmental performance was 28.8% (Sousa and Veiga, 2007b).

## 2.4 Conclusion

As in most ASGM sites worldwide, in the pilot site of this study in the Brazilian Amazon there was no environmental management system in place. The proposed matrix was an intermediate alternative in between the current scenario and a more complex environmental risk assessment study, which would be beyond the miners’ capabilities. The simplified matrix of environmental impacts brought more transparency and accuracy for decisions made in the process of selecting the most significant variables to be monitored and controlled in the environmental program for ASGM. As this participatory process involved key stakeholders in the site of this study (GMP team, SEMMA, miners' representatives) this reduced significantly the subjectivity and bias of the criteria, and created participant's commitment with the solutions addressed in the training program. SEMMA is the local authority that issues the environmental licence to the artisanal miners, and its representatives acknowledge their limited resources to enforce the existent requirements and the complexity of the ASGM situation in the region. A local survey demonstrated that 99.3% of miners have been operating without proper licensing for decades. One of the rare cases of successful environmental licensing in the region known as "Garimpo Canaan" used this heuristic approach to justify its environmental controls. This area has been used as a reference to others in the region.

The ASGM activities were discussed with the key stakeholders and a training program was implemented in the area to address the critical issues. Variables that generated "substantial" or "extreme" DoBs on environmental impacts (such as vegetation removal, excavation, mercury use, manual amalgamation, etc, as demonstrated on Table 2-6) were the object of training, monitoring and control, aiming to mitigate their adverse impact. Variables with "substantial" or "extreme" beneficial environmental impacts (such as mercury reactivation, use of retorts, backfilling pool for amalgamation, backfilling old pit, etc) were promoted in the program for 4,200 artisanal miners and their community members.

This matrix proved to be simple and efficient, and it can be easily adapted to be used in other sites elsewhere. The simplicity of the process makes it feasible for ASGM, reduces subjectivity and increases the interested parties' participation and commitment.

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# CHAPTER 3 – ENVIRONMENTAL PROGRAM IMPLEMENTED IN THE STUDY SITE - THE GLOBAL MERCURY PROJECT[2]

## 3.1 Introduction

### 3.1.1 Miners' motivations and needs

In order to educate artisanal miners, it is necessary to understand their motivations and needs. The study by psychologist Abraham Maslow, proposed in his 1943 paper "A Theory of Human Motivation (Maslow, 1943), became an icon in the field of psychology. Maslow's theory has been accepted as a basis for thousands of studies to understand the human's needs and motivation. According to this theory, the physiological needs, such as breathing, food, water, sex, sleep, homeostasis and excretion form the base of the pyramid of needs, and any subsequent level of need can only be perceived by humans when the inferior level is satisfied. Above the basic physiological needs, humans are motivated by safety needs, such as physical security, employment, health, family security and property. This level becomes a motivation for humans only after the physiological needs are satisfied. One step higher in the hierarchy of needs, are the needs of belonging, which includes the social relationship. Above this level are the needs for esteem, including recognition, respect to others and respect by others. The highest level is called the need of self actualization, which includes morality, creativity, and self-realization.

[2] A version of this chapter has been published. Sousa R. N. and Veiga M. M., 2009. Using Performance Indicators to Evaluate an Environmental Education Program in Artisanal Gold Mining Communities in the Brazilian Amazon. Ambio 38(1): 40-46

When Maslow first proposed his theory (1943), environmental issues were neither a strong social value nor were they disseminated as nowadays. It is a likely conclusion that environmental awareness and respect for nature would be situated at any point after the first levels of basic physiological needs, and increase from the base to the top (From point 1 to 3, as indicated in Figure 3-1. In the light of this motivation theory, it is not effective to promote environmental programs for artisanal miners if such programs are not associated with economic and technical aspects that can help miners satisfy their basic needs. Techniques to increase the efficiency in prospecting and recovering gold would improve miners' revenue and help satisfy their physiological needs.

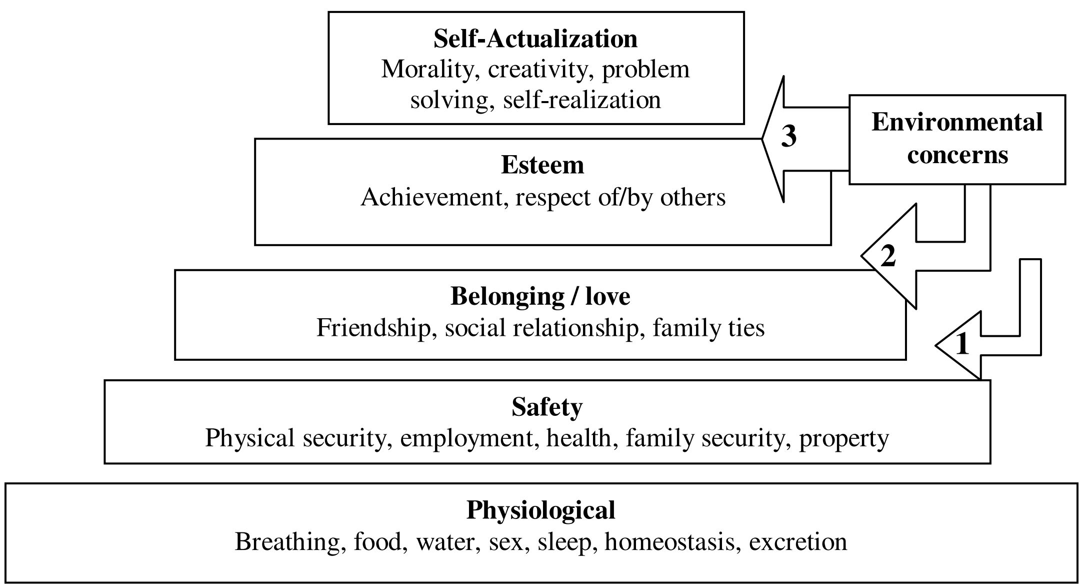



Figure 3-1 – Pyramid of human motivation and needs
(Adapted from Maslow, 1943)

According to Krishnamurti (1956), once a human being's basic needs are satisfied, "education" is the greatest asset one can possess, and this does not mean merely acquiring knowledge, gathering and correlating facts; it refers to seeing the significance of life as a whole. This includes perception of the environment as something of relevant value.

In order to combine variables that improve physiological needs and simultaneously encompass environmental concerns, education becomes a key factor as an effective approach to prevent environmental impacts. The most immediate subject that attracts miners' attention is technology, which allows them to improve gold recovery and satisfy their socio-economic needs (Sousa and Veiga, 2009).

Education is a very broad term and not only is it related to formal knowledge, but also to the holistic view of problems, with consideration to contexts beyond the local environment, other people's values, realities, priorities, limitations, etc. Government authorities also demonstrate some "lack of education" or holistic view when establishing unrealistic regulations, without consulting with artisanal miners or providing proper infra-structure to enforce them. Education is also a process to build common sense, using the best of the existing knowledge to contextualize situations, to adapt solutions and to evaluate chances of success. A real understanding of the miner's motivations and needs is necessary when planning programs to address the main ASGM concerns (Seigel, 2007).

Siegel (2007) points out the conflicts of ideological rupture between ecocentrists (focus on ecology) and technocentrists (focus on technology). While ecocentrists view ASGM as an environmental problem, where mercury contamination is a component, technocentrists see ASGM as a problem generated by the use of rudimentary techniques. However, neither is sufficient as there are other aspects to be considered, such as the social conditions driving miners to their activities. Although technology transfer may appear as an attractive solution for environmental problems, they are generally awkward, slow and sometimes unrealistic if the socio-economic environment is considered. This may be due to the lack of government authorities in the field, the high level of bureaucracy, and the resistance of miners to change existing practices. According to Heemskerk (2005), cited by Siegel (2007), there is an anthropological deficit in the data taken into consideration by the projects addressing ASGM, e.g., most data focus on what miners do rather than what motivates their actions. Most intervention in the field fails to meet the miners' needs because they lack adequate microeconomic data. The same author concludes that progressive policies should aim to reduce social inequality as the foundation of the environmental progress. This approach corroborates the original idea of Maslow (1943), by recognizing the economic factor as crucial for attainment of physiological and safety needs, creating conditions for miners to consider the environment as something of intrinsic value.

### 3.1.2 Training and awareness

As described by Reigeluth (1999), there are many theories describing a variety of methods of instruction and different options for facilitating human learning, development of their knowledge and appropriate use of skills. This is much more about skills than knowledge, i.e., it is about how to do rather than the theories behind the skills. As mentioned by Reigeluth (1999), trainees are more inclined to learn content and skills that they find interesting and important for them to achieve their goals. For example, in the case of ASGM, miners would be more inclined to learn something that, if incorporated to their activities, could be translated into gain.

Reigeluth (1999) refers to the "learning by doing" process, which is a concept of economic theory that refers to the capability of workers to improve their productivity by regularly repeating the same type of action. The increased productivity is achieved through practice, self-perfection and minor innovations (Dutton and Thomas, 1984).

The constructivism learning theory, as described by Hein (1991), refers to the idea that learners construct knowledge and meaning for themselves. In fact, learning integrates many aspects that extend beyond the idea of instructor, learner and subject.

There are at least four stages in the learning process that need to be considered when addressing a training and awareness programs. Considering the learning progress, these stages are identified:

- Stage 1 - **I do not know, therefore, I do not do:** in the ASGM context, this phase is the most common situation among artisanal miners, before any external intervention. In a situation where most of the people are illiterate or semi-illiterate and have limited access to information, environmental impacts resulting from ASGM activities are not a topic of interest for most miners. They have been using their mining methods for many years, learning by copying techniques from their neighbours, and any change requires a reasonable time investment to be incorporated, unless an economic stimulus is present.

- Stage 2 - **I know how to do, but I am not used to do:** this is generally the second stage of the learning process, when miners receive information about what to do, why to do and how to do. However, if this information is not delivered in a practical way, the receiving information will not be absorbed. Information transfer does not assure incorporation of the behaviours into daily practices.

- Stage 3 - **I know and I frequently do:** this is a very mature phase of the learning process, when miners show evidence that they really have incorporated good practices into their routine.

- Stage 4 - **I know, I frequently do, and I influence others to do:** the highest level of awareness goes beyond the individual. When people are really convinced of the benefits of their practices, not only do they implement them but they also invest real effort in convincing others to also incorporate their ideas and techniques. For example, when people are not aware of the consequences of throwing garbage anywhere, they simple do so. After becoming aware of why and how to dispose garbage properly, they will incorporate the good practice into their daily activities. At some higher level of consciousness, they realize that they need to influence others to do the same, since other's wrong doing affects everyone.

## 3.2 Material and methods

The Global Mercury Project activities examined in this case study were conducted during the period of 2006 to 2008, in the Tapajos River Basin, in the Brazilian Amazon. When the GMP was implemented in this region, the strategic plan involved frequent contacts with local authorities and community leaders to design an integrated plan. These contacts involved the three levels of government (Federal, State and Municipal), local associations, cooperatives of miners and community leaders. Another agency working at the same location, USEPA (United States Environmental Protection Agency), also became a partner in a project for development of fume hoods for gold shops. The main stakeholders were: The City of Itaituba, DNPM and MME (Federal Government – Mineral Resources Ministry), SECTAM and SEICOM (State of Para Government – Environment and Industry Secretary), SEMMA (Itaituba Mining and Environment Secretary), AMOT (Miners' Association of Tapajos Region). The GMP prioritized the involvement of the local community representatives and gave credit to the locals for successes. The project was renamed locally as "Cuide de seu Tesouro" (Take care of your treasure) as suggested by the mayor of Itaituba. As mentioned by Hilson (2006), in order to ensure long term sustainability of educational and technological initiatives in the ASGM sector, local ownership is essential.

A training program and an awareness campaign for artisanal miners were designed, considering these priorities:

1. Training and awareness campaigns must be associated with economic advantages (gold recovery and/or cost reductions) to improve the miners' socio-economic conditions and enhance interest and participation;

2. Miners must become more engaged in the environmental practices if they realized that results would be monitored and beneficial to them;

3. Awareness and training must be conducted *in situ* by local trainers, which facilitate confidence, interaction, logistics, accommodation, etc.

4. The content of the training program must be based on the program's objectives and must address variables that can be associated with significant environmental impacts, based on a matrix of environmental impacts that have been developed previously (Sousa and Veiga, 2009).

5. The program must identify and promote “role models” based on the incorporation of best practices. These miners (or mining sites) must be show cases to be followed, and their practices must be promoted locally.

The main objectives the GMP were discussed with local stakeholders in order to adapt the objectives to the regional context, bringing on board the stakeholders’ interests and considerations. The conceptual structure of the project is presented in Figure 3-2

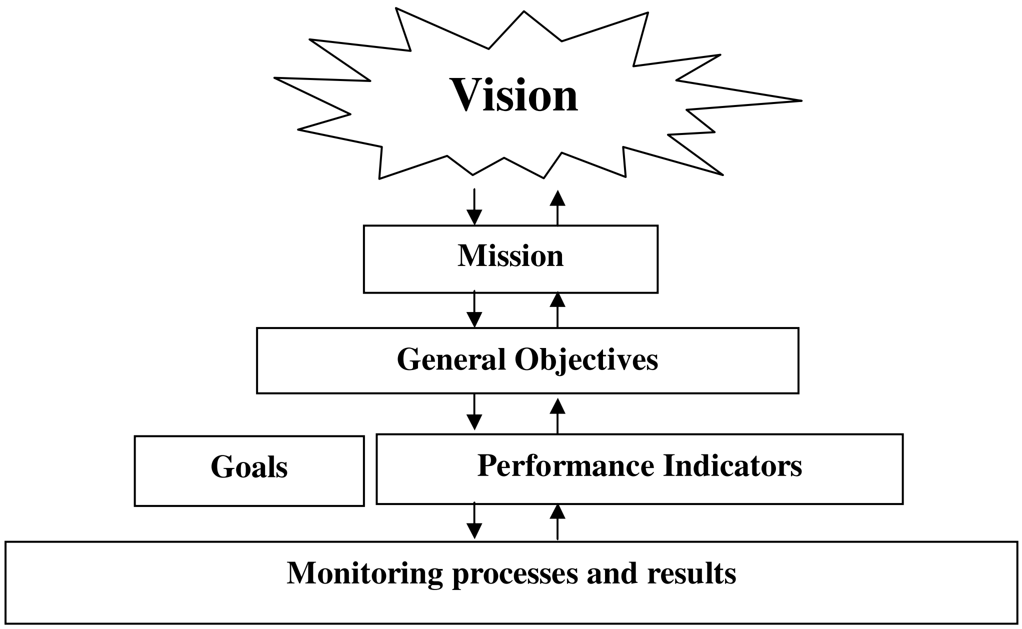



Figure 3-2 – Conceptual structure of the GMP: from vision to results

The **Vision** expressed the ideal long-term result desired by the GMP team. For example, “elimination of mercury use in ASGM” belongs within the sphere of “vision”. The overall improvement of miner’s working conditions was also desired central objective. However, considering the current low level of education of miners, low level of capitalization, lack of awareness about mercury risks, lack of knowledge about alternative techniques, and the other site specific difficulties, it would not be realistic to target the full elimination of mercury in a short-term plan, but it can start focusing on reduction of mercury use and losses.

The **Mission** expressed the general role of the project managers in order to gather and concentrate efforts towards the vision. Whereas the vision aimed at an ideal scenario, the mission was more grounded on possible outcomes, involving combinations of actions that could eventually lead to the vision. One of the key missions of GMP was the "effective implementation of training and awareness campaign, among others, addressing mercury recycling, reduction and gradual replacement of mercury use by alternative cleaner technologies.

The **General Objectives** expressed the areas in which the project would address efforts in order to accomplish the mission. The general objectives were broad and divided into five themes: 1) legalization of mines, 2) increase of gold production, 3) protection of water bodies and forest, 4) reduction of mercury emissions and 5) improvement of health and sanitation. These themes accommodated most of the stakeholders interests. For each theme, a series of specific tasks were prepared and the expected results were measured by specific indicators.

The **Goals** were defined as benchmarks established to evaluate the success of the objectives. However, in practical terms, goals were established by performance indicators, as ultimately they express the result of specific objectives. For example, for the general objective of improving legalization of mines, goals were established for indicators that represented this objective, such as "obtaining environmental license, mining permit and providing receipts of gold sale".

**Performance Indicators** expressed the accomplishment of actions, and to what extent the goals had been attained. The project managers, in agreement with the main stakeholders, set goals for each indicator that represented the challenges to be achieved. The magnitude of the challenge is an executor's decision that can be either conservative or audacious. When there is insufficient background information about the current status of the indicator, the philosophy generally applied was "the greater the better".

The idea of performance indicators was largely disseminated with the creation of Balanced Scorecard methods, as proposed by Kaplan and Norton (1992; 1996). The success of the GMP was evaluated not only based on the training delivered to miners, but on the actual incorporation of good practices by the miners in their daily mining activities. To evaluate changes of behaviour, a record of evaluation of each mine site was developed to be used prior to and after the 120 days of training. This record is presented in APPENDIX D.

Sutter (2002) suggests four criteria to select performance indicators: (A) an indicator should be pertinent, i.e. should represent well the phenomenon being studied; (B) operational, i.e. it should be easily understandable, collectable and measurable; (C) accumulative, i.e. it should relate to other indicators and show evidence and trends; and (D) economically appraisable, i.e. it should be related to impacts in terms of costs. Even when health and environmental impacts are considered, there is always an economic aspect related to the impacts. For example, health improvement implies reduction in health treatment costs, and extra revenues can be turned into well-being and social improvement.

Rozados (2005) includes the mission, objectives and goals as the first criteria to be taken into consideration when selecting indicators. Other criteria include the external environment, infra-structure, available database and facility for implementation and monitoring. Performance indicators must maintain strong correlation with the objectives of the program, offering response for the objective's accomplishment. Thus, indicators are measurable results, in which the main characteristics should be simplicity, feasibility, reliability and traceability.

The establishment of the right relationship between indicators of success and objectives of the program is a key point in the evaluation process (Fischmann and Zilber, 1999). For the GMP purposes, the main indicators were selected on the basis of consultation with stakeholders and technical factors affecting the performance of the gold production and environmental impacts. It is possible to assign different weights for each indicator according to the relevance, however, the exclusion of weight (i.e., all indicators were assumed to have the same importance) simplifies the process and eliminates another subjective variable.

**Degree of Accomplishment** **(D.A.)** is the result of comparison between the observed outcome (measured result of a performance indicator) and the intended goal. As a hypothetical example, if preliminary evaluation shows that only 20% of miners use retorts to condense mercury while amalgams are burned, although the ideal condition is 100%, it would be preferable to set more realistic goals, depending on how conservative or audacious the project manager is. (For instance, if it was assumed that at least 80% of the miners in a region use retorts as a result of the training (goals), and after training and re-evaluation it was observed that half of this (40%) in fact use retorts, this leads to a D.A. of 50% (achievement was 40%, goal was 80%).

**Absolute Improvement** **(A.I.)** is the direct difference between the observed outcome (achieved result after training) and the preliminary evaluation (prior to training). Again, using the above hypothetical example, the absolute improvement would be 20% (achievement was 40%, previous situation was 20%).

Educational programs are expensive in areas where infrastructure is poor and transportation costs are high. In order to deal with such limitations, the proposed approach involved the use of local people to be trained by external experts. These people became multipliers or trainers for training the miners. The employment of local trainers not only reduced the costs of the program, but also increased the chances of success by using people familiar with the local knowledge and values.

The establishment of local partnerships with miners and local authorities was crucial for the success of the educational program. Effort was made for local partners to feel that they were an active voice in the program. This brought credibility to the project and acceptance by the local communities.

The GMP team developed the content of the training aimed at meeting the project objectives. Thirteen local trainers were hired by the program. The training material included demonstrational videos, brochures, posters (APPENDIXES B and C) and above all, practical demonstration of simple technologies in the field, allowing the full interaction between miners and local trainers.

Among the topics included in the training program were: methods to increase gold recovery, methods to recycle mercury, practical use of retorts, impacts of the mercury on the health and environment, mercury in the gold shops, protection of water bodies, methods to diversify the miners' economy, legalization of a mining site, tailings management, improvement of mercury amalgamation, use of latrines and mosquito nets, water filtration, garbage disposal, and reforestation of degraded areas. Special booklets were developed in language tailored to the miners. A strong awareness campaign for the community members was also associated with the miners' training. Trainers spent 3 to 5 months contacting miners providing advice on changes to be introduced in their operations.

The technical information for the training program was based on the work of Veiga et al. (2006). The training was aimed at conforming to the five general objectives previously described. For each of these general objectives a number of indicators were selected, representing good practices that were expected to be implemented, as shown in Table 3-1.

Table 3-1 – Relationship between objectives, actions and performance indicators

| Objectives of the program | Actions | Performance Indicators |
|---|---|---|
| Increase legalization of the mining activities | Training program addressing legalization of mining sites;<br>Implementation of TDU (*)<br>Workshops/ proposals to simplify legal processes | Environmental License as required by law<br>Mining License as required by law<br>Receipt issued by gold buyers |
| Introduce cleaner techniques to increase gold recovery | Training program addressing gold production<br>Implementation of TDU | Use of scientific method to find gold<br>Right equipment and process available<br>Equipment and process to recover fine gold<br>Equipment maintenance and stock of supplies |
| Reduce water pollution and deforestation caused by artisanal mining activities | Training program addressing protection of water and forest<br>Implementation of TDU | Refilling old pits with tailings<br>Reforestation of degraded areas<br>Water turbidity / sediment containment |
| Reduce mercury contamination derived from artisanal mining activities | Training program addressing use, recycling and reactivation of mercury<br>Implementation of TDU | Mercury reactivation and recycling<br>Mercury confinement (pool for amalgamation)<br>Use of retorts during burning process<br>First steps towards mercury-free technology |
| Improve health and sanitation by developing community awareness about impacts from artisanal mining | Training program addressing health and sanitation<br>Implementation of TDU | Use of latrines<br>Use of filtered drinking water<br>Proper garbage disposal<br>Use of methods to prevent malaria<br>Reduce exposure to risks / safety<br>Incorporation of practices by leaders |

* TDU - Transportable Demonstration Unit (Trainers, equipment and material to demonstrate good practices)

An explanation of the selected Performance Indicators for each of the General Objectives is shown as follows.

**Legalization of the mining sites**

Environmental license: in each mining site the trainer verified the existence of the environmental license issued by the governmental agency (SECTAM) and trained miners about the need of compliance. Mining permit: in each mining site the trainer verified the existence of the mining permit issued by the governmental agency (DNPM) and trained miners about the need of compliance. Receipt issued by gold buyers: in order to avoid tax evasion during gold commercialization, receipts must be issued by the gold shops whenever miners sell their gold. As such, the miners were trained to request receipts when selling gold.

**Techniques to increase gold recovery**

Use of more effective methods to find gold: most artisanal miners find gold deposits by guessing based on their own experiences. This process increases the environmental impact due to the amount of earth removed unnecessarily, consuming time, fuel and other resources. Miners were trained to count on specialized technicians to work with geochemical prospecting techniques to identify gold anomalies (e.g. panning and counting gold specks). Working correctly with existing equipment: the basic equipment used by local artisanal miners to mine and concentrate gold includes hydraulic monitors and sluice boxes with carpets, or hammer mills and copper plates. They were taught how to use this equipment more effectively, eliminating riffles, adjusting the angles of the zigzag sluice boxes, using adequate carpets, adjusting hammers in the mills, replacing copper plates with carpets. Methods to recover more fine gold: the most effective way to show miners that their recovery is not satisfactory is by reprocessing their tailings and recovering more gold either trapped in coarse fragments or too fine to be recovered by rudimentary concentration processes. On average the current gold recovery was estimated to be around 30 to 40%. It was demonstrated how to increase gold recovery by grinding to liberate gold and by concentrating gold in centrifuge. Maintenance and stock of supplies: most miners do not plan their activities nor maintain their equipment. Usually it takes time to find spare parts when the equipment breaks. They were trained to establish a preventive maintenance scheme.

**Protection of water and forest**

Refill of old pits with tailings: when artisanal miners work with alluvial and colluvial gold along the riverbanks, they just dump the tailings into the river. They were trained to return sediments to back fill old pits. The soil is contained and the reclaimed water is used in ongoing operations. Revegetation of degraded areas: GMP has identified a mine owner (Garimpo Canaan) conducting revegetation in his area as well as refilling old pits. Miners were informed of the advantages of rehabilitating degraded areas, and some of them have started a modest plantation of fruit trees (such as mango and cashew trees) for their own consumption. Tailing containment: sometimes miners work in new areas where no old pits are available to receive tailings. Then, miners dispose tailing over land or in the rivers. Miners were taught to build a triple barrier made of palm leaves that retain a large part of the tailings. The quality of the reclaimed water is evaluated visually based on suspended matter.

**Reduction of mercury use**

Mercury activation and recycling: considering the current low level of miners' education, capitalization and awareness of health risks, the elimination of amalgamation cannot be accomplished in short-term. Therefore GMP has concentrated efforts on reducing mercury use. Miners learned how to activate mercury by using an electrolytic process with a car or motorbike battery and 10% table salt solution (Pantoja and Alvarez, 2000). This simple process forms sodium-amalgam which is more coalescent and effective in the amalgamation process than pure mercury. Sodium amalgam is easily recovered and less mercury is lost by "flouring" (droplets formation). This was promptly assimilated by the miners since more gold has been recovered from the gravity concentrates. Amalgamation in designated places: amalgamation of concentrates in confined pools eliminates the losses of mercury to rivers. Miners are taught how to excavate a small pool far away from rivers, lined with canvas or a plastic sheet. Miners amalgamate the concentrates in these pools, and if any mercury is lost with tailings, it becomes confined and can be recovered later. Use of retorts during the burning process: this is one of the most important goals of GMP as retorts reduce miners' exposure to mercury vapours and recover mercury to be reused. Many different types of retorts were demonstrated to miners such as those made of kitchen-bowl or with salad cups or with water pipes (Veiga et al., 2006). The GMP also bought retorts from a local manufacturer and donated to miners. The measured mercury recovery was above 95% using this local retort. Use of mercury-free technology: there are some miners using cyanide but they do not have sufficient understanding of this technique, making the practice as dangerous as mercury. Some of them use amalgamation followed by cyanidation, exacerbating the environmental problems. The GMP has implemented a new and affordable technique to pre-concentrate gold by gravity concentration (e.g. using a sluice box or a centrifuge) and the concentrate is leached with cyanide in a small ball mill. This is still in a preliminary phase of development but the results are very promising to replace completely amalgamation of concentrates.

**Improving health and sanitation**

Use of latrines: this is not part of miners' culture. Miners were trained in latrine construction methods. The benefits of using latrines were discussed with miners and community members. Use of filtered drinking water: most miners consume water from the local streams and rivers or wells. They have been taught to use ceramic filters, which can be bought locally, or to simply boil water before consumption. Bio-sand filters (CAWST, 2007) were also donated to some sites to be tested. Transport of these cement filters in the roadless Amazon is difficult due to their high weight (around 130 kg), but they are suitable for established mining areas with road access. GMP has also developed alternatives to build lighter bio-sand filters. Prevention of malaria: it is common to find miners who have had malaria over 20 times. Fortunately there are efficient medicines to treat malaria in the Amazon, but prevention is better because healthy miners can work more effectively. Miners are taught to use mosquito nets and screens on their windows whenever suitable (most of them live in tents). By refilling old pits they will also contribute to reducing the mosquito population. The GMP has also promoted an initiative of a local miner, Mr. Paulo Carneiro, who is using the extract of the Neem tree leaves (*Azadirachta indica*) as a repellent against the malaria carrying Anopheles mosquito (Journey to Forever, 2007). Safety: one of the most common accidents is landslides when miners use hydraulic monitors or when they dive into the river. Another common accident involves the exposure of hands to unprotected motor belts. During the evaluation of the areas, the trainers took into consideration the potential risks and how miners understand the risks. Proper garbage disposal: miners commonly dump garbage everywhere, with a strong preference for rivers. They were taught how to bury garbage to keep the mining area free of plastic bags, bottles and other type of garbage. Training also included how to burn the garbage to avoid mosquitoes and cover the hole before leaving the area. Practices of environmental education, health and awareness of miners: virtually all of the miners visited during the training said that this was the first time they have received a formal training on environmental, health and technical procedures. The trainers persuaded mine owners or managers to provide regular and formal talks to the miners, encouraging them to adopt the good practices brought by the GMP trainers.

A total of 141 artisanal gold mining sites ("garimpos") were evaluated (APPENDIX E). Three levels of compliance were considered (complete compliance, partial compliance, and no compliance). When in complete compliance the "garimpo" scores one point. When partial compliance occurs, one half point is given, and no compliance resulted in zero point. By using these criteria, if 50% of "garimpos" comply partially with a certain condition, for simplification purposes it will be assumed that 25% of "garimpos" meet the requirement. For other combinations, calculations were adjusted accordingly.

## 3.3 Results and discussion

The proposed educational program, within its scope and budget, was tailored to reach at least 10% of the contingent of miners estimated in the Tapajos River Basin. Around 60 local individuals took part in the training of the trainers, and 13 of them were selected to train 4,200 miners. Overall, 141 evaluated areas represented the whole population (2000 "garimpos") very well, and showed a level of compliance of 51.0% and an absolute improvement of 28.8% (from 22.2 to 51.0%). The overall improvement obtained by successive evaluations is one of the best indicators of the results of the training program, since it is representative of the miners' behavioural changes. Field evaluations demonstrated the extent to which the miners incorporated the good practices promoted in the training program. The results are shown in Tables 3-2 and 3-3.

Table 3-2 – Degree of accomplishment (DA) of goals and absolute improvement (AI) after training

| General Objectives | | Performance Indicator | % Mining sites complying with the indicators | | | | |
|---|---|---|---|---|---|---|---|
| | | | Results before training | Goals of the training | Results after training | Absolute Improv. (AI) | Degree Accompl (DA) |
| Legalization of the mining sites | 1 | Environmental license | 0.7 | 5.0 | 2.1 | 1.4 | 42.0 |
| | 2 | Mining permit | 1.4 | 5.0 | 2.1 | 0.7 | 42.0 |
| | 3 | Receipt issued for gold sale | 13.4 | 20.0 | 33.3 | 19.9 | 166.5 |
| **Mean** | | | 5.2 | 10.0 | 12.5 | 7.3 | 125.0 |
| Improvement of gold recovery | 4 | Use effective methods to find gold | 44.2 | 50.0 | 50.0 | 5.8 | 100.0 |
| | 5 | Working correctly with equipment | 46.0 | 50.0 | 50.0 | 4.0 | 100.0 |
| | 6 | Methods to recover fine gold | 46.7 | 50.0 | 50.0 | 3.3 | 100.0 |
| | 7 | Maintenance and stock of supplies | 51.4 | 60.0 | 66.7 | 15.3 | 111.2 |
| **Mean** | | | 47.1 | 52.5 | 54.2 | 7.1 | 103.2 |
| Protection of water and forest | 8 | Refill of old pits with tailings | 40.6 | 80.0 | 91.7 | 51.1 | 114.6 |
| | 9 | Re-vegetation of degraded areas | 1.5 | 5.0 | 5.0 | 3.5 | 100.0 |
| | 10 | Tailing containment | 35.1 | 60.0 | 91.7 | 56.6 | 152.8 |
| **Mean** | | | 25.7 | 48.3 | 62.8 | 37.1 | 129.9 |
| Reduction of mercury use | 11 | Mercury activation and recycling | 4.3 | 50.0 | 91.7 | 87.4 | 183.4 |
| | 12 | Amalgamation in designated places | 10.9 | 50.0 | 75.0 | 64.1 | 150.0 |
| | 13 | Use of retorts | 20.3 | 40.0 | 41.2 | 20.9 | 103.0 |
| | 14 | Mercury-free technology | 0.0 | 5.0 | 0.0 | 0.0 | 0.0 |
| **Mean** | | | 8.9 | 36.3 | 52.0 | 43.1 | 143.4 |
| Improvement of health and sanitation | 15 | Use of latrines | 26.8 | 50.0 | 91.7 | 64.9 | 183.4 |
| | 16 | Filtered drinking water | 17.0 | 60.0 | 81.3 | 64.3 | 135.5 |
| | 17 | Prevention of malaria | 62.0 | 80.0 | 81.3 | 19.3 | 101.6 |
| | 18 | Safety | 4.3 | 30.0 | 4.3 | 0.0 | 14.3 |
| | 19 | Proper garbage disposal | 16.3 | 50.0 | 100.0 | 83.7 | 200.0 |
| | 20 | Practices of awareness of miners | 0.7 | 10.4 | 10.4 | 9.7 | 99.8 |
| **Mean** | | | 21.2 | 46.7 | 61.5 | 40.3 | 131.6 |
| | | **General Mean** | **22.2** | **40.5** | **51.0** | **28.8** | **110.0** |

At least 8 good practices have had high impact: refill of old pits with tailings, i.e. sluice boxes were removed from the rivers (indicator number 8 in Table 3-2), tailing containment (#10), activation and recycling of mercury (#11), amalgamation in designated places (#12), use of retorts (#13), construction and use of latrines (#15), use of filtered water (#16), garbage disposal (#19). Assuming at least one open pit per "garimpo" in the 141 areas evaluated, around 128 pits were been refilled when the 2nd evaluation took place.

Table 3-3 – Absolute Improvement and degree of accomplishment by objective

| General Objectives | % Mining sites attaining requisites | | | | |
|---|---|---|---|---|---|
| | Results before training | Goals of the training | Results after training | Absolute improvement (A.I.) | Degree of Accomplishment (D.A.) |
| Legalization of the mining sites | 5.2 | 10.0 | 12.5 | 7.3 | 83.5 |
| Improvement of gold production | 47.1 | 52.5 | 54.2 | 7.1 | 102.8 |
| Protection of water and forest | 25.7 | 48.3 | 62.8 | 37.1 | 122.5 |
| Reduction of mercury use | 8.9 | 36.3 | 52.0 | 43.1 | 109.1 |
| Improvement of health/ sanitation | 21.2 | 46.7 | 61.5 | 40.3 | 122.8 |
| **Mean** | **22.2** | **40.5** | **51.0** | **28.8** | **110.1** |

The most successful objectives were "protection of water and forest" (A.I.= 37%), "reduction of mercury use" (A.I.= 43%), and "improvement of health and sanitation" (A.I.= 40%),. This was achieved by implementing novel methods to refill old pits with tailings from new pits. The sluice boxes were repositioned in the old pits and a triple barrier of palm leaves retained sediment, thus preventing river siltation. The use of retorts to burn amalgam was largely promoted, as well as methods to reactivate and to re-use mercury. Miners were more motivated to recover and re-use mercury when they appreciate the economic value this may represent, as a kg of mercury is sold locally by US$200. Miners also incorporated a technique to amalgamate in small canvas pools, confining mercury in closed tanks. Other good practices that achieved general acceptance by miners included the construction and use of latrines, garbage disposal in holes in the ground, use of mosquito nets and filtration of drinking water.

The objectives “legalization of the mining sites” (A.I.=7%), and “improvement of gold production” (A.I.=7%), were not as successful as others. Changes in behaviour regarding the legalization of the areas are more difficult to be adopted, as the government presence in the region is not strong enough to provide mechanisms of registration and control. Thus, even when the miners take the initiative to legalize their areas, they face a complex bureaucratic process which consumes time and money. On the other hand, the federal government is also limited, as their inspectors have no resources allocated for field visits. Thus, the licensing process has been a failure. It is difficult to encourage miners to fulfill the legal requirements when they are aware that there is no major consequence for acting in an illegal manner. The GMP worked with 3 levels of government (Federal, State and Municipal) in order to propose methods to simplify the legalization process. Regarding improvement of gold production, this also requires some time and effort to disseminate good practices. The most convincing method has been obtained by reprocessing tailings, e.i., extracting gold from their wastes.

After evaluation of 141 mining sites, the “garimpos” were grouped into 5 classes according to their results, to facilitate the understanding of the overall level of conformity to the standards of the training. These groups are presented in Table 3-4. Before training (first evaluation) 45.8% of “garimpos” had grades (conformity to standards) below 20% (Class E), and after training (second evaluation), there were no“garimpos” remaining in the lowest class. In the highest class (class B, with grades that vary from 60 to 80%), the number of "garimpos" escalated from 4.2% in the first evaluation to 37.5% in the second evaluation. (Details are shown in APPENDIX E). This shows that miners respond well to training. No "garimpo" had yet reached class A at that point, which indicated that the criteria had a good calibration, as it allowed progress but had reasonable degree of challenge.

Table 3-4 – Distribution of "garimpos" per classes of grades*

| Classes | Range | % 1st evaluation | % 2nd evaluation |
|---|---|---|---|
| **A** | 80 - 100 | 0.0 | 0.0 |
| **B** | 60 - 80 | 4.2 | 37.5 |
| **C** | 40 - 60 | 29.2 | 37.5 |
| **D** | 20 - 40 | 20.8 | 25.0 |
| **E** | 00 - 20 | 45.8 | 0.0 |
| | | 100.0 | 100.0 |

* Grades express levels of conformity (existing situation versus established standard)

In order to create a successful case, the GMP identified a mining site called "Garimpo Canaan", which was already adopting good environmental procedures and, with the incorporation of a few more good practices, obtained the highest compliance to the GMP goals (overall compliance of 72%). This has served as an example for all miners in the region to demonstrate that it is possible to be environmentally responsible, with little investment. The GMP team worked extensively with the owner of this "garimpo" to even further improve his operating conditions and his mine reclamation methods. Figures 3-3 to 3-9 provide an overview of this program and the best practices.


1 – Training of trainers in the Village of Creporizao


2 – Training of trainers in the field

3 – Tailings redirected to refill old pits

4 – Tailings containment with barriers of Palm trees

5 – Garbage collected and buried in every “garimpo”

6 – Construction and use of latrines

Figure 3-3 – Some of the good practices addressed in the training program

1 – Use of retorts to burn amalgam in the field

2 – Amalgamation in confined pools

3 – Mercury reactivation and reuse

4 – Development of local retorts to burn amalgam

5 – Awareness: health (malaria) and safety (Accidents)

6 – Training on legalization of mines

Figure 3-4 – Some of the good practices addressed in the training program

1 – Lab / pilot plant for tests and demonstrations


2 - Lab prepared for cyanidation test

3 – Preparation of chemicals / prototypes

4 – Activated charcoal in a perforated tube

5 – Cyanidation in ball mill in progress

6 – Gold recovery by zinc precipitation

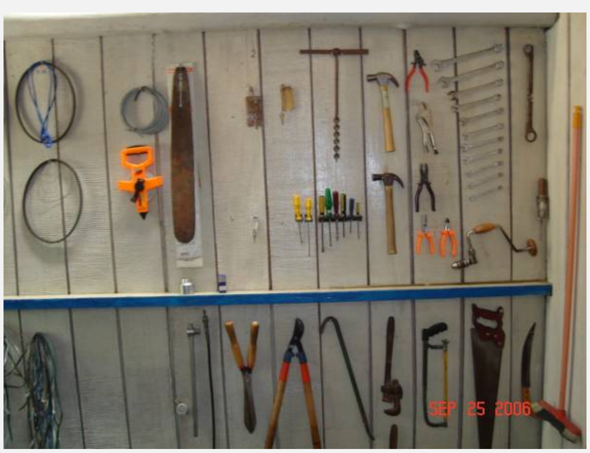
Figure 3-5 – Training facility for demonstrations in Garimpo Canaan

1 – Overall superior infra-structure


2 – Concern with legalization

3 – Pioneer. First to adopt the biosand filter


4 – Pioneer: good practices on reclamation




5 – Overall superior organization in an ASGM context


6 – Pioneer: exceed in ideas for the ASGM context

Figure 3-6 – Examples supporting selection of Garimpo Canaan as role model

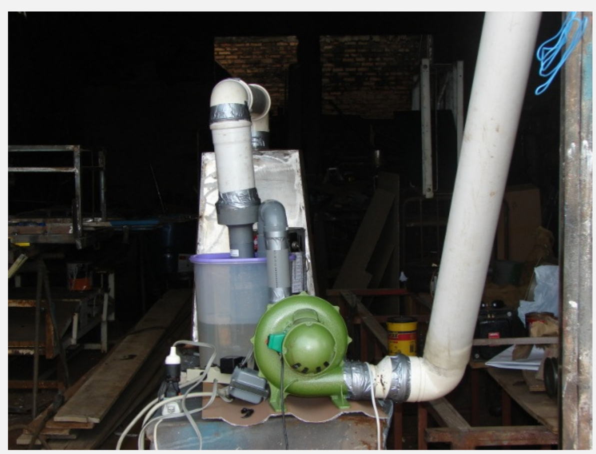
1 – Local street of Itaituba with 3 gold shops

2 – Filter under construction at local shop

3 – Gold shop and chamber without mercury filter

4 – Gold shop after the filter installation
(GMP and USEPA teams working together)

5 – Training local gold shop owners



6 – Fume hood from Indonesia installed in Itaituba

Figure 3-7 – Fume hoods installed in Itaituba

1 – General view of the biosand factory

2 – Cement biosand filters under fabrication

3 – Biosand filter in use in Garimpo Canaan


4 – Biosand filters purchased by GMP for “garimpos”

5 – Layers of pebbles, sand and biofilm

6 – Water before and after filtration

Figure 3-8 – Biosand filters promoted and disseminated in mining sites


1 – Retort model


2 – Retort model 2


3 – Retort model 3

4 – Most accepted model. GMP purchased 60

5 – Retort in use in Garimpo Canaan

6 – Smelting after retort

Figure 3-9 – Promotion and dissemination of retorts

## 3.4 Conclusion

A common mistake made by many development organizations when implementing training programs is to consider that the mission has been accomplished after the training is delivered. Training is just a means to reach results, but not the results themselves. Another common indicator of training success is the number of trainees involved. Again, this does not adequately reflect positive results, as training people does not imply that they have learned lessons, and learning lessons does not imply that they will implement what they have learned. The real result of training occurs when the trainees incorporate the lessons learned into their daily work (Sousa and Veiga, 2009). In this training program the level of compliance of 141 mining sites ("garimpos") with 5 objectives, evaluated through 20 performance indicators, was improved from 22% to 51% in 4 months after the training implementation. Objectives such as protection of water and forest, reduction of mercury use and improvement of health and sanitation were improved by 40%.

To successfully reduce the health and environmental impacts caused by ASGM there is no single remedy, but an efficient strategy should encompass a combination of actions on different fronts, dealing with technology, education, legislation, and awareness. These topics separately do not produce the intended results. For example, mercury use is one of the most visible and relevant problems affecting health and the environment, but this cannot be dissociated from other inter-correlated health issues such as malaria, poor quality of drinking water, river siltation, safety risks, tropical diseases, sanitation, etc. Not only miners, but also their families and communities, must be involved in environmental programs to produce meaningful behavioural changes.

Practices such as amalgamation of concentrates instead of the whole ore, the confinement of mercury in plastic-lined pools during the amalgamation, and the use of retorts to recover mercury and avoid vapour emissions can reduce drastically the level of contamination of soil, sediments, fish and miners. Simple practices, such as the retention of sediments by using rudimentary barriers built with local palm tree leaves, can significantly reduce the amount of sediment returning to the rivers. Old pits can be backfilled and there are simple and viable alternatives that could be considered for re-vegetation (Sousa and Veiga, 2009).

It is useless to address environmental programs without taking into consideration the motivations and needs of miners, which are not necessarily aligned with those of outsiders. An effective way to engage the interest of miners in environmental issues is to provide them with solutions that improve their processes in terms of gold recovery and/or cost reduction. Environmental awareness is just a consequence of implementation of more efficient cleaner practices.

An evaluation of 20 indicators before the training demonstrated that 46% of "garimpos" had a level of conformity to the training standards below 20%. A second evaluation after the training showed that no "garimpos" had remained at their original class of conformity. This is clear evidence that miners respond favourably to training.

Previous evaluation showed that only 4.3% of miners were recycling mercury by using retorts. As the average Hg consumption per capita was 40 g/month, this led to a consumption of 2,016 kg Hg/annum by the 4,200 miners involved in the training process. By introducing mercury activation and retorts, these simple measures have resulted in mercury consumption per capita of 5 g/month. In other words the training may have potentially reduced 1,762 kg/annum of mercury that would be lost to the environment.

These results clearly illustrate the level of accomplishment of the "effective implementation of a training program addressing mercury reduction" of the project and the accompanying contribution to the overall "vision" of the project directed towards the elimination of mercury use in ASGM.

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# CHAPTER 4 – REHABILITATION OF DEGRADED AREAS – CASE STUDY: GARIMPO CANAAN[3]

## 4.1 Introduction

### 4.1.1 The ASGM and deforestation in the Brazilian Amazon

Deforestation in the Brazilian Amazon region has escalated from the end of the decade of 1960, in particular after a governmental policy of developing farms in the region, which included fiscal incentives. This motivated numerous agricultural and livestock projects, replacing the forest in a disorderly way. According to Fearnside (2005), in 2003 the deforestation in the Brazilian Amazon forest accumulated an area of 648,500 $km^2$ (16.2% of 4,000,000 $km^2$ of the original legal Amazon forest). A Brazilian official Institute (INPE, 2007) concluded that the deforestation rate has decreased from 27,379 $km^2$/a in 2003 to 11,224 $km^2$/a in 2007, but the average rate is close to 1% of the forest every year. The original extension of the Brazilian Amazon forest was approximately equivalent to the Eastern Europe area. Fearnside (2005) mentions that the major enemy of the forest is the fatalism, as some authorities in charge of developing policies for the Amazon believe that the forest is fated to destruction. Moreover, some government officials recognize their limitation to control deforestation. The establishment of cultivated pastures has been identified as one of the main causes of deforestation (Margulis, 2003). The area deforested was not totally

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converted into productive activities, as in addition to pastures, agriculture and mining activities, large part of deforested areas was simply followed by abandonment.

Mining activities were initiated basically in the 1970's, when thousand of artisanal miners, who use rudimentary processes to extract gold from secondary and primary ore bodies, occupy areas in different locations in the Amazon. Artisanal mining activities remove portions of forest along the riverbanks and streams, and although it is smaller in extent than farming, it is causes more intense soil disturbance. Enormous pits are open along the rivers and they are generally inundated in the rainy season, which cause severe changes in the local ecology. Millions of tonnes of sediments are displaced and the most common final destination are the water bodies, causing siltation and mercury contamination.

Thousands of pits were opened in the process of exploitation of colluvial gold in the last three decades and most of these pits have never been refilled. According to Veiga and Hinton (2002), the artisanal mining cycle is well known: discovery, migration, and relative economic prosperity followed by resource depletion, outmigration and economic destitution. There is no precise estimation about the number of abandoned mines in the whole Amazon, but only in the Tapajos region it was estimated that between 300 and 600 pits with dimension above 10,000 $m^3$ each have been open and abandoned annually (Sousa and Veiga, 2007b).

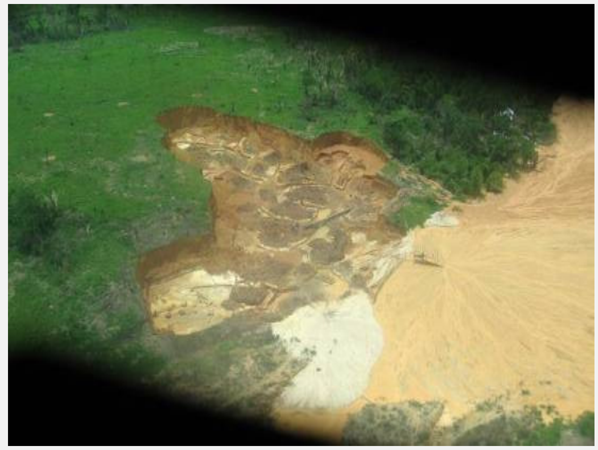
Depletion of surficial ore: most of the easily accessible deposits have already been identified in the Amazon, which means that ASGM, with the current technological level, is not sustainable and tends to decline (Veiga and Hinton, 2002). Hard rock deposits are more complex and technically demanding for artisanal miners. As surficial deposits are depleted, miners migrate to other areas, and such migration can occur in a matter of few months or weeks.

ASGM has never been addressed properly by the government and the existing regulatory framework has not been effective to solve the ASGM problems. The Brazilian government limited the locations where artisanal miners can work in Brazil, creating mining reserves and a special permit that miners must obtain from the official regulatory organ (DNPM – National Department of Mineral Production). In order to obtain such permit miners must present an elaborate environmental impact assessment. As the process and requirements are beyond the reality of miners, they remain illegal, and consequently do not have access to any credit and incentive, including proper training and environmental awareness.

Disorganization and transience is a basic characteristic of artisanal mining. In general miners work either independently or in small groups. The concept of associations and cooperatives has not been successful in the past and miners are very suspicious of initiatives in this regard.

In summary, there is a combination of elements causing the abandonment of mines, including depletion of ore bodies, lack of proper technology and control, lack of formal support from government, poor law enforcement, poor environmental awareness and the inability of the miners to organize into associations, and this forms a scenario for rapid prosperity followed by abandonment of areas. Figure 4-1 shows the typical excavations from ASGM operations in the Amazon.

1 – Use of hydraulic monitors for excavation



2 – Pit is open and tailings released into the rivers

3 - A typical open pit after mining is over

4 - Open pit in activity


3 - A sluice box in operation

3 – Aerial view of degraded mining sites

Figure 4-1 – Excavations in artisanal mining in the Tapajos River Basin

### 4.1.2 Rehabilitation of exploited mines

In the Amazon, programs addressing prevention in the past were rare, and those few successful examples did not have the necessary scale to cover the dimension of the problem. As artisanal mining has been initiated in the area for at least 30 years and no significant work on reclamation has been done since then, the environmental "debt" is enormous. This "debt" encompasses basically the totality of areas worked and abandoned by ASGM. Although there are many environmental impacts related to the abandonment of such areas, three impacts in particular deserve special consideration: siltation and mercury contamination of streams and rivers, and deforestation.

Logging in the "garimpo" areas aims to supply the local needs, as the artisanal miners depend on the forest for their infra structure. Mining villages are generally 100% constructed with wood extracted locally, without any legal support and control (Mathis, 2003).

Preliminary survey in the Tapajos region indicates that the releasing of sediments into the streams and rivers may vary from 3,000,000 to 6,000,000 tonnes/a (Sousa and Veiga, 2007a). Twenty pits in the Crepori region evaluated randomly showed volumes of sediments varying from 10,000 $m^3$ to 50,000 $m^3$. Generally miners start a new pit when the depth reaches more than 10 m, as the operation becomes more complex. This survey led to a rough estimation of 300 to 600 new pits open every year in the whole Tapajos area (Sousa and Veiga, 2007b). Most of these pits remain opened as the current practices do not properly address mechanisms of retention of sediments, and the miners' preferred destination for tailing disposal are the streams and rivers.

The area disturbed directly by excavation of pits by artisanal mining in the Tapajos region is estimated to be at least 12,000 ha annually (Sousa and Veiga, 2007b), and the rate of reclamation is insignificant. The extension is not the most relevant fact in this particular case, but the distribution, as these mines are located in very sensitive areas along the rivers.

Any complex and costly reclamation method will not be effective in a region with severe scarcity of basic infrastructure, low level of education and high logistic costs. Therefore, the ideal procedures to rehabilitate degraded areas in artisanal mining are not necessarily the ones with highest technical level, but the ones with highest chances of successful implementation. Simplicity is, thus, mandatory. As mentioned by Hilson (2005), “when dealing with less exposed and/or illiterate miners, it is imperative that technological assistance, education schemes and support systems are simplified and made more user-friendly”.

The success of a reclamation program depends on the understanding of the relationship between the living and non-living components of the soil. The ultimate objective of a reclamation program is to create suitable conditions for the development of a self-sustaining ecosystem, which form and function satisfy desired criteria without additional human intervention (Stracker and Welham, 2006). Such criteria depend on the context, the environment and objectives of the program. A limiting factor in ASGM is the economical condition of the miners; however, any initiative toward reclamation will produce better results than accepting the current trend, as the area reclaimed is insignificant.

Amongst the main variables to be considered in a reclamation program in the ASGM, soil salvage is probably the most crucial step, as soils provide the medium for plant growth, control water balance and flow to the environment and serve as a shield to retain hazardous compounds (Stracker and Welham, 2006). These characteristics are a direct function of the amount and quality of organic matter and this explains why soil salvation is a crucial component in a reclamation program. Elements like nitrogen is largely available in organic matter and its absence may compromise significantly the plants development. Recapping open pits increases substantially the chances of success of a revegetation program, however, soil handling and movement is one of the most expensive parts of the reclamation process. In ASGM, removing and saving surficial layer of soil for reclamation purpose is a challenging and expensive task for the miners. As this layer of soil has to be removed anyways in order to give miners access to surficial gold deposits, the main issue is how to remove and save the organic layer of soil properly for future use. The technique suggested for retained the surficial soil is very similar to the one described to retain the tailings, by using triple barrier of Palm leaves for filtration of the slurry after the sluice box.

The large majority of the roots seeking nutrients are located on the surface, in the first 30 cm of soil. The natural seeds and vegetative propagules in the area are also located in the litter layer, and deeper roots are generally related to water catchment. This means that if a simple capping with organic soil is made, colonization by seeds of local plants will occurs naturally, when environmental factors like moisture and temperature are favourable. Besides the chemical properties of surficial soils, the physical characteristics also need to be favourable for vegetation development. It is actually easier to compensate chemical demands by supplying nutrients through artificial fertilization, than working the physical condition, which generally requires expensive soil movement.

A reclamation program does not necessarily imply reforestation, as natural revegetation is always an option to be considered. When the option is reforestation, however, the choice of the species is another crucial factor of success. The choice depends on ecological, technical and economic considerations.

## 4.2 Material and methods

### 4.2.1 Garimpo Canaan - A successful case of reclamation in the Amazon

Artisanal miners work under very adverse conditions in remote areas, and any process of rehabilitation of degraded areas has chances of being successful only if it is perceived as beneficial by miners, and the procedures are practical and inexpensive enough to encourage mines' owners to comply. As stressed by Ribeiro (2006), the Brazilian environmental legislation in the Amazon is very strict. However, preliminary survey showed that around 99.3% of miners do not attain the legal criteria to obtain the environmental license, and operate regardless proper licensing (Sousa and Veiga, 2007a). In this scenario, cases of rehabilitation of ASGM sites have happened due to volunteer initiatives rather than to law enforcement.

In a location in the Tapajos river basin known as Garimpo Canaan, a miner named Mr. Paulo Carneiro is considered a role model artisanal miner. His 10,000 ha property was used as a case study due to Mr. Carneiro's proved high standard practices for reclamation of degraded areas (Sousa and Veiga, 2007). Garimpo Canaan is a typical mining site in terms of gold processing, and employs basically the most common technology to recover gold in the region: the use of carpeted sluice boxes to concentrate gold which is amalgamated with mercury in designated pools away from water streams. As this technology employs hydraulic monitors to excavate pits, a highly significant environmental impact is observed. The main river in the area is Marupa River, a tributary of Crepori River, which is a tributary of Tapajos River. In terms of gold recovery, there is not much difference between the usual practices in the region and the practices of Garimpo Canaan. The main differences are the environmental concepts and practices applied locally.

In Garimpo Canaan, for the last seven years most old pits have been backfilled with the tailings of new excavations. In some refilled pits the vegetation is reseeding naturally and others have been reforested with species such as African Mahogany (*Khaya ivorensis*), Neem (*Azadirachta indica*), Teak (Tectona grandis), Brazil Nut Tree (*Bertholletia excelsa*), Crabwood (*Carapa guianensis*), Açaí Palm (*Euterpe oleracea*), Amazonian Mahogany (*Swietenia macrophylla* King) and Eucaliptus (Eucalyptus spp). This is the single case identified in the Tapajos region, and the first plantation happened around 7 years ago. An inventory was conducted in some of these areas, and the diameters and heights of the trees were measured in appropriate samples aiming to estimate the survival rate, the growth and yield of these plantations.

In the present case study, the main objectives of the reclamation program were:

- Reduction of river siltation, and consequently of mercury transport into the rivers, as the tailings are contaminated with mercury;
- Mitigation of the effects of deforestation by recomposing the landscape;

- Diversification of the local economy, as surficial gold deposits tends to be depleted and quickly the mine owners' have to diversify their activities to assure economic sustainability.

Reforestation not only represents an environmental step, but also an alternative livelihood for miners in long-term. According to Barros and Verissimo (2002), one $m^3$ of Amazonian Mahogany (*Swietenia macrophylla King*) can reach US$800, sold in the State of Pará. Although currently there is no road in Garimpo Canaan to transport these trees to the consuming centers, this is a long-term investment, as the harvesting age is expected to be 25 years.

The idea of sustainable mining has been largely discussed in the region of Itaituba, and the authorities tend to agree that artisanal gold mining is not a sustainable activity as the mineral deposit is finite and most mines are surficial. However, everyone agrees that the economy of the region must be sustainable, as mining can be replaced by other economic activities based on renewable resources. Reforestation with valuable trees is undoubtedly one of these sustainable activities and has to be encouraged and disseminated early among miners.

According to Mr. Carneiro's expectations, one hectare of his plantation, with 556 trees/ha may reach the gross value of US$200,000 /ha in 25 years. With examples like this it is easier to convince mine owners that reforestation is not only an environmental activity, but it can be a highly profitable business. In other words, these mine owners will be more motivated by economical approaches than by the environmental aspects.

Gold mining has been conducted in Garimpo Canaan for more than 20 years, but reclamation started about 7 years ago. In some cases the tailings have been discharged to the river many years ago, which reduces the chances of a successful reclamation. There are different levels of reclamation: some pits were refilled and natural revegetation occurred; few were recapped with soil; and others replanted with local species selected by Garimpo Canaan.

According to Mc Claim et al. (2001), the choice of species for rehabilitation in the Amazon should be based on their nutrient use efficiencies and growth rates. In Garimpo Canaan, the species were selected based on technical and economic aspects, in consultation with EMPRABA (Brazilian Institute of Agricultural Research). The seeds were purchased from EMBRAPA or collected locally when available. The substrate for the preparation of seedlings used 1/3 of ovine or cattle manure, 1/3 of decomposed wood and 1/3 of organic soil. Each seedling was accommodated in a plastic bag ranging from 0.5 to 1 kg of substrate. The seedlings were watered regularly and the main pests were controlled based on monitoring. The most common pests were Ants (*Atta capiguara*), termites (*Isoptera*), caterpillars (*Hypsipyla grandella*) and fungus. They were controlled with industrial insecticide (deltametrine) and natural insecticide (such as an infusion of Neem leaves (*Azadirachta indica*). The seedlings were produced in a simple nursery with 50% shadow, covered by palm leaves, and the weeds were removed manually.

In Garimpo Canaan, refilling open pits has been the most important activity in the whole reclamation process. The sluice boxes are positioned in such a way that the tailings are drained to old pits. A triple barrier made of palm leaves is positioned after the sluice box to filter the sediments in 3 stages and after the third stage only clean water, containing only very fine grains not retained by the barriers, returns to the river. These barriers are moved accordingly, as the pit is refilled. In some pits, the process of reclamation was considered finished as soon as the pit was refilled, and the miners moved to another location. This was the most basic stage of reclamation. Without a cap of organic matter the natural revegetation takes long time, as the lateritic soil is very poor in nutrients. As the surrounding area is rich in organic matter and seeds which disseminate in the environment, the natural process of green coverage of the refilled pit occurs, but requires many years.

Soil salvation was done in a few cases. When new pits were opened the soil (about 30cm of depth) was saved in a separate location, in order to be reused for reclamation. This operation was done by using hydraulic monitors to remove the surficial cap first, similar to the process used to excavate the ore body. The stockpiled soil was returned manually and used for recapping part of the area. This represented some extra activities for the miners and brought difficulties as the whole activity is manual. In some pits, the process of reclamation was considered finished as soon as the pit was partially recapped. The surficial layer of organic matter is rich in seeds and nutrients, and in just a matter of months these areas were covered by vegetation. When natural vegetation finds suitable condition to develop, its early stages of succession are usually dominated by grasses (Poaceae), sedges (Cyperaceae), and herbaceous dicots (Skole et al. (1999). As the forest around the mining site is a rich source of seeds, the natural regeneration generally occurs with all types of species from the original forest.

In areas where the pits were reforested, in some cases the plantation limits went beyond the pit borders. The seedlings were planted in a 50x50x50 cm pit, filled with the same material used for the preparation of seedlings. The pits were prepared manually and the spacing between trees ranged from 18 to 35 $m^2$/plant. Figure 4-2 shows steps of reclamation.

1 - Open pit before refilling

2 - Palm barriers to retain sediment

3 – Sediment containment in progress

4 – Refilling in progress

5 – Refilling completed

6 – After 6 months, natural revegetation

Figure 4-2 – Refilling of pits and natural revegetation

After plantation, several interventions were necessary to assure the plantation's phyto-sanitation and growth. These included manual and chemical weeding (use of herbicides) to eliminate competition, use of insecticide to controls mainly ants, and use of fertilizers to assure proper growing and yield. These interventions varied case by case, depending not only on technical recommendations but also on the investment capacity of Garimpo Canaan each year. Overall, the main procedures included:

- For fertilization, 120 g/pit of fertilizer NPK 10-28-20 was applied during the plantation and repeated each year for the first 4 years. According to Mr. Carneiro, the original formula was suggested by EMPRABA, and he adapted according to his possibilities. He also used the fertilizer ARAD and NPK 04-30-10 to replace NPK 10-28-20, when it was not available. In some cases, manure from a neighbouring farm was also used, although the dose has not been controlled.

- Silvicultural treatments started from the preparation of seedlings, with pulverization of Neem oil for combating fungus, insects and bacteria. In some occasions the insecticide Decys was employed against ants (*Atta capiguara*). According to monitoring, termites (*Isoptera*) and caterpillars (*Hypsipyla grandella*) were also controlled. The Neem oil, produced locally, was the main weapon against pests and diseases.

- The control of weeds was done mainly manually according to visual monitoring of competition. Trimming was also employed to eliminate undesirable branches and bifurcations, in order to assure a better shape of the tree. There is no precise estimation of cost of these operations, but according to Mr. Carneiro most of these activities were incorporated by the cost of his gold mining operation, as the labour employed to maintain his plantations is the same he uses to maintain the infra-structure for his mining activities.

The growth and yield of these plantations were inventoried through sampling. In each sample the following characteristics of the trees were measured: the diameter at breast height (DBH) (at 1.3 m from ground), the total height, and characteristics as bifurcation, mortality and diseases. In the Blocks 1A, 1B, 1C and 1D, 10 plot samples varying from 20 to 40 trees each (area varying from 738.5 to 1,303.8 $m^2$) were established in the area. Shape factors used for calculating the volumes varied from 0.4 to 0.6. Figure 4-3 shows the final stage, after revegetation. The reforested areas used in this case study are shown on Table 4-1.

According to Barros and Verissimo (2002), the natural density of mahogany in the State of Para varies from 0.3 to 2.1 trees/ha. The spacing adopted in Garimpo Canaan provides from 285 to 555 trees/ha, which is equivalent to 1 hectare of planted mahogany which may have the same number of mahogany trees as 1000 ha of natural forest. Moreover, for each mahogany tree harvested in the natural environment, about 31 other trees of diameter above 10 cm are damaged in order to remove the mahogany. This gives an idea of the environmental impact of extracting mahogany in the natural environment, and the importance of plantations. The main results of the inventory are presented in Tables 4-2 and 4-3.

1 - Old pit completely refilled

2 - Effect of organic cap

3 - Seedlings production with local species

4 – Amazonian Mahogany at 6 years of age


5 – Reforestation with lemon trees


6 – Reforestation with Cashew trees

Figure 4-3 – Refilled pits capped with organic matter followed by revegetation

Table 4-1 – Characteristics of reforested area in the site study

| | Area denomination | | | |
|---|---|---|---|---|
| | 1A | 1B | 1C | 1D |
| Common name | Afr. Mahogany | Neem | Teak | Amaz. Mahogany |
| Scientific name | *Khaya ivorensis* | *Azadirachta indica* | *Tectona grandis* | *S. macrophylla King* |
| Area ($m^2$) | 16310 | 54215 | 17885 | 7578 |
| # seedlings | 466 | 1549 | 511 | 421 |
| Date plantation | Feb/03 | Feb/03 | Mar/04 | Apr/02 |
| Age (years) | 5.8 | 5.8 | 4.7 | 6.6 |
| Spacing (m) | 7 x 5 | 7 x 5 | 7 x 5 | 6 x 3 |
| # trees/ha | 285 | 285 | 285 | 556 |

Table 4-2 – Results of inventory in Blocks 1A, 1B, 1C and 1D

| Block | Specie | Sample | | Diam | Height | Basal area ($m^2$) | | | Survival |
|---|---|---|---|---|---|---|---|---|---|
| | Common name | Trees | Area ($m^{2)}$ | (cm) | (m) | B/tree | B/sample | B/ha | Rate (%) |
| 1A | Afric.Mahogany | 21.1 | 738.5 | 15.16 | 9.59 | 0.0189 | 0.3411 | 4.61 | 81.05 |
| 1B | Neem | 22.0 | 770.0 | 14.43 | 7.40 | 0.0171 | 0.5163 | 6.73 | 90.00 |
| 1C | Teak | 37.3 | 1303.8 | 10.94 | 7.68 | 0.0099 | 0.3644 | 2.79 | 97.91 |
| 1D | Amaz. Mahogany | 42.0 | 756.0 | 13.72 | 8.05 | 0.0155 | 0.5610 | 7.57 | 84.91 |

The overall growth is compatible to other existing plantations in the Amazon, as reported by Guimaraes et al. (2004) and Browder et al. (1996). Block 1A (African Mahogany) shows an average diameter of 15.16 cm and average height is 9.59 m, at the age of 5.8 years.

Table 4-3 – Statistical analyses of volume ($m^3$/ha)

| Block | Age | Volume ($m^3$) | | | | Statistics of Volume/ha | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Stand | C.V. | Confidence | | Sampling |
| | years | V/tree | V/sample | V/ha | V/ha.y | Deviat | (%) | Inf. | Sup | Error (%) |
| 1A | 5.8 | 0.0952 | 1.72 | 23.19 | 4.00 | 2.88 | 12.41 | 21.31 | 25.07 | 8.10 |
| 1B | 5.8 | 0.0649 | 1.97 | 25.61 | 4.41 | 2.45 | 9.50 | 21.72 | 29.50 | 15.20 |
| 1C | 4.7 | 0.0401 | 1.47 | 11.29 | 2.40 | 0.95 | 8.37 | 9.79 | 12.80 | 13.32 |
| 1D | 6.6 | 0.0647 | 2.36 | 31.66 | 4.79 | 3.12 | 9.84 | 27.66 | 36.23 | 14.45 |

It is expected that at the harvesting age (25 years) the trees will reach a commercial diameter for sawmilling. Another inventory in five years may show the growth trend. Average survival rate of 81.05% is very positive for native species, compared with similar projects, as the mentioned by Guimaraes et al. (2004).The reason of some mortality is not well established, however, most tree deaths have occurred in the first year, which indicates poor adaptation of seedlings to the field conditions is the most probable cause of mortality. The survival rate of teak is extremely high, 97.91%. Basal area of African mahogany is 4.61 $m^2$/ha and volume is 23.19 $m^3$/ha. Statistical analysis of the Volume/ha showed a Standard Deviation of +/-2.88 $m^3$/ha and C.V. (Coefficient of Variation) of 12.41%, indicating that the samples are relatively homogeneous in terms of volume distribution. The Sampling Error was 8.10% and the Limits of Confidence varied between 21.31 and 25.07 $m^3$/ha (95% probability) which is relatively low for native species, indicating that the sample is sufficient for the purpose of this inventory. The low sampling error validates the sampling method for volume as a function of diameter, height and shape of the tree.

At this point it was not possible to foresee the yield at 25 years of age, but the current productivity gives an indication that the overall growth rate is satisfactory. Similar interpretation made for Block 1A is valid for other plantations, validating the results. For the Block 1B (Neem), not only the wood has intrinsic value but the economic interest is highly associated with the leaves and seeds, which are used to extract vegetable oil, with gross revenue that can potentially reach US$2,000 /ha.annum (Bittencourt, 2006). As an additional advantage, the areas are re-colonized by birds and small mammals of the region.

## 4.3 Conclusion

Refilling open pits is a crucial step in the rehabilitation of degraded artisanal mines in the Tapajos region. In Garimpo Canaan, the use of triple barriers made of palm leaves is efficient for retaining sediments. The loss of material (not retained by the barriers) varies according to the particles size, the slurry flow and the quality of these simple barriers, which affects the effectiveness of refilling. Even partially refilled pits represent some advancement when compared to the usual abandonment of mined areas. In areas refilled and not recapped, natural vegetation has a slow growth rate, but some natural vegetation coverage occurred after some months. Saving surficial soil for recapping pits is expensive for mine owners as this requires intensive manual labour. This step, when realized, was generally very superficial and the layer of soil used for recapping was very thin. In other cases the organic soil was used directly in the seedlings pits. Reforestation was the last step in reclamation in Garimpo Canaan, which the owner saw as an attractive economic opportunity that could assure economic sustainability to his property in the future. The plantations are still young for commercial purpose (6 years), as harvesting is expected after 25 years, but an inventory has indicated consistent growth rates. The current growth rate of mahogany and teak is comparable to other plantations mentioned in the literature, with annual growth around 4 $m^3$/ha, which may represent a future gross revenue of US$3,200/ha.annum at the current price of mahogany. Neem trees are presently an important source of leaves and seeds for the production of vegetable oil frequently used in Garimpo Canaan as natural insecticide and fungicide. Another benefit of reforestation is production of fruits, which are consumed locally by the artisanal miners and the community. The most common fruits produced in the area are lemon, orange, cashew and mango, appreciated by the local population for juice, sweets or for fresh consumption. Rehabilitation of degraded areas must be promoted among artisanal miners and Garimpo Canaan is a consistent reference to be followed. It is easier to convince the miners by approaching reforestation not only as an environmental activity, but above all, as profitable business or for local production of fruit, oil or seeds. In other words, miners are more motivated by economical approaches than by the environmental discourse only.

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# CHAPTER 5 – ALTERNATIVE METHOD FOR GOLD RECOVERY WITHOUT USING MERCURY - GARIMPO OURO ROXO[4]

## 5.1 Introduction

The main objective of this chapter is to describe an effective alternative to replace traditional artisanal gold mining activities using amalgamation or vat-leaching, with gravity pre-concentration followed by cyanidation of the concentrate. The proposed alternative is a combination of steps of existing processes with new steps adapted to make it simple and accessible to artisanal miners. A pilot plant implemented in a pilot site in the Tapajos region has shown positive results not only by improving gold recovery, but also by contributing to replace mercury amalgamation and reduce cyanide consumption.

### 5.1.1 The use of mercury in Garimpo Ouro Roxo

Mercury amalgamation has been a traditional method for gold recovery for centuries. In artisanal mining, due to the low efficiency of the gravity concentration and amalgamation, the gold recovery is generally not higher than 30 to 40% and the tailings contain residual mercury (Veiga et al., 2006).

Amalgamation is more efficient with gold liberated from the gangue material, generally coarser than 200 mesh (0.074 mm) (Veiga et al., 2006). This also depends on the shape of the

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[4] A version of this chapter will be submitted for publication. Sousa R.N; Veiga M.M; Klein, B.; Telmer, K.; Gunson A.J.; Bernaudat, L. Strategies for Reducing the Environmental Impact of Reprocessing Mercury-Contaminated Tailings in the Artisanal and Small-Scale Gold Mining Sector: Insights from Tapajos River Basin, Brazil.

gold particles. Grinding is a crucial step in this process, permitting the exposure of gold particles to mercury.

As the miners generally squeeze the amalgam in a piece of canvas, the amount of mercury in the final amalgam depends on how strongly they squeeze off the excess mercury. Usually, manually squeezed amalgam contains between 60 to 70% gold. As not all mercury forms amalgam with gold, the ratio between mercury lost and gold produced can range from 0.001 to as high as 30 (Veiga et al., 2009).

The main concern regarding the use of mercury amalgamation is the high toxicity and potential to pollute the environment. Mercury accumulates in vital organs, affecting the human's nervous system and causing serious neurological diseases (Castilhos et al., 2006).

Once the amalgam has been formed, in order to separate mercury from gold, miners generally burn the amalgam and evaporate the mercury. Ideally, retorts should be used to condense the evaporated mercury, but this practice is not sufficiently disseminated among artisanal miners worldwide (UNIDO, 2006b; Sousa and Veiga, 2007).

Slowey et al. (2005), studying placer gold mine, have found that the metallic mercury used by the miners can form different compounds in the ore processing steps, undergoing volatilization, globule relocation, dissolution, oxidation, precipitation and amalgamation and sorption onto sediments. A significant part of the mercury, in form of a colloid, may stay in solution or adhere to sediment components such as iron and aluminum (hydr) oxides, which facilitates mercury transportation by water (Kim et al., 2004). Slowey et al. (2005) found that more than 50% of the elemental mercury added to the sediment during amalgamation can be transformed into soluble and particulate species, including mercury organically bound, mercury absorbed to sediment minerals, and forming HgS. Depending on the mercury species, it may become more, or less, amenable to gravity concentration.

Telmer et al. (2006), studying mercury in the Tapajos River, found that Hg bound to suspended sediment has around 600 times the concentration of dissolved Hg per litre of water in impacted areas, and 200 times in unpolluted areas. This allows mercury transportation up to 200-300 km downstream in the Tapajos River.

Velasquez-Lopez et al. (2010), working with ASGM in Ecuador, found that from the total metallic mercury in the tailings submitted to cyanidation, 24% is trapped at the bottom of agitated tanks, 33% is lost as tailings associated with solid material, 12% is lost in solution and 31% of Hg in solution is found in zinc precipitation cells. From the latter, 28% is precipitated on the zinc shavings and evaporated when the shavings are burnt, and 3% stays in the barren solution.

### 5.1.2 The use of cyanide in Garimpo Ouro Roxo

According to Akcil (2003) cyanidation is used in nearly 90% of the gold processed in the world. Hilson and Monhemius (2006), studying many alternative lixiviants for gold, concluded that cyanide is yet the most effective option for artisanal miners, if it is handled properly. The technique is efficient to dissolve fine gold, usually smaller than 0.2 mm. In Garimpo Ouro Roxo, a solution is prepared with the ground ore, the pulp pH is adjusted to be alkaline and a diluted solution of cyanide is added to the pulp. Typically sodium cyanide crystals are used.

The control of pH is critical to avoid loss of cyanide as gaseous hydrogen cyanide, which is highly toxic. At low pH, hydrogen cyanide may be formed, as follows: $CN^{-}(aq) + H^{+}(aq) \rightarrow HCN(g)$. Therefore the free proton concentration is kept low by the addition of alkali such as lime (calcium hydroxide) or sodium hydroxide to ensure that the pH during cyanidation is maintained over 10 (Marsden and House, 2006; Kozin, 2004).

The chemical reaction proposed by Elsner (1846), cited by Marsden and House (2006), is as follows:

$$4Au + 8NaCN + O_2 + 2H_2O \rightarrow 4\,Na\,[Au(CN)_2\,] + 4NaOH \qquad (1)$$

Cyanidation requires, therefore, the presence of free or exposed gold, a cyanide solution and dissolved oxygen in an aqueous system.

As per Equation 1 dissolved oxygen is an integral component of cyanidation, and deficiency in solution can slow or even halt the leaching reaction. Oxygen ($O_2$) can be supplied through natural or forced air, or pure oxygen bubbled into the pulp to increase the dissolved oxygen concentration. Oxygen can also be added into the system through hydrogen peroxide solution.

The effectiveness of the leaching process depends on the interaction of every component in the system gold-air-cyanide, but generally gold recoveries are above 90% when the pulp is agitated.

Cyanide is highly toxic to human and to the environment, but it is safe if handled accordingly. Free cyanide is readily absorbed through inhalation, ingestion or skin contact and is distributed throughout the body via blood (Veiga et al. 2006). It induces tissue anoxia so that oxygen cannot be utilized by the cells and death can result from the depression of the central nervous system. In solution, only 3 to 5 mg of cyanide/kg body weight can be lethal, and in respiratory exposure to hydrocyanic acid gas (HCN), only 0.1 to 0.3 $g/m^3$ can cause death. Fish are even more sensitive to cyanide, and concentration of free cyanide between 0.05 and 0.2 mg/L are enough to cause mortality (Veiga et al., 2006).

According to Veiga et al. (2006), the main advantages for miners to use cyanide leaching are:

- The cyanidation process is relatively quick and generally takes less than 24 h;
- Involves small concentrations of cyanide needed to recover gold, which are usually less than one kg of cyanide per tonne of ore;
- Cyanide is very selective to leaching gold and only minor amounts of other minerals in the ore are dissolved.
- Free weakly bound cyanide species remaining in the tailings can be destroyed to minimize eventual environmental impacts;
- Free cyanide degrades naturally in the environment, primarily from exposure to the sun ultraviolet light, to less toxic forms and ultimately to nontoxic carbon dioxide and ammonia; and,
- Cyanide does not bioaccumulate in animals or plants

According to the same authors, the main disadvantages of cyanide leaching are:

- Cyanide is highly toxic and at high concentrations it may kill wildlife and humans;

- Cyanide can react with mercury to produce soluble complexes that are easily transported with water;
- The compound originated from reaction of cyanide and mercury is more bioavailable, therefore more harmful than methyl mercury.

The use of cyanide in ASGM can be safe provided that miners implement safe procedures to monitor the use in all stages of the process and to destroy residual cyanide in the tailing. Processes requiring the cyanidation of the whole ore must handle large amount of cyanide, whereas processes based on pre-concentration of gold followed by cyanidation can reduce the amount of cyanide by several hundred times.

Vat-leaching with cyanide is relatively new to most miners in Brazil. Millions of tonnes of tailings accumulated for decades in streams and riverfronts from old operations are now being reprocessed to extract the residual gold. This is particularly true in the cases where alluvial and colluvial deposits are exhausted and miners have difficulties in finding new deposits. Vat-leaching has been used with poor adaptations and it is very inefficient. This may pose risks of cyanide spills and human and fauna contamination. Miners work in highly environmental sensitive areas located along the rivers and other water bodies, creating impacts to these habitats.

Cyanide dissolves not only gold but also any remaining mercury left behind from the amalgamation process. Mercury cyanide can be formed and it is more bioavailable or easier to be methylated than metallic Hg when discharged into the water streams (Veiga et al., 2009). Mercury cyanide released by ASGM can cause serious environmental damages, which may include higher levels of Hg in fish in regions where amalgamation and cyanidation have been used combined and the tailings have not been properly treated and disposed (Castilhos et al., 2006).

Due to its properties, effectiveness and low cost, cyanide has shown to be the most promising reagent to replace mercury. Artisanal mining tends to follow the trend of large operations, where cyanidation has been the main reagent for leaching gold.

### 5.1.3 Intensive cyanidation

Conventional cyanidation generally uses cyanide concentrations around 0.2 to 1 g/L and natural oxygen concentration. However the kinetics can be accelerated with the use of high concentrations of cyanide and forced oxygen into the system, referred to as intensive cyanidation (Gray, 2000; Gusman et al., 1999). Intensive cyanidation is commonly used to leach concentrates obtained by gravity separation or flotation. An intensive cyanidation procedure has been used by Gekko Systems (manufacturer of an intensive cyanidation unit ILR - InLine Leach Reactor) and it has shown recoveries above 95.0% (Gray and Katsikaros, 1999). In intensive cyanidation processes, conventional activated carbon circuits can be removed by using direct electro winning of gold bearing solutions (Gray et al. (2003).

Atmospheric oxygen acts as the oxidant agent in gold cyanidation but its solubility in the leaching solution can be limited depending on the leaching process. The cyanidation rate is determined by the oxygen concentration in solution. Oxygen concentration decreases as the reactions proceed and it is not replaced rapidly enough due to the viscosity of the medium and inadequate aeration. This decreases the gold leaching rate (Gusman et al., 1999).

According to Guzman et al. (1999) and Longley et al. (2002), several authors have reported that the addition of small amounts of hydrogen peroxide (0.012 g/L) in the gold leaching has no effect on the cyanidation rate. Kameda (1949) reported that larger concentrations of $H_2O_2$ (0.20 g/L) increases the gold dissolution rate, but concentrations higher than 0.40 g/L start decreasing the dissolution due to cyanide oxidation by peroxide. Day (1967) found that there is no direct correlation between the gold dissolution rate and the cyanide or peroxide concentrations. Guzman et al. (1999) concluded that although some authors described that hydrogen peroxide is as important as cyanide, at concentrations lower than 0.34 g/L, pH 11.5 and 25$^{o}$C, cyanide is not oxidized, and therefore any decrease in the cyanidation rate cannot be attributed to cyanide oxidation by $H_2O_{2.}$ Nevertheless, the cyanidation rate can be doubled by adding $H_2O_2$ at concentrations close to 0.50 g/L, varying from 0.17 g/L to 0.68 g/L, compared to conventional cyanidation at pH 10.

Gray et al. (2003) and Longley et al. (2003), describing Gekko Systems, recommends the use of 2% (equivalent to 20,000 ppm or 20g/L) of NaCN and 20 mg/L (equivalent to 20 ppm or 0.02 g/L) of $H_2O_2$. According to Deschenes et al. (2003), the minimum oxygen concentration [$O_2$] inside a ball mill has to be at least 6 times larger than the concentration of cyanide [CN]. The free space in the mill is sufficient to assure $O_2$ supply, and over the course of the leaching process the mill is frequently stopped for analysis of pH and [CN], which allows air replenishment.

When adding lime to the solution, pH above 12 has to be avoided as it slows the cyanide reaction due to formation of lime crusts on the gold surface (Gusman et al., 1999).

## 5.2 Material and methods

### 5.2.1 Site description

The study site is called Garimpo Ouro Roxo (GOR) and is located in the municipal district of Jacareacanga, state of Para, in the village of Sao Jose. GOR is located in the Pacu River Basin, a tributary of the Tapajos River, as shown in Figure 5-1 and Figure 5-2. The geographic coordinates are lat 04º16,' lon 55º35', and altitude 45.0m.

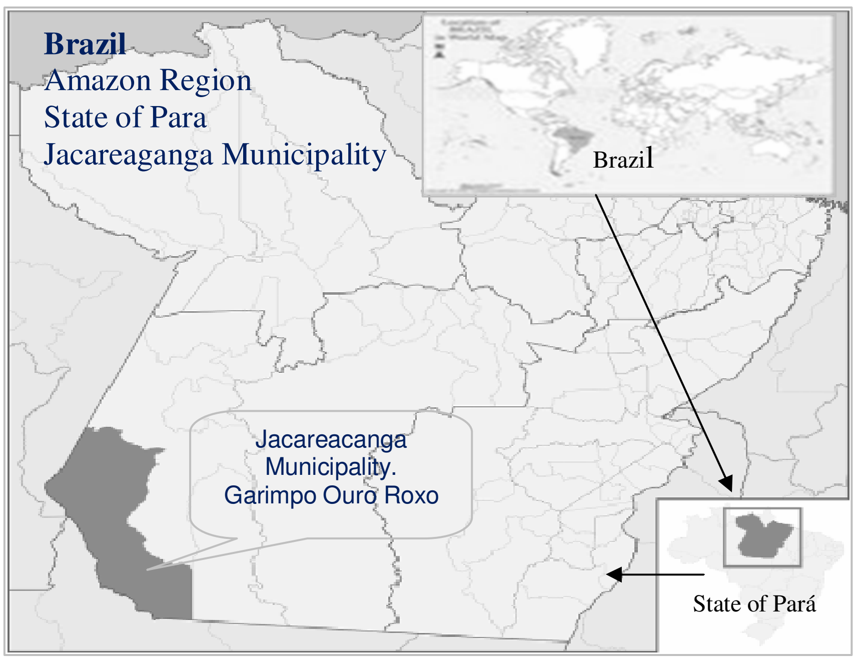


Figure 5-1 – Garimpo Ouro Roxo location

Although miners work all year long, the period from May to November is ideal for their work. The vat-leaching cyanidation are affected during the raining season as the cyanide solutions are diluted by rainwater and the transit of people and equipment become more complex and expensive. The GOR mining claim covers 150 ha, larger than most typical “garimpos” in the region. However, GOR’s use of mercury and cyanide are representative of most locations in the Amazon. The first mining activities in this area were initiated in the 1960s with manual exploitation of alluvial gold and later on with the use of hydraulic monitors and carpeted sluice boxes for gold concentration from colluvial deposits. Mercury amalgamation has been largely employed over this period of time. In a second phase, in the 1990s, miners discovered the primary deposits and started to exploit gold veins in shafts and drifts. Miners extract the auriferous ore and grind the chunks of rocks in hammer mills to recover gold in copper plates amalgamated with mercury (Amerix, 2009). Tailings have accumulated over the past 3 decades in low lying land close to the operations which the miners have nicknamed “baixao”, These tailings are the source of material to vat-leaching.

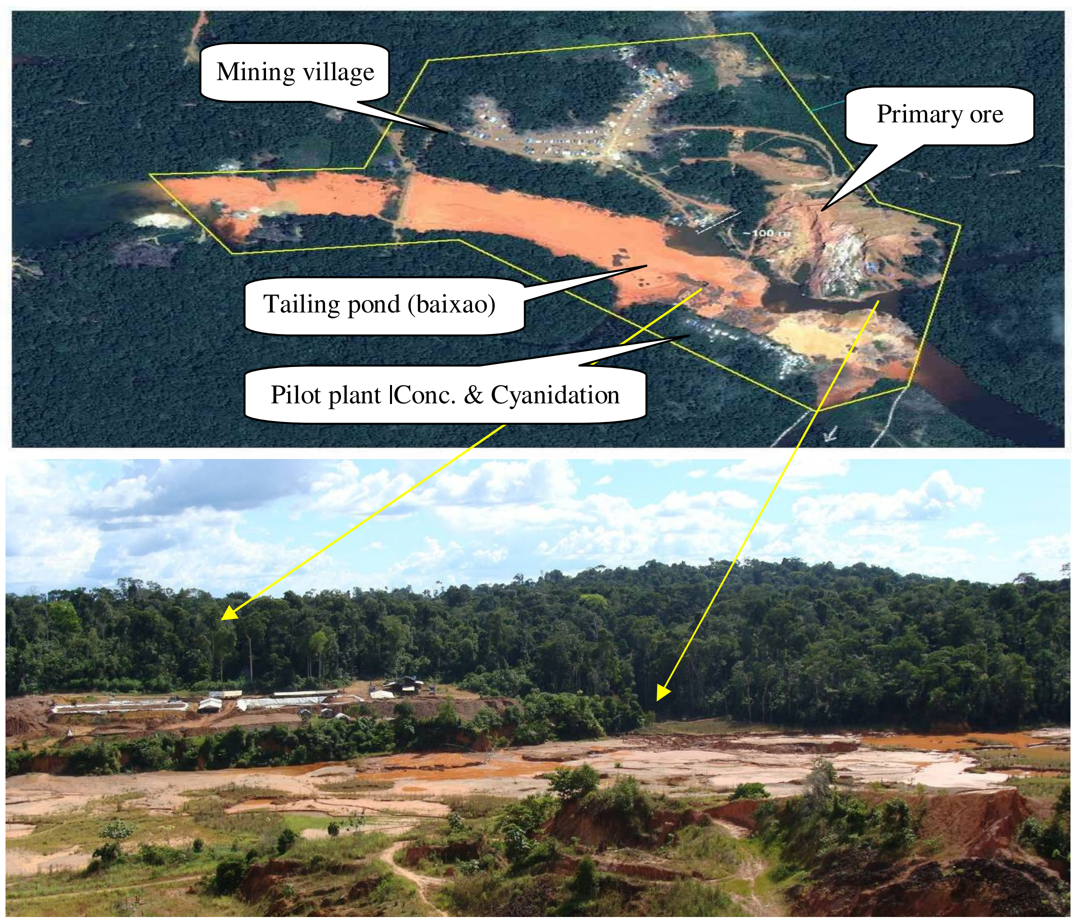


Figure 5-2 – Panoramic view of the “baixao” (“improvised” tailing pond) at GOR

### 5.2.2 The current processing procedure

According to GOR miners, 80 kg of gold have been produced since the introduction of vat-leaching in 2007. The miners practice no method to estimate gold recovery from the vats. The current process flow is shown in Figure 5-3.

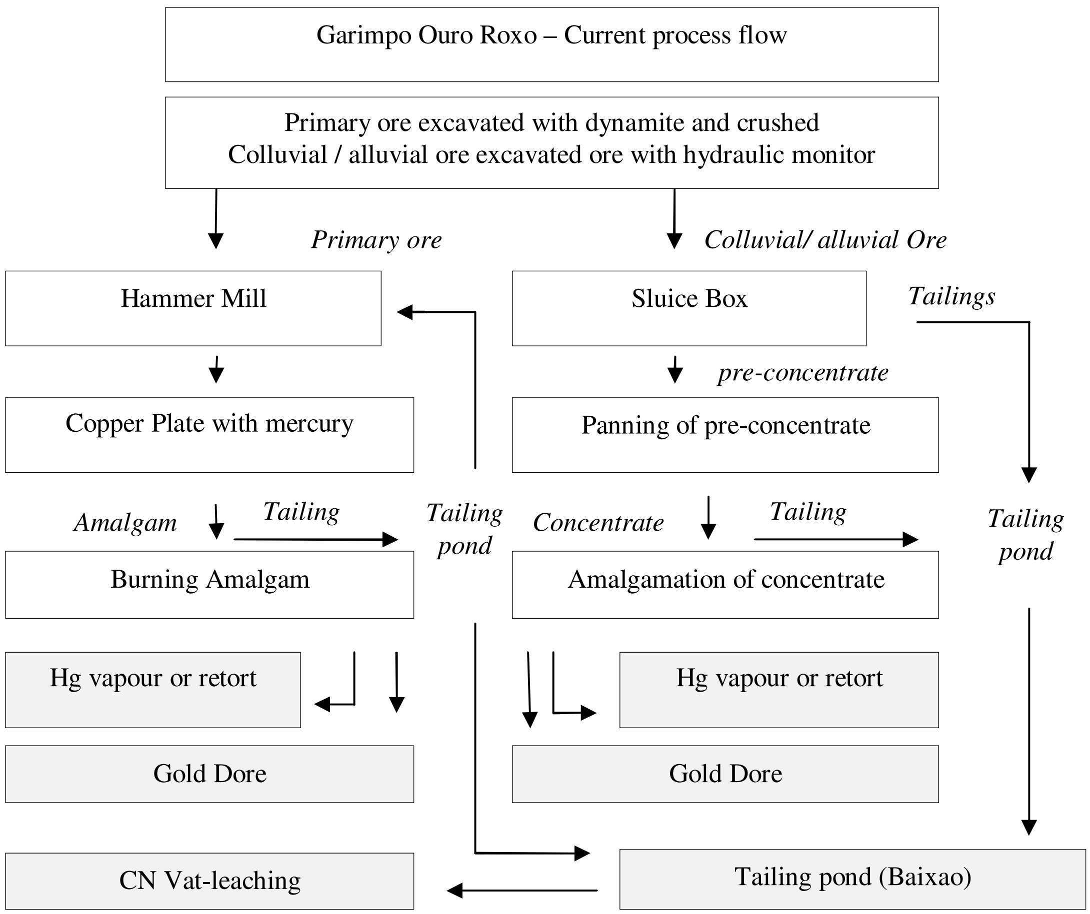


Figure 5-3 – Overview of Garimpo Ouro Roxo process flow

Since 1990, more than 40 shafts and drifts were constructed at GOR, of which 6 are currently in operation. The ore is crushed with hammer mills, and then passed over mercury coated copper plates. The resulting amalgam is scratched off the plates and then burned with a propane torch. Each shaft generally employs about 10 miners and 2 supervisors/ shaft and requires 1 or 2 hammer mills. One or two operators manually shovel ore into the hammer mill while operating the copper plate.

Average daily ore production is 3.6 t/day and the average gold production is 60 g/day per shaft, which corresponds to 17 g Au/tonne (recovered gold by amalgamation alone). Miners believe the overall grade ranges between 5 to 55 g/t, while recoveries can vary from 30 to 60%.

All amalgamation tailings are discharged into the "baixao" (Tailing pond). The GOR's partners decided to restrict the use of amalgamation to primary ore: they do not reprocess tailings with copper places. Amalgam is collected at the end of every day and gold production is around 1.5 kg Au/month.

GOR implemented the first vat-leaching tank in September 2007 in order to reprocess the tailings. By February 2009, 10 tanks with the capacity of processing 3,120 tonnes/tank per cycle had consumed a total of 33,000 kg of NaCN (22,000kg/year), representing an average of 1.0 kg NaCN / tonne ore. Each tank has area of 960 $m^2$, with dimensions of 40 m x 24 m, subdivided in 24 sections aiming at better percolation control of the cyanide solution. Each section has 8 m x 5 m x 2.5 m receiving about 100 $m^3$ of ore, with the apparent density estimated in 1,300 $kg/m^3$.

As the tank is filled with tailings from the "baixao", a cyanide solution is prepared in a 60 $m^3$ pool, with the dimensions of 8 m x 5 m x 1.5 m (depth). The cyanide solution is pumped into the system through irrigation of the sections. The pH of the system is adjusted to 10 with addition of lime. A second pool of 60 $m^3$ receives the gold-pregnant solution. The total amount of water in the system is affected by rain but this variable is not properly controlled. The $CN^-$ concentration in solution is verified by operator using titration with $AgNO_3$, as described at Cyanide Management Code (2009), and is usually kept around 1.0 g/L. Figure 5-4 gives the general view of the vat-leaching process.

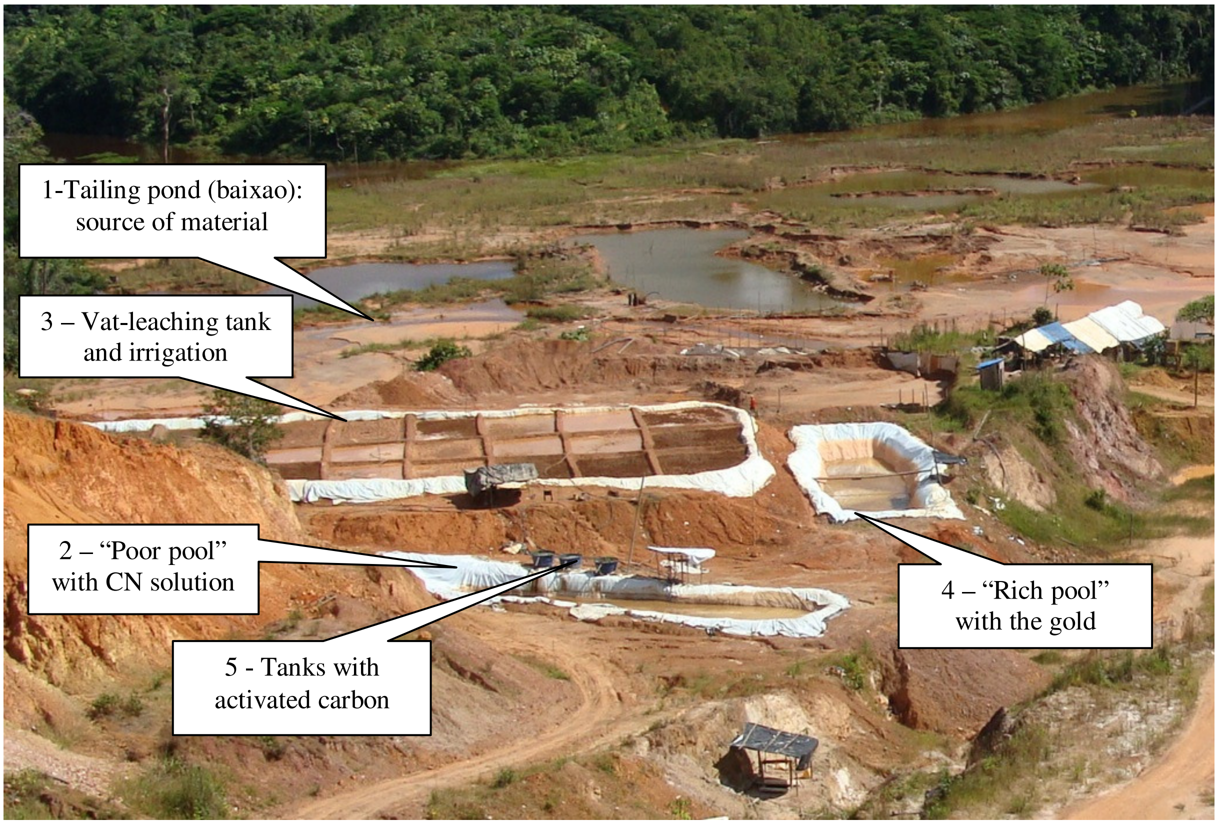


Figure 5-4 – General view of the vat-leaching process

The miners take around 8 days to fill the vat-leaching tank with tailings, using a front end shovel and a team of 8 men per 12 h working shift. Once the vat is filled, the cyanide solution passes through activated carbon and is recycled to the vats. After 12 days, 300 kg of loaded carbon is removed for elution and replaced with 150 kg of fresh carbon, which is removed after 8 days. Thus in theory, the production cycle is 28 days. However, the real cycle is often over 50 days due to operating problems, such as broken machines, excessive rain, delays in transportation, or the lack of material to leach.

At the end of each cycle, the spent $CN^-$ solution is recomposed by increasing the $CN^-$ concentration to at least 1 g/L and adjusting the pH to between 10 to 11, using lime. If the used solution needs to be discharged the CN is first destroyed with the addition of sodium hypochlorite and by exposure to sunlight. Despite the fact that miners have oversimplified the process and have also an inadequate control of CN concentration and pH, this process is yet more efficient than previous processes relying on amalgamation. Past production figures indicates that the gold recovery in this vat-leaching process is around 50%.

### 5.2.3 Centrifugal concentration

Through this study, the most recent innovation implemented at GOR was a pilot plant for concentration and cyanidation of concentrate. This pilot plant was implemented in February/2009, and since then it has been frequently adapted and improved, with the goal of gradually replacing the existing process based on vat-leaching and mercury amalgamation. Gravity pre-concentration was selected as it dramatically reduces the chemicals required for leaching while also reducing the amount of mercury contaminated tailings exposed to cyanide. Gravity pre-concentration also allows for the removal of sulphides from reprocessed tailings reducing the potential mobilization of heavy metals and acid generation (Gray and Katsikaros, 1999). The reduced use of cyanide also lowers the amount of cyanide which needs to be destroyed.

In the start up phase, the pilot plant equipment consisted of 2 hammer mills, a vibratory 2mm sieve, one Falcon iCon® centrifugal concentrator and a small ball mill. Figure 5-5 shows the general process flow sheet.

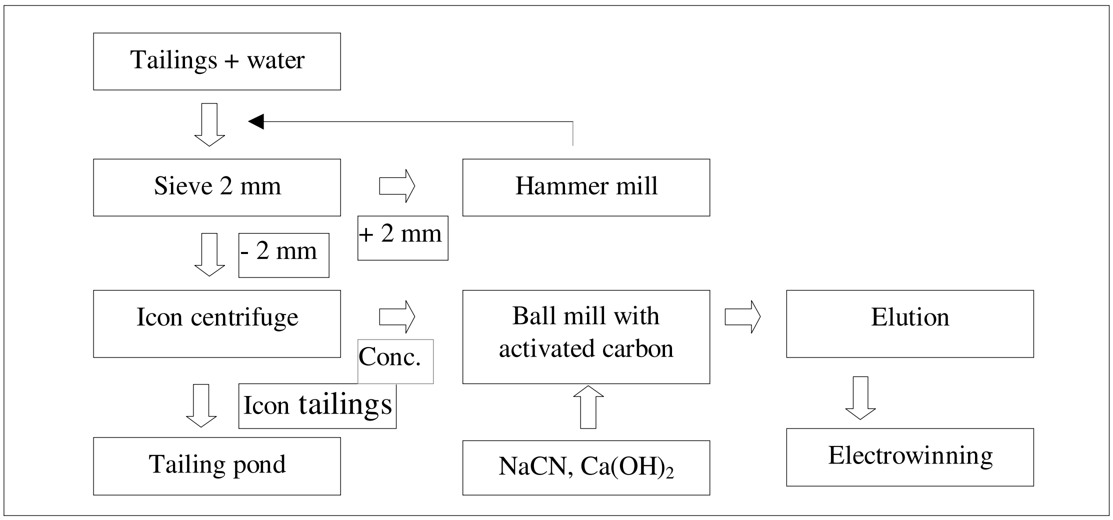


Figure 5-5 – Flowchart of the cyanidation pilot plant process

The tailings from "baixao" are fed into the pilot plant manually at about 30% solids by weight, at a rate of approximately 1.4 t/h. As the feed is handled by one miner with a shovel, the flow and pulp density are not constant. Another operator cleans the centrifuge and a third operates the cyanidation of the concentrate in the ball mill. The Figure 5-6 shows some pictures of the pilot plant for concentration and cyanidation.

The iCon® centrifuge was developed by Falcon Concentrators to make modern gravity concentration equipment affordable for some ASGM sites. The current cost of an iCon® in Brazil is around US$7,000. An iCon is shown in Figure 5-7.

1 – Pilot plant for concentration and cyanidation

2 – Internal view of sieve and hammer mill

3 – iCon centrifuge

4 – Capsule of activated carbon in the ball mill

5 – Training of miners to operate the pilot plant

6 – Plant for elution of charcoal and electrolyses

Figure 5-6 – Pilot plant for cyanidation of concentrate in Garimpo Ouro Roxo

Equipment (Icon) specifications include:

- Capacity: pulp of 30% solids, up to 2 t/h.
- Transportation: The centrifuge assembled in a 200 L drum. The base is set in concrete to avoid bouncing in operation.
- Process water: Water pressure 10 PSI, eliminates the lightest material in the bowl, by opposing the centrifugal force. (how much per hour, cleanliness)
- Rinse hose is used to wash the bowl after discharge.
- Concentrate is retained in the bowl and flushed periodically.

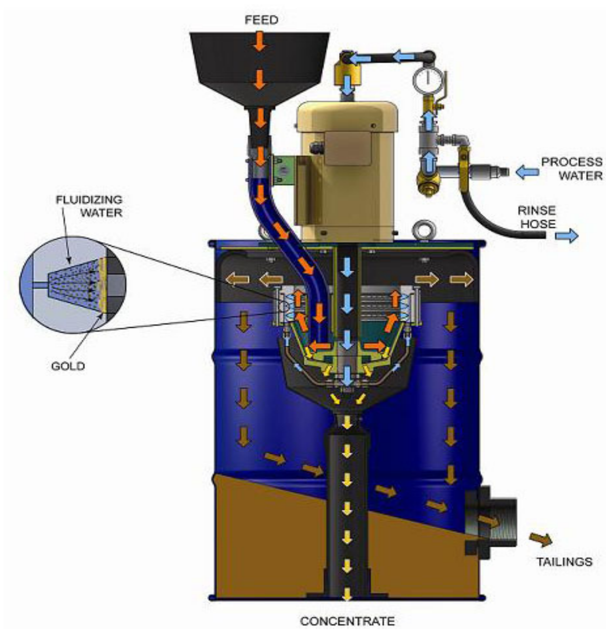


Figure 5-7 – iCon® centrifugal concentrator (Falcon concentrators' website, 2009)

The concentrator flush cycle was tested at several different times. Tests performed previously indicated that longer concentration times yielded richer concentrates but the final recovery was compromised.

A combination of variables, including particle size and shape, specific gravity, and mineral liberation size influences the optimum retention time. Generally, recovery rates decrease when the flush cycle time increases and the grade of gold usually has the opposite behavior (Luz and Almeida, 1998; Trindade and Filho, 2002; Gray, 2000).

At GOR, a typical flush cycle time was 20 to 30 minutes, producing around 1kg of concentrate per discharge. Field tests were undertaken with cycle times of 15, 20, 30, 45 and 60 minutes.

### 5.2.4 Cyanidation in a ball mill

Traditional cyanidation plants make this process in distinct steps. In a first step the ore is crushed and ground into pulp of 70% solids for gold liberation or exposure to cyanide. Resident times in ball mill varying from 15 minutes to 2 hours are common, and the final product may present grain size (P80) varying from 48 meshes (0.419 µm) to 200 meshes (0.105 µm) (Veiga et al., 2006). In a second step the ground pulp is diluted to 30% to 40% of solids and submitted to cyanide leaching. This solution generally circulates through activated carbon columns, where carbon traps the gold in solution.

At the GOR pilot plant the gravity concentrates were treated with intensive cyanidation. Traditionally grinding, cyanidation, and carbon absorption stages take place in series, but at GOR all three stages were combined in a small ball mill with capacity of 100 kg/batch. The concentrates were leached with 3 g of NaCN per 1kg of ore, in a solution with 2 g NaCN/L. Thus 150 g of NaCN would be added to 50 kg of concentrate and 75 L of water. According to Marsden and House (2006), a recommended gold concentration on activated carbon should not exceed 10,000 ppm, which represents 100 g of carbon for each gram of gold to be leached. However, historical data of the activated carbon used by GOR has shown 60 g of carbon per gram of recovered gold. Using this ratio, 3.3 kg of activated carbon is needed to adsorb 55 g of gold per batch, and this was the amount used in the tests.

During grinding, a perforated PVC capsule containing a nylon screen bag with activated carbon was introduced into the mill. The capsule has diameter of 12.7 cm and 56.0 cm long, holding 3.3 kg of activated carbon. The nylon bag accommodates the carbon firmly into the PVC capsule, assuring that the carbon does not have excessive attrition with the turbulence of the grinding process. The screen size was 1 mm, much smaller than the carbon grain size (15 x 18 mm).

After removing and draining the PVC capsule, the carbon moisture content was found to be around 25%.

The capsule of activated carbon is introduced in the ball mill at the beginning of the grinding, or after the first 8 hours of grinding and leaching, to avoid stress of the capsule and loss of carbon. The pH was adjusted with lime to stay around 10 to 11. After each batch the capsule of carbon was removed, washed, identified and stocked for subsequent elution and electrolysis.

Several tests were performed to validate gravity pre-concentration followed by cyanidation in the ball mill, as shown in Table 5-1.

Table 5-1 – Summary of 6 tests performed

| Test | Description | Main objective | Characteristics of sample/test |
|---|---|---|---|
| 1 | No grinding and conventional leaching of head sample | Intended to be the closest comparison to vat-leaching, although it is agitated | Head sample, [CN] of 1.00 g/L, pH of 10-11, 72 h |
| 2 | Simultaneous grinding and conventional leaching of concentrate | Test of resistance of the activated carbon in the mill and effects on gold recovery | Concentrate, [CN] of 2.00 g/L, pH of 10-11, 72 h |
| 3 | No grinding and conventional leaching of concentrate | Emulation of agitated tank (ball mill without balls) and cyanidation without grinding | Concentrate, [CN] of 2.00 g/L, pH of 10-11, 72 h |
| 4 | Previous grinding and conventional leaching of concentrate | Emulation of agitated tank (ball mill without balls) and cyanidation after grinding | Concentrate, [CN] of 2.00 g/L, pH of 10-11, 72 h |
| 5 | No grinding and intensive cyanidation of concentrate | Test intensive cyanidation without previous grinding (emulate Gekko system process) | Concentrate, [CN] of 20.00 g/L, pH of 10-11, 0.3 g/L $H_2O_2$, 24 h |
| 6 | Grinding and intensive cyanidation of concentrate | Test intensive cyanidation after grinding extensively for maximum gold liberation | Concentrate, [CN] of 20.00g/L, pH of 10-11, 0.3 g/L $H_2O_2$, 24h |

The basic steps in these tests involved:

*1 - Sample preparation:* The pulp was prepared with 30% of solids. Before cyanidation, sub-samples of the material were analyzed for Au content by Fire Assay.

*2 - Preparation of the PVC capsule with activated carbon:* Coconut shell activated carbon with grain size 6 to 12 mesh was utilized. The carbon was sifted and washed to eliminate fine grains to avoid loss of gold with carbon during the grinding-leaching process. The mesh of the fabric used to accommodate the carbon generally defines how much fine particles have to be eliminated in the washing process. The carbon was later dried in open air until constant humidity, weighted and firmly accommodated in the capsule.

*3 - pH control and CN concentration:* The natural pH of the process water was 6.0 and the pH of the gravity pre-concentrate slurry was 6.5. The pH of the solution was adjusted to 10.5 with the addition of lime. The [CN] was controlled by titration of the samples with $AgNO_3$.

*4 - Au in solution:* Samples of the solution were collected every 12 h. Previous test confirmed that when the activated carbon is present, gold in solution is promptly adsorbed, and the concentration in solution remains very low.

*5 - Au in the activated carbon:* The gold in the carbon was estimated based on metallurgical balance, considering the original grade of the sample and the final tailings and was confirmed with the balance between gold in the carbon and gold in the tailings.

## 5.3 Results and discussion

### 5.3.1 Centrifugal pre-concentration

The average gold grade of the feed of 2.13 g/t was obtained by fire assay and was relatively stable throughout the test program. The inflow of 1,408 kg/h was assumed to be constant for all cases. Tailings grades were obtained by fire assay and concentrate grades were calculated by difference through mass balance of the gold concentration in the feed and centrifuge tailings. The average found for 30 minutes was 205 g/t. Gold recovery with time was calculated and presented in Table 5-2.

Table 5-2 – Gravity pre-concentration gold recovery with time

| | Feed | | Concentrate | | Tailing | | Recovery |
|---|---|---|---|---|---|---|---|
| Time | Weight | Au | Weight | Au | Weight | Au | |
| minute | kg | g | kg | g | kg | g | % |
| 15 | 352.1 | 0.75 | 1.0 | 0.37 | 351.1 | 0.38 | 49.44 |
| 20 | 469.5 | 1.00 | 1.0 | 0.47 | 468.4 | 0.53 | 46.60 |
| 30 | 704.2 | 1.50 | 1.0 | 0.72 | 703.2 | 0.78 | 47.96 |
| 45 | 1056.3 | 2.25 | 1.0 | 0.97 | 1055.3 | 1.28 | 43.11 |
| 60 | 1408.4 | 3.00 | 1.0 | 1.21 | 1407.4 | 1.79 | 40.42 |

As shown in Table 5-2, gold recoveries ranged from 40 to 50%. Recovery decreased significantly after 45 minutes. Historical data shows that the average grade of tailings from "baixao" is around 3.0 g/tonne. The mass of the concentrate at the centrifuge discharge was variable, in general varying from 0.8 to 1.5 kg of wet material, with a mean of 1.4 kg/discharge, which corresponds to 1.0 kg of dry material. Assuming for instance discharges every 30 minutes, the daily concentrate production of one centrifuge, after 40 discharges, can reach around 54 kg (wet mass).

The concentration ratio must also be considered when deciding the discharging time. Table 5-3 shows a summary of the concentrate production for different discharging times in a regular day of operation in the pilot plant (20 h/day).

Table 5-3 – Production of concentrate and concentration ratio

| Time | Concentrate / day | Concentration ratio | Au balance / day (20 h/day) |
|---|---|---|---|
| | Dry mass | Feed mass / Concentrate mass | Au in the Concentrate |
| Minute | kg | | g/day |
| 10 | 122.40 | 230.13 | |
| 15 | 81.26 | 345.19 | 29.66 |
| 20 | 60.94 | 460.25 | 27.96 |
| 30 | 40.63 | 690.38 | 28.78 |
| 45 | 30.60 | 920.49 | 25.86 |
| 60 | 20.40 | 1380.73 | 24.25 |

Although a discharge time of 15 minutes results in better recovery, it generates a larger amount of mass to be leached. Conversely, the longer time of 60 minutes generates richer concentrates but a smaller amount of mass, resulting in lower gold production. The combination that results in best gold production is situated between 20 and 30 minutes.

The operating availability is 20 h/day due to frequent interruptions. In a regular day, the pilot plant processed 28 tonnes of tailings. A flush cycle of every 30 minutes resulted in a production of 41 kg/day of dry material, resulting in a gold recovery of 50% in 0.14% of the mass.

A flotation plant has been developed to be tested as an alternative method of concentration, but it has not been put in operation yet.

### 5.3.2 Cyanidation of concentrate

The result of the tests described in Table 5-1 are shown in Figure 5-8

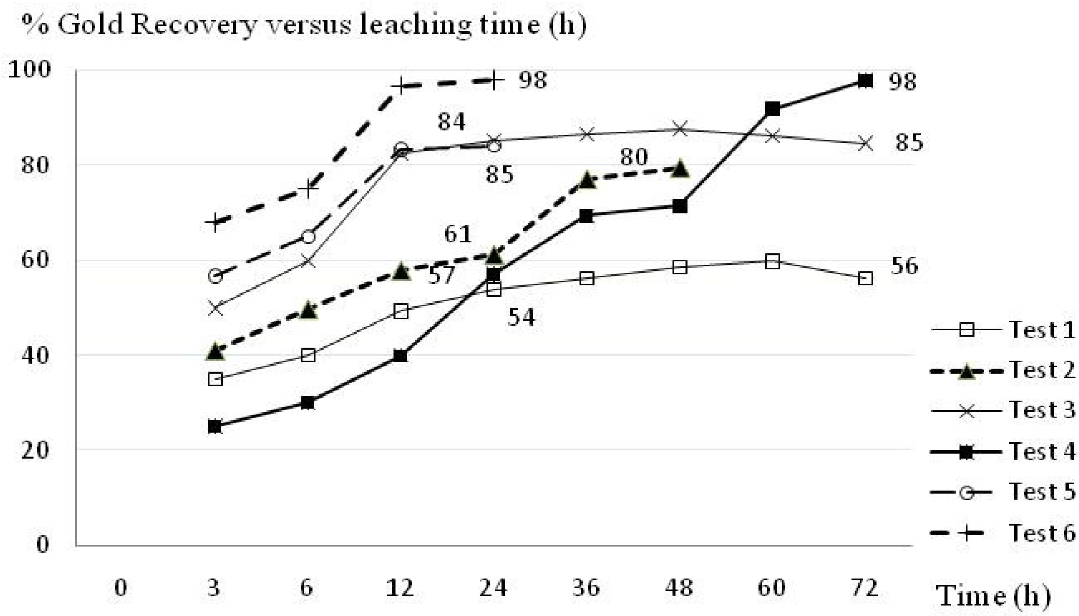


Figure 5-8 – Gold recoveries in tests 1 to 6

### 5.3.3 Test 1 – Conventional cyanidation of head sample

The objective of this test was to observe the effect of conventional cyanidation of a head sample without grinding. In this case the [CN] was 1 g/L, as used in the vat-leaching process at GOR. No grinding was performed and no $H_2O_2$ was used. This process simulates an agitated tank for a period of 72 h.

Gold recovery resulted in 56.3%. The carbon adsorbed 91.8% of the gold in solution, as determined by comparing the gold in solution before and after the introduction of the capsule.

### 5.3.4 Test 2 – Cyanidation of concentrate – the resilience of the activated carbon

This test aimed to verify the results of simultaneous grinding and leaching of the concentrate in the ball mill with a capsule of activated carbon introduced at the beginning of the process. The initial [CN] was 2.00 g/L. The processing time was 72 h, to verify the influence of such long grinding time on the activated carbon. The pH was controlled between 10 and 11 with lime.

Although there was no direct contact between the grinding balls and the activated carbon, the carbon was partially ground inside the capsule by friction. This was evidenced by the presence of a black smudge similar to coffee powder left behind after the capsule was removed. This loss was not noticed in the first 24 h but after 36 h it became evident. Considering the rotation of the mill, of 31 RPM, after 48 h the PVC capsule had been subjected to 89,280 internal tumbles, and this stress caused partial disintegration of the carbon. At the end of the process, the net carbon loss was estimated in 11.2%, resulting in an unnecessary loss of gold to the tailing. Subsequent tests did not leave the PVC capsule in the ball mill for longer than 24 h. For longer leaching tests, the capsule was added during the last 24 hours of the test. Gold recovery was 79.6%.

### 5.3.5 Test 3 – Conventional cyanidation of concentrate

The objective of this test was to observe the effect of conventional cyanidation of the concentrate without grinding, simulating an agitated tank. The [CN] concentration was 1 g/L, and the leaching time was 72 h. This test simulates an agitated tank.

Gold recovery stabilized after the first 12 h (82.4%), with peak at 48 h (87.7%). The small decrease after 48 h (84.7%) may be a case of re-adsorption of gold or simply a problem with the sampling. The carbon capsule adsorbed 93.0% of the gold in solution.

### 5.3.6 Test 4 – Simulation of agitated tank with previous grinding

Test 4 used conventional [CN] as described in Test 3, however, the concentrate was ground previously for 2 h without cyanide. After grinding, the balls were removed, and NaCN and the capsule with carbon were inserted, simulating an agitated tank.

The concentrate was ground to 80% of the material passing through a 0.074 mm screen (a P80 of 200 mesh) at a pulp density of 70% of solids by mass. After grinding the pulp was diluted to 30% of solids, the balls were removed, the pH was adjusted to 10.5 and the leaching was initiated.

The initial [CN] was 2.0 g/L, using 4.7 g of NaCN per kg of gravity concentrate. The preparation of the PVC capsule with activated carbon followed the same procedure explained for Test 3. Samples of solution were collected every 12 h. The [CN] dropped drastically in the first 12 h, requiring addition of NaCN and lime to adjust the process. The effective consumption of CN was estimated as 3.1 g/L.

Gold concentrations in solution were as low as 0.03 mg/L, indicating rapid adsorption on the carbon. Gold recovery reached 97.8% after 72 h. As there were no balls in the mill, no significant carbon loss was observed. After 72 h the mill had rotated 133,920 times (31 RPM) and the capsule remained positioned at the bottom part of the mill.

The leaching time was longer than expected. The gold particle size is one of the most important factors affecting leaching time. Study by Veiga et al. (2009) working with ore from ASGM in Indonesia has shown that gold recovery after 2 h of grinding and 8 h of leaching reached 93.0%, and artisanal miners in Ecuador using agitated tanks took 31 h to obtain the same results (Veiga et al., 2009). This provides an indication on how grinding can accelerate the leaching process. In Test 4 an equivalent recovery was obtained only after 60 h. As both pH and [CN] were controlled in the process, the most probable cause of a higher time is the presence of coarse gold in this particular sample. An alternative to handle this problem is by removing the coarse gold of the concentrate prior to cyanidation.

### 5.3.7 Test 5 – Intensive cyanidation without grinding

The objective of this test was to observe the effect of the intensive cyanidation on the gravity concentrate without grinding. The concentrate was submitted to leaching with cyanide concentration of 20 g/L NaCN, using $H_2O_2$ and processing for 24 h. A solution of $H_2O_2$ 0.3 g/L was added to the pulp at the beginning of the process. The balls were removed from the mill, and a clean solution was collected every 12 h. The capsule of activated carbon was introduced only after the first 24 h, and stayed in solution for 3 hours. This whole cycle took 27 h, with 24 h for leaching and 3 h for carbon adsorption.

Gold recovery based on gold in solution was 84.1% after 24 h and based on difference of grades before and after cyanidation was 85.8%. The efficiency of the carbon adsorption was 95.7%, comparing the gold in solution before and after the introduction of the capsule with carbon.

### 5.3.8 Test 6 – Intensive cyanidation after grinding

The objective of this test was to observe the effect of the intensive cyanidation on the concentrate after grinding aiming to liberate the gold particles. The concentrate was previously ground for 2 h (P80 < 200 mesh) with a high concentration of cyanide before the capsule of activated carbon was introduced. All other conditions were kept as in previous tests.

Gold recovery based on gold in solution was 98.0% after 24 h and based on difference of grades before and after cyanidation was 97.0%. The efficiency of the carbon absorption was 97.4%, comparing the gold in solution before and after the introduction of the capsule with carbon.

The difference in gold recovery between 12 h (96.8%) and 24 h (98.0%) was not significant. This test confirms the importance of grinding for gold liberation and exposure of gold particles to cyanide. As both tests 5 and 6 were performed in the presence of $H_2O_2$, the difference in gold recovery can be attributed to previous grinding. Table 5-4 summarizes the results of Tests 1 to 6.

These results show that process 6 is promising for the GOR site. The intensive cyanidation results in high recovery in 12 h (96.8%). The capsule of carbon should not be introduced at the beginning of the process to avoid carbon destruction by friction.

Table 5-4 – Summary of gold recoveries of tests 1 to 6

| Test | Description | Au Rec. (%) in 24 h | Au Rec. (%) Total time (h) | Main finding |
|---|---|---|---|---|
| 1 | No grinding and conventional leaching of head sample | 53.96 | 56.28 (72 h) | Low recovery after long leaching time |
| 2 | Simultaneous grinding and conventional leaching concentrate | 61.17 | 79.60 (48 h) | Capsule of carbon leaks if left more than 24 h, losing Au to the tailings |
| 3 | No grinding and conventional leaching of concentrate | 85.25 | 84.66 (24 h) | Reasonable gold recovery, low leaching time, stable after 12 h |
| 4 | Previous grinding and conventional leaching concentrate | 57.02 | 97.83 (72 h) | High recovery, but long leaching time |
| 5 | No grinding and intensive cyanidation of concentrate | 84.06 | 84.06 (24 h) | Reasonable gold recovery, low leaching time, stable after 12 h |
| 6 | Grinding and intensive cyanidation of concentrate | 97.97 | 97.97 (24 h) | High recovery, low leaching time, stable after 12 h |

At Garimpo Ouro Roxo, mercury in the tailings is not uniformly distributed as miners used a mix of traditional concentration with carpeted sluice boxes and whole ore amalgamation using copper plates, but the average concentration was found to be 0.1 g of Hg/t. The pilot plant was preliminary developed to recover residual gold from tailings, and the residual mercury in the tailings has always been a concern, as it may react with cyanide. The gravity tests have shown that only 17.1% of mercury was retained with the gravity concentrate in the centrifuge. This low concentration may have different reasons, but it is most likely that mercury is associated with very fine suspended particles and it is carried way with the centrifuge tailings.

The analyses of the tailings of the ball bill after cyanidation of concentrates have shown that 62.5% of mercury in the concentrate (10.7% of the total mercury entering the centrifuge) was adsorbed into the charcoal and the 37.5% residual mercury (6.4% of the total mercury entering the centrifuge) was disposed with the final tailings. In the event of mercury cyanide formation in the leaching process, the amount of mercury exposed to cyanide was reduced more than 5 times after gravity concentration, compared to the current vat-leaching method.

### 5.4 Conclusion

Despite the opposition to cyanide from some environmental groups, it has proven to be a practical lixiviant for gold, affordable to ASGM, not persistent to the environment, and safe if it is handled by trained people (Hilson and Monhemius, 2006).

The results of tests in Garimpo Ouro Roxo have shown that the intensive cyanidation (NaCN 20 g/L + $H_2O_2$) in a ball mill reduces the leaching time considerably. While the current vat-leaching process at GOR takes over 20 days per cycle, the new process requires less than 24 h. Intensive cyanidation has proven to be effective resulting in gold recoveries from concentrates of up to 98%. However, gravity concentration recovered only around half of the gold, indicating room for improvement, either by using centrifuges in series or by implementing a separate operation, such as flotation. Although the final gold recovery (97.97% of 50.0%) is equivalent to the existing gold recovery of vat-leaching (50.0%), the main advantages of the new process are the significant reduction of time, operating cost, chemicals and environmental impacts.

With a concentration ratio varying from 1/500 to 1/700, the cyanide consumption is reduced around 22 times, and the amount of mercury-contaminated tailing in contact with cyanide is reduced up to 700 times. Whereas vat-leaching uses 1.0 kg NaCN per tonne of material processed, the pilot plant of concentration followed by cyanidation uses 47.0 g of NaCN per tonne of material. Assuming the full replacement of the current process (vat-leaching) by the proposed concentration and cyanidation method, the annual consumption of 22,000 kg NaCN could drop to 980 kg. Furthermore, as mercury concentration is low (17%), the amount of mercury exposed to cyanide was reduced more than 5 times after gravity concentration, compared to the current vat-leaching method. The economical and environmental components of such cyanide reduction are a great incentive for the implementation of the new process. Veiga et al. (2009), comparing cyanidation of the whole ore in Ecuador with pre-concentration followed by cyanidation of concentrate, showed in the latter both the capital cost and the operating cost can be reduced between 10 to 15%. In addition, pre-concentration prior to cyanidation reduces significantly the amount of tailings to be treated at the end of the process. More detailed economical studies currently in progress have shown that diesel consumption and labour are also reduced with the new process. The proposed method can be adapted for different artisanal mining sites according to mineral characteristics, location, and investment capacity of the owners. The pilot plant is transportable, which allows its reinstallation at new sites where tailings may be available for reprocessing.

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# CHAPTER 6 – POLICY AND REGULATION FOR ASGM[5]

## 6.1 Introduction

### 6.1.1 The artisanal gold mining sector in the Brazilian Amazon

The limits of the legal Brazilian Amazon area were established in the law nº 1.806, in January, 06th 1953, and since then this area has been redefined by successive complementary laws. In total (including forest, savannas and swamps), the Brazilian Amazon area is 5.09 million $km^2$, which is around 60% of the Brazilian territory, of which 3.85 million $km^2$ remain forested (INPE, 2008).

Although the deforestation rate in the Amazon has shown some retraction in the recent years, the rate of deforestation is still alarming. According to INPE (2008), the annual deforestation rate has varied from 27,400 $km^2$ in 2003 to 10,000 $km^2$ in 2007. The accumulated deforested area reached 732,000 $km^2$ in 2008, which corresponds to almost 16% of the original forested area. The escalation is evident, when it is considered that until 1980 the deforested area of the Brazilian Amazon was below 300,000 $km^2$ (6% of total area) and it has almost tripled in less than 30 years. This represents an average of 24,000 $km^2$/ annum.

The main environmental impacts in the Amazon encompass deforestation as well as soil and water contamination, as a result of a realm of anthropogenic activities involving logging,

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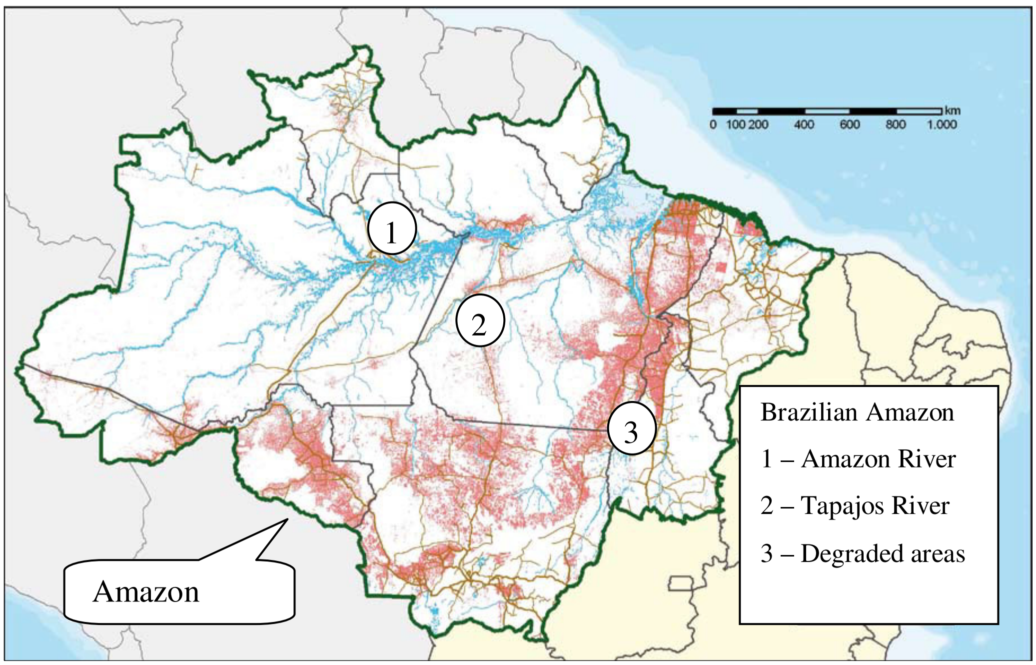
farming, disorganized occupation and ASGM (Artisanal Small-Scale Gold Mining). This study focuses on impacts resulting from ASGM and analyses the policies and legislation in this area.

In the Amazon, the ASGM activities take place in very sensitive ecosystems such as river beds and river banks. When a gold deposit is depleted, miners simply abandon the area and move to another location. The main causes for the abandonment of artisanal mining sites in the Amazon are: 1) the depletion of easily extractable ores; 2) miners disorganization and transience that leads to breakdown of operations; 3) misconceptions of the legislation and regulations; 4) externally induced and internally created financial barriers; 5) lack of government or civil society support and services. The main consequences of abandonment include mercury contamination, contamination of biota, environmental degradation, human health impacts, and degradation of socio-economic conditions. This scenario makes deforestation, in addition to mercury contamination and siltation of rivers, one of the the most relevant environmental issues to be considered when studying and planning interventions in the ASGM sector in the Amazon (Veiga and Hinton, 2002)

Since 1953, when the Amazon as a political region was officially created, the socio-economic and environmental problems associated with ASGM have been poorly addressed by Brazilian development policies. Despite considerable political discourse and the creation of many environmental laws, the public authority has remained distant from the ground for many years (Procopio, 2008). Considering the scale of the issue, the government has never put relevant effort into formalizing ASGM. To this day, the approach towards formalization has been the creation of laws rather than technical and social assistance. Hilson et al. (2007) points out that “formalization speaks not only to the presence of legislation, but to the activation and enforcement of it by authorities and the extent of their success." In addition, both domestic and international press have demonised ASGM without pointing out the root causes of problems or benefits and opportunities. This has coloured the public opinion and influenced policies, which are generally developed in far away cities without consultation with miners. Figure 6-1 shows the map of deforestation of the Amazon to date.




*Source: PAS (Sustainable Amazon Plan) (2008)*

Figure 6-1 – Map of the Brazilian Amazon indicating deforestation

This study discusses and analyzes the main policies and legislation affecting ASGM in the Amazon, particularly in the Tapajos River Basin. The main weaknesses of the existing laws related to ASGM activities, the reasons for their ineffectiveness, and recommendations for improvements are given.

### 6.1.2 The principle of “Lei para Ingles ver”

For non-Brazilians, in order to understand the policies and legislation surrounding the environmental and ASGM issues in the Amazon, it is necessary to understand a very curious Brazilian popular expression called “Lei para Ingles ver”. The translation to English could be something like “just for the Englishmen to see”, meaning “to do something just for show" or "just for the sake of appearances". According to Gurgel (2007), this expression dates back to the end of the traffic of slaves, as it was promoted by England in the mid 19th century. England and Brazil had signed a treaty in 1831, according to which the Brazilian government had to patrol its coasts in order to control the traffic and arrest the ships trying to bring in more slaves to the country. The Brazilian government was only half-heartedly doing its part, as it had a clear interest in keeping the slave business going, and out of British control. So, the patrolling was often fictitious and ineffective, but enough to keep the British partners calm with the agreement.

Almost two hundred years later, the Brazilian government still produces many laws that may be well intentioned but are not enforced meaningfully and so, to some degree, serve to keep appearances, to follow protocols and create the impression that appropriate governance is occurring. ASGM is a good example of this systemic problem in governance that occurs in many other countries beyond Brazil that have ASGM communities. Without proper preparation, education and enforcement, laws related to ASGM cannot be effectively applied and may in fact be obstacles to progress. As an example, the Law 97507/89 forbids the use of mercury and cyanide without previous licensing, which to a developed world citizen may seem like a reasonable law, however a recent survey in the Tapajos Region showed 99.3% of miners using mercury or cyanide without any permit (Sousa and Veiga, 2009). So, what is the use of a law when 99% of its constituents do not have the capacity or/and motivation to abide by it?

The introduction of this concept before the introduction of the main legal framework affecting ASGM as a whole is very important as some other examples are presented in the following sections.

### 6.1.3 The authorities in charge of the environmental and mining policies

The Brazilian environmental legislation is quite complex, sometimes inconsistent and the jurisdiction of different local environmental agencies is not clear. According to Milare (2009) in the past decades a set of environmental regulations were created but there is low integration among them, as they are scattered and lack consolidation.

The main framework of the environmental legislation relies on an administrative arrangement under the umbrella of the SISNAMA (National Environment System), composed by organs and agencies of the Union, the States, and Municipalities. In the SISNAMA, at the federal level, the main players are the MMA (Ministry of Environment - Secretary of Environment), responsible for the formulation of environmental policies, the CONAMA (National Environment Council), a consulting organ for the federal government on environmental policies and the IBAMA (Brazilian Institute for the Environment and Renewable Natural Resources), that implements the government’s policies and procedures for environmental protection (Ribeiro, 2006).

According to Procopio (2008), IBAMA (Brazilian Institute for the Environment), the agency in charge of implementing the environmental policies for the Amazon, has more employees, including Forest Engineers, working in Brasilia's offices than in the entire Amazon (which is 7 times the area of France). According to FNAP (2007), IBAMA has 1,400 employees in 64 million ha of parks and reserves, which represent 1 employee per 50,000 ha, including administration. In addition to the lack of personnel and a questionable distribution, the lack of vehicles and supporting material also exacerbates the limitations of the agency to perform its roles.

From the mining side, the organizational structure is headed by the MME (Ministry of Mining and Energy), involving the SMM (Secretary of Mines and Metallurgy), the DNPM (National Department of Mineral Production) and the CPRM (Mineral Resources Research Company). The SMM main role is to formulate and to coordinate policies of the mineral sector and to supervise its execution. The DNPM main roles are to promote planning and mineral exploration, to supervise geological and mineral research and to ensure control and inspection of mines (DNPM, 2010). The CPRM's main role is to generate and promote the geological and hydrological base knowledge (CPRM, 2010). Another important agency, the CETEM (Mineral Technology Centre), is an institute of research under the umbrella of the Science and Technology Secretary. CETEM's main role is to promote technological development for the mineral sector (CETEM, 2010). CETEM was an important partner of the GMP (Global Mercury Project) during the first phase of the project from 2002 to 2005 (GMP, 2010).

The environmental requirements created by the legislation aimed to harmonize the economic development with the protection of the environment. In this respect, mining activities are considered potentially polluting, and require licensing. According to the Federal Decree

99.274/90, all polluting companies must have permission from the government authorities in order to operate (Milare, 2009).

The Federal Constitution of 1946 created the first mechanisms to implement the economic development of the Amazon, promoting extraction, farming, livestock and mining (PAS, 2008). This was the first attempt to develop a consistent policy for the natural resources of the Amazon. In 1953 the government created the SPVEA (Superintendence for the Economic Plan of the Amazon) the first agency to coordinate the development of the Amazon. Later in 1966 the SUDAM (Superintendence for the Development of the Amazon) was created to develop and implement policies to the Amazon (SUDAM, 2010).

The policies of regional development have always had the objective of stimulating the expansion of the economic activities and occupation. From 1964 to 1982 Brazil was ruled by military government and the national sovereignty and occupation of the Amazon were seen as major priorities, as Brazil has always feared foreign domination. One of the official slogans of the military government of the 1970s was "Integrar para não entregar" ("Integration to avoid giving it away") but essentially the message was "use it or lose it" (Oliveira, 1988). The military government made a determined attempt to consolidate the Brazilian control of Amazon by opening roads through the jungle to occupy its interior.

In this period the Amazon had the first major highways such the Trans-Amazon and other roads connecting the cities of Brasilia (Capital of Brazil), Belem, Cuiaba, Santarem and Porto Velho. Public land occupation was characterized by conflicts with aboriginals, absence of public power and lack of consideration to human rights and environmental issues (LonelyPlanet, 2010).

### 6.1.4 The mining licensing process

According to Barreto (2001 and 2003), there are different mineral claim procedures defined in the laws, based on the economic importance, mine type and the type of permit: exploration permit, mining licensing, industrial mining license, and "garimpo".

*Exploration permit:* this is granted for mineral exploration projects before the mining license, by the DNPM to companies or individuals legally enabled to comply with all legal requirements. This permit cannot be applied to "garimpos" as there is specific permit for them (Garimpo license);

*Mining license:* this is granted for the operating phase of a mine, covering activities from the extraction to industrialization. This permit is not intended for "garimpos" either. There is no restriction regarding the number of permits granted to the same company.

*Industrial minerals license:* created especially for quarries, sand, gravel and other industrial minerals used in civil construction. It is a simplified license created in 1978 (Law n° 6567/78) and it may be used only by the owner of a property or by someone authorized on the owner's behalf. It requires license and permit from the municipal authority and from DNPM, and an environmental license from the State environmental authority. It is limited to 50 ha.

*Garimpo license:* it is used for soil, river, and deposits of gold and other minerals (diamonds, iron, manganese, mica, quartz, precious stones, etc). According to the Law 7.805/89 the extraction of mineral substances without the proper mineral permit is a crime subject to a maximum of 3 years of imprisonment and other penalties. This license is called PLG ("Permissão de lavra garimpeira")

In order to grant licenses for mining (including PLGs), DNPM requires the applicant to get an environmental license. In the State of Para these licenses are granted by SECTAM. According to Sirotheau and Barreto (1999), there are basically 3 types of environmental licenses granted for different phases of implementation and operation: 1) *Previous License (LP):* it is requested in a preliminary stage of the undertaking planning and feasibility studies; 2) *Installation License (LI):* it is requested on the development of the project, including the construction and extraction of raw materials for preliminary tests, and when the environmental controls are in place; 3) *Operation License (LO):* it authorizes the company to start operations keeping environmental controls in place.

According to Guimaraes (2004), in order to legalize a "garimpo" in the State of Para, the Law 7.805/89 requires the following steps:

- To get the permit from a municipal authority if the deposit is located in urban area.
- To get the previous environmental license (LP) from SECTAM.
- To request a garimpo license from the federal mining agency (DNPM).
- To implement the conditions that DNPM may determine to grant the permit.
- To get an installation license (LI) and an operation license (LO) from SECTAM.
- To present both the installation and operation licenses (LI and LO) to the DNPM in order to have the "garimpo permit decree" published in the official gazette.

### 6.1.5 Legislation addressing mine closure and rehabilitation of degraded areas

The Federal Constitution (1988) establishes that whoever explores mineral resources has to reclaim the degraded environment to a condition accepted by the public authorities. This is called "the polluter-pay principle", whereby non-compliance subjects the transgressors to penal and administrative sanctions independent of the requirement to repair the environmental damages (Jurisambiente, 2009).

There is no systematic survey at the national level regarding the environmental liability left by abandoned or orphan mines and the potential risks associated with these mines. Legislation approaching mine closure is relatively a new topic in Brazil and the plan of reclamation has been demanded from companies since the issuance of the environmental license in the early stages (Lima et al., 2006). The legislation makes no exception for "garimpos" in terms of reclamation, however authorities have not enforced it.

The decree nº 97.632 from Apr/10/1989 created the obligation of a mine reclamation plan called PRAD - Plano de Recuperação de Áreas Degradadas (Degraded Areas Rehabilitation Plan). This is an integral part of the EIA (Environmental Impact Assessment).

## 6.2 Materials and methods

### 6.2.1 Environmental legislation addressing the mineral resources and ASGM

The main legislation addressing the use of mineral resources and artisanal mining are presented and analyzed here. According to Ribeiro (2006), Brazil has a wide-ranging system of protected areas, which form part of the National Protected Areas System (SNUC). The 1965 Brazilian Forest Code, Law n$^{o}$ 4.771, defined two categories of protected forests:

- Legal Reserves: it is required that in the legal Amazon (except in Savannas regions) every property keeps at least 80% of the land to be covered with the natural vegetation. These limits are 35% for the savannas and 20% for the rest of the country;

- Permanent Preservation Areas: it depends on definitions based on key geographic watershed features such as divides, riparian areas, hilltops and steep hillsides.

While the forests that make up a legal reserve may be managed for timber production, although never clear-cut, permanent preservation areas are untouchable. Violations to this law are defined as crimes against the environment subject to both penalties and imprisonment. The Brazilian Law 6.938/81, known as the National Environmental Protection Act, did much more than establishes a contemporary environmental policy framework. It has provided the foundation of a strict liability standard for environmental damages. This law defines as crime subject to imprisonment all conducts that pose serious risks to human life or health, or to the environment, even when covered by a valid permit. The 21 main laws and standards that affect ASGM for the purpose of this study, emphasizing the Tapajos Region, are listed in Table 6-1 along with further explanation.

Table 6-1 - Summary of main legislation affecting ASGM in the Amazon (Tapajos)

| # | Legislation Code | Short Description |
|---|---|---|
| **Laws addressing environmental protection** | | |
| 1 | Law 4.771 (Set/15/1965) | Brazilian Forest code (areas of preservation) |
| 2 | Law 6.902 (Apr/27/1981) | Areas of environmental protection |
| 3 | Law 9.605 (Feb/12/1998) | Law of Environmental Crimes |
| 4 | Law 5.197 (Jan/03/1967) | Crime against fauna |
| 5 | Law 6.938 (Jan/17/1981) | National Environmental Protection Act |
| 6 | Law 9.433 (Jan/08/1997) | Water resources management |
| 7 | Law 9.985 (Jul/18/2000) | National System of Conservation Units |
| 8 | Resolution 369/06 (Mar/28/2006) | Exceptions to Forest Code (CONAMA) |
| 9 | PAS - Sustainable Amazon Plan (May/08/2008) | Policy to orient the legislation for the Amazon |
| **Laws addressing mining permit and mine reclamation** | | |
| 10 | Decree-Law 227 (Feb/28/1967) | Mining Code (criteria to claim mineral rights) |
| 11 | Degree 882 (Jul/28/1983) | Creates the Tapajos Mining Reserve (28,745km$^2$) |
| 12 | Law 7.805 (Jul/18/1989) | Mining Permit (Regulates the ASGM activities) |
| 13 | Resolution DNPM 178 (Apr/12/2004) | "PLG – Permissão de Lavra Garimpeira" |
| 14 | Law 11.685 (Jun/02/2008) | Statute of "Garimpeiro" (artisanal miner) |
| 15 | Law 5.887 (May/09/1995) - SECTAM | Environmental licensing - State of Para |
| 16 | Law 1.834/06 (Dec/28/2006) - SEMMA | Environmental licensing - Itatuba |
| 17 | Decree 97.632 (Apr/10/1989) (EIA / RIMA) | PRAD–Degraded Area Reclamation Plan |
| 18 | Standard NBR 10030 (ABNT – Jun/1999) | Guidelines for mine reclamation |
| **Laws addressing use of mercury and cyanide in ASGM** | | |
| 19 | Decree 97.634 (Apr/10/1989) / Resolution 32/95 | Control of metallic mercury (IBAMA) |
| 20 | Decree n° 97.507 from Feb/13/1989 | Mercury and cyanide prohibition in ASGM |
| 21 | Resolution IBAMA nº 435 from Sep/08/1989 | Use of retorts for amalgamation (96% recovery) |

Laws addressing environmental protection

- Law 4.771 (Set/15/1965) - Creates the Brazilian Forest code. It determines the level of protection for native forests and defines areas of permanent preservation and reserves. For instance, areas located between 30 to 50 meters from rivers (depending on the width) and lakes, as well as hilltops and declivities superior to 45°, altitudes above 1800 m, etc. It also requires that properties located in the Southeast of Brazil must maintain 20% of original forest. In the Amazon region, these reserves may reach 80% of the property.

- Law 6.902 (Apr/27/1981) – Creates special areas of environmental protection. Around 90% of these areas are considered untouchable and 10% can be altered for scientific purpose only.

- Law 9.605 (Feb/12/1998) – Also called "Law of Environmental Crimes", it establishes punishment and infraction for environmental crimes. Detention time can be up to 4 years and penalties vary from US$25 to US$25 Million.

- Law 5.197 (Jan/03/1967) – Institutes crimes against fauna. According to this law, it is a crime to keep in captivity, hunting and trade of native species.

- Law 6.938 (Jan/17/1981) – The National Environmental Protection Act, also called the Brazilian Environmental Policy, defines, for instance, that a polluter has to repair damages to the environment. This law also created the EIA/RIMA (Environmental Impact Assessment, Environmental Impact Report) preceding any major project associated with the environment. It was later regulated in 1986 by Resolution 001/86 of CONAMA (National Environmental Council).

- Law 9.433 (Jan/08/1997) – it institutes the water resources management policy. It defines water as a limited resource with economic value. It stipulates controls based on river basins; defines rights and limits of use, fees per use, classification of water bodies, water management, etc. The use of water for industrial purposes without specific permit and fees constitutes a violation subject to sanctions.

- Law 9.985 (Jul/18/2000) – creates the SNUC (National System of Nature Conservation Units). It defined two categories: 1) Strictly protected areas, which include national parks and biological reserves, and 2) protected areas of sustainable use, e.g. national forests and extractive reserves. The study of Rylands and Brandon (2005) indicates the existence of 478 strictly protected areas spanning over 370,197 $km^2$, and 436 sustainable-use ones covering 745,927 $km^2$, created and enforced at both federal and state levels. These areas comprise, respectively, 4.3% and 8.8% of Brazil's territory (8.51 million $km^2$). With this law, the environmental compensation became mandatory for companies and individuals causing significant environmental impacts

- Resolution 369/06 (Mar/28/2006) – enacted by CONAMA (National Environmental Council), this resolution has introduced regulatory exceptions into the Brazilian Forest Code. This resolution oversees a wide range of situations in which the intervention or even the removal of vegetation on permanent preservation areas is imperative and strictly in the interest or for the benefit of the general public, which includes mineral resources (Ribeiro, 2006).

- The PAS (The Sustainable Amazon Plan) – policy originally created in May/2003, it was re-issued in May/2008 by the Brazilian government. The plan establishes a partnership between the 3 levels of government to solve 5 main issues: 1) sustainable production with innovation and competitiveness; 2) environmental management and land control; 3) social inclusion and citizenship; 4) infra-structure for development; 5) new standard for investment and finance (PAS, 2008).

Laws addressing mining permit and mine reclamation

- Decree-Law nº 227 (Feb/28/1967), updated by Law 9.314, of 1996 – also called the Mining Code, creates the criteria for interested parties to claim mineral rights, establishes rights, duties and regulations for the DNPM (National Department of Mining Production) to control the mining exploration in the country. It is the main regulation covering the types of utilization of mineral resources, defines concepts such as mineral and mine research, rights of miners and land owners, priority rights and areas available for mining Barreto (2000).

- Degree 882 (Jul/28/1983) – creates the Tapajos Mining Reserve ("Reserva Garimpeira do Tapajós) with an area of 28,745 $km^2$, the largest mining reserve in the country. Similar decrees created 6 other mining reserves in the Amazon, where "garimpeiros" were allowed to mine provided they attain the legal requirements (Guimaraes, 2004).

- Law 7.805 (Jul/18/1989) – Regulates the ASGM activities, creating the mining permit, issued by the DNPM (National Department of Mineral Production) to "garimpeiros" or associations. This law defines the garimpo mining permit to a maximum area of 50 ha valid for 5 years. It requires the environmental license, issued by IBAMA or the State environmental agency designated by IBAMA. In the State of Para, the agency is

SECTAM (Secretary of Science, Technology and Environment of the State of Para). According to this law, operating without a license is a crime.

- Resolution nº 178 (Apr/12/2004) – DNPM establishes criteria and procedures for artisanal miners to require the mining permit (called "PLG – Permissão de Lavra Garimpeira").

- Law 11.685 (Jun/02/2008) – Statute of Garimpeiro. This law creates rights and duties for "garimpeiros". They have the right to mine provided they comply with Decree-Law nº 227 (Feb/28/1967) – "Reserva garimpeira" and law 7.805 (Jul/18/1989) – "Mining permit". This law requires that artisanal miners reclaim the areas they degrade. It also determines that people under 18 are not allowed to work in ASGM.

- Law 5.887 (May/09/1995) – It regulates the environmental licensing by the State of Para issued by SECTAM (Secretary of Science, Technology and Environment). It determines that every individual or organization conducting business that can affect the environment, including ASGM, must hold a valid environmental licence (SECTAM, 2010).

- Law 1.834/06 (Dec/28/2006) – It regulates the environmental licensing of Itaituba Municipality issued by SEMMA (Secretary of Mining and Environment of Itaituba). It establishes the environmental policy of Itaituba, including "garimpos". SEMMA is working on an agreement with SECTAM for the delegation of authority in environmental licensing (SEMMA, 2006).

- Decree 97.632 (Apr/10/1989) – It complements the Law 6.938/81 and creates the plan for mine closure, instituting the "PRAD – Plano de Recuperação de Area Degradada"

(Degraded Area Reclamation Plan). Mine companies are required to prepare and implement this plan, which is approved by the regional environmental authority.

- Standard NBR 13030 – these guidelines issued by the ABNT (Brazilian Association of Technical Norms) show the main components of a mine reclamation plan, including description of the area, environmental diagnosis, environmental impacts, the main activities in order to ensure proper reclamation, monitoring and controls.

Laws addressing use of mercury and cyanide in ASGM

- Decree n° 97.634 from Apr/10/1989 and Resolution IBAMA n° 32/95 - controls the production, importation, and commercialization of metallic mercury. These laws require that all establishments importing metallic mercury must be registered with IBAMA. The importers should notify IBAMA prior to every importation. The same law requires every mercury trader in Brazil to send to IBAMA the "Documento de Operações com Mercúrio Metálico" (Metallic Mercury Trade Report). Through this report IBAMA hopes to keep track of mercury in the country.

- Decree n° 97.507 of Feb/13/1989 – prohibits the use of mercury and cyanide in "garimpos", unless it is permitted by the legal authority.

- Resolution IBAMA n° 435 from Sep/08/1989 - determines the use of retorts when mercury is authorized to be used for gold amalgamation and requires that the minimum efficiency of 96% (mercury recovery) is achieved. IBAMA determines that retorts must be registered, and according to the resolution, retorts with mercury recovery below 96% are subject to interdiction by IBAMA.

## 6.3 Results and discussion

Despite these laws and plans, actions on the ground to reduce environmental impacts and support technological innovation in ASGM are still not evident. According to Oliveira (2005), Brazil is one of the few countries in the world that have characterized damages to the environment as a crime (Law of Environmental Crimes, n$^{o}$ 9.605 from Feb/12/1989), by extending not only financial but also penal sanctions to corporate entities and individuals. However, one of the main criticisms of this legislation is its frugal application. In other words, transgressors are not discouraged by stringent legislation if chances of getting caught are almost null. The laws that made environmental crimes punishable are not enforced, and in rare occasions a violator is arrested. The imprisonment time is generally no longer than a couple of hours or a few days, as the law offers many subterfuges or loopholes for lawyers.

At this point, non-Brazilian readers have probably got a bit of the grasp of the expression "Lei para Ingles ver" (Just to remind, "for the sake of appearances")

If ASGM is expected to operate legally, legislation must be at least even-handed in allowing miners access to suitable land for prospecting activities, and the permitting process must be accessible to miners as well (Hilson, 2005). The problem is that most governments in developing countries are not prepared to tackle the problem effectively (Hilson and Vieira, 2007). Sousa and Veiga (2009), reporting from the GMP (Global Mercury Project) work in 141 "garimpos" in the Tapajos region, concluded that 80% of miners using mercury did not use retorts or any other kind of protection against mercury emissions, and none of the few retorts used could recover more than 96%, as required by the Resolution 435 (Sep/08/1989). These authors also reported that 99.3% of miners in these "garimpos" (visited from 2006 to

2008) had neither an environmental license nor mining permit as required by Law 7.805 (Jul/1989). This number is consistent with the studies of Barreto (2003), which found that around 90% of artisanal mines in Brazil are illegal. Barreto (2003) defines as illegal the mines that do not attain requirements of mining permits, environmental licences and are not formally registered as a business in the terms of the law.

Despite the relative success of the GMP in promoting the use of retorts (use increased from 20.3% before intervention to 41.2% after intervention in the site of the study, covering 4,200 miners (Sousa and Veiga (2009), it was not practical to pursue the level of 96% efficiency as required by IBAMA (Resolution 435 Sep/08/1989) for field retorts. The GMP research concluded that in a location where the use of retorts was extremely low (20%), any retorts, including the home made ones, were better than no retort at all. The retort promoted by the GMP, as mentioned in Sousa and Veiga (2009), had an efficiency of 90% according to tests performed by the local supplier ("CIMAQ da Amazonia"). Moreover, the fume hood developed by the USEPA (United States Environmental Protection Agency), as also described by Sousa and Veiga (2009), presented an efficiency of 80%, as demonstrated by Habegger et al. (2007).

According to Mathis (2003), studying the mining community of Creporizinho on behalf of the GMP, only 61.3% of the miners had personal identification documents. In other words, they do not exist officially. Most of them (58.1%) had never had any contact with any government representative, except from agents from SUCAM (Superintendence of Health Campaigns – Malaria Control).

In the Tapajos River Basin, the GMP study area, when comparing the legal requirements with compliance in the field, it is clear that a wide gap exists between the intention of the law and reality. Enacting new laws, without enforcing the existing ones, has been the government's preferred approach to deal with the environmental issues and mercury is only one of these examples.

In the last decades, the use of jargons such as "sustainable development, green technology, clean process, chemical-free, etc" became almost a mandatory fashion in most laws and policies addressing the environment. The term sustainable development has become highly ambiguous, with different meanings, but supporting a vast array of arguments and decisions (Hilson, 2003). It seems that regulators in developing countries are rapidly influenced by the concepts created in the developed world, which may lead to some unrealistic laws in developing countries.

To reinforce the idea of the distance between some environmental laws and compliance, the State of Para approved the Law nº 6.921 in Nov/20/2006 prohibiting the use of Hg for the purpose of dentistry in the State of Para. None of the dentists inquired by these authors in the region has ever heard about this law, in effect since Jan/28/2007 and according to the Regional Association of Dentists in Belem they do not provide orientation to their members to eliminate the use of mercury.

In October 2009, in an effort coordinated by the UNEP (United Nations Environmental Program), many countries took the first significant steps towards a legally binding treaty to control mercury pollution at a global level. The treaty recommends the gradual ban of mercury use to complete elimination by 2013 (Zeromercury, 2010). It is difficult to predict how this treaty will affect the ASGM worldwide, but even in the event of mercury being smuggled into Brazil, the price is expected to increase and it is possible that miners will pay more attention to recycling. According to COMTRADE (2010) Brazil imported 38 tonnes of metallic mercury in 2009. Currently, while international price of mercury is around US$17-18/kg (Metalprices.com, 2009), in the ASGM sites in Brazil it reaches US$200-250/kg (Telmer and Veiga, 2008).

Mercury use in the ASGM has been highly debated in international forums, but actions in the field have not been proportional with the office decisions. In the last 20 years the overall expenditures on regulations, studies, publications, debates, conferences and meetings on mercury pollution from ASGM is far higher than the amount of resources invested in practical solutions (Veiga and Hinton, 2002). This also indicates that there are more professionals and experts making their living from exploiting the problem than the amount of people focusing on effective solutions for the miners. This includes national and international agencies, government officials and regulators that invest millions in monitoring programs without offering realistic solutions for affected communities. According to Hilson (2007), "many individuals who have been entrusted to resolve the sector's policy problems are not seeking to develop amicable solutions, but rather working toward maximizing project work and fulfilling their own profit-driven agendas".

The PAS (Sustainable Amazon Plan) proposed by the government in 2008 (PAS, 2008) acknowledges that the current legislation and mining policies have been inadequate to address the problems generated by ASGM. According to the PAS (2008) the control of ASGM fails due to a combination of lack of government infrastructure and political willingness to deal with the situation and enforce the Law nº 7.805/89, which regulates the ASGM in the Amazon and requires both environmental and mining permits.

As the “garimpeiros” cannot comply with the requirements and governments do not have mechanisms to enforce the law or remove thousands of people from their work without offering a better alternative, the illegality has been “tolerated”, as literally mentioned in the PAS (2008).

Another example of this inconsistency was experienced by the GMP (Global Mercury Project) when proposing a partnership work with IBAMA in 2006. At the time, the proposed partnership involved the training of miners to improve their processes and use mercury safely. IBAMA officials declared that they could not be involved in training illegal people, since miners did not have their permits. In the view of those officials, miners should legalize first, in order to be trained later.

The disorganized and uncontrolled reality of ASGM in Brazil provides evidence of the inefficiency of the laws and policies. For instance, the PAS (Sustainable Amazon Plan), republished in 2008 is in its essence the same policy issued earlier in 2003, and no major transformation was observed in the field in 5 years.

### 6.3.1 Environmental licensing and mining permit

The environmental license and mining permit are virtually inseparable as they are both requirements for legalization. Most miners are not familiar with the paper work and only a few hire agents and consultants to obtain the legal status. Mineral exploration reports, environmental impact assessments, etc and supporting documents such as maps, property titles, etc are the main hurdles to miners, not only because of the cost but the ownership of lands and mineral titles in the Amazon have been a complex topic.

Another important limiting factor in this process is the ability of the government agencies in speeding up the process. The official agencies (IBAMA, DNPM, SECTAM, SEMMA), in order to grant permits, are supposed to analyze the documents and inspect the situation "in situ". At this point, limitations arise such as the lack of personnel, lack of funds for traveling, etc. Many of these applications can be accumulated in the offices for a long period of time. For example, in 2006, "garimpeiros" from the municipality of Itaituba only had applied for 17,903 garimpo permits ("PLGs"), of which only 12 had been approved in that year. The DNPM is in charge of inspecting these "garimpos" and at that time the DNPM office in Itaituba had been shut down. The applications had to be analyzed in the State Capital, Belem. According to DNPM (2010), in 2008 alone, 29,888 garimpo permits were requested all over Brazil and only 106 had been approved.

Furthermore, the DNPN Resolution nº 178 from Apr/12/2004 establishes that in order to approve a PLG, a field inspection "may or may not" be carried out at the DNPM discretion. In the case of need, it is done at the expenses of the applicant. This is becoming a common trend in some other areas of public services in Brazil, where the onus of inspection has been transferred to the applicant, in addition to the regular fees paid by the applicants. This procedure helped to discourage miners from legalizing their areas and creates a conflicting situation for the inspector.

CONAMA resolution nº 369/06 (Mar/28/2006) has introduced regulatory exceptions into the Brazilian Forest Code, including situations in which the intervention or even the removal of vegetation on permanent preservation areas is of interest to the general public. Such enactment was, in part, the acknowledgement of the government's lack of capacity to enforce the law as it was originally. This resolution "allowed" the "garimpo" into permanent preservation areas. This was a legal accommodation of an awkward situation as miners have been working in these areas for over 40 years. According to the resolution, the exploration and exploitation of mineral resources in permanent preservation areas can be granted by the appropriate authority. This was recognized by the Brazilian government to be of public utility. According to Ribeiro (2006), this represented one of the first tangible steps to insert artisanal gold mining into the formal economy and to have it properly included in local and regional development plans. This may represent an opportunity for miners to have access to credit and other benefits, which was inaccessible before due to illegality. However, miners are still required to obtain their permits for mining in legal reserves, and respect the environmental regulation applicable to water bodies, soils, use of mercury and cyanide, etc. Miners are also expected to reclaim areas they may degrade.

### 6.3.2 Mine closure and rehabilitation of degraded areas

As mentioned by Sousa and Veiga (2007 and 2008), cases of mine reclamation in ASGM are extremely rare. According to SEMMA (2006), no record was found to date of "garimpeiros" being demanded by authorities to reclaim their areas or of having suffered any criminal sanctions other than eventually having their machinery temporarily confiscated after one or another of the rare IBAMA operations in the ASGM in the Tapajos. A common belief among "garimpeiros" is that the only 2 things capable of stopping "garimpeiros" from working are bad weather or gold depletion.

According to Guimaraes (2004), the Brazilian government recognizes that due to technical or financial difficulties, the authorities responsible for the environmental licensing, in many cases are not capable of analyzing or even inspecting the adoption of the measures proposed to mitigate environmental impacts or to reclaim areas.

In addition, there is a massive number of abandoned artisanal mines not recorded by the authorities (Veiga and Hinton, 2002). As a rough estimate, according to Sousa and Veiga (2009), around 300 to 600 new pits with volumes varying from 10,000 $m^3$ to 50,000 $m^3$ per pit are opened every year in the Tapajos area. This does not include small pits with volume below 10,000 $m^3$. Most of these pits have never been refilled.

Further to this, most of these mines have been deactivated even before the enactment of laws that demanded rehabilitation. It is difficult to determine the environmental liability of these orphan mines and in most cases as it is virtually impossible to identify the people responsible for the degradation.

Even in the formal mining sector reclamation is not a mature process in Brazil. Lima et al. (2006) compared 20 PRADs (Degraded Areas Rehabilitation Plan) from formal mining companies in Brazil and reached interesting conclusions:

- Due to government environmental agencies' lack of human and financial resources to analyze, inspect and approve the PRADs, many processes remain on files waiting for approval for an indeterminate period of time. Yet, according to Brandi (1994), the PRADs have been seen as a mandatory document to approve the entire EIA-RIMA, but very few of them are really used by the companies to orient the field work in mine closure. According to Lima et al. (2006), it is clear that many PRADs made by consulting companies working for different clients have exhaustively used the “copy and paste” technique to elaborate their documents. In other words, the PRADs have been seen much more as a formality to comply with a legal requirement, rather than an instrument to support mine closure.

- The PRADS did not identify the interested parties in the process nor did they consider any community consultation.
- Based on most sophisticated mine closure plan, as shown more than 10 years ago by Morrey and Van Zyl (1994), these plans should also consider the analyses of risks and benefit/cost, for technical, social and environmental aspects. Uncertainties should be considered, and it seems that none of this was part of the PRADs analysed by Lima et al. (2006).
- In many PRADS there was no consideration of costs, budget or timeline. As there was no financial provision since the early stages for reclamation, there is always risk that the proper mine closure may not be accomplished in case the company faces financial problems. In this case the burden would be placed on society.
- Most PRADs assume that revegetation is a synonym for mine closure, and very few considered aspects of decommissioning, progressive rehabilitation, water or fauna impacts, etc. In addition, no provision was presented for actions following revegetation. In other words, it is assumed the company’s liability ceases immediately after revegetation.

The examples above show that even in the formal sector, mine reclamation laws have not been fully effective. The government limited structure to inspect the mines seems to be one of the main causes of such ineffectiveness. Compared to the formal sector, “garimpo” areas are more numerous, more remote and scattered, which makes law enforcement a more complex task for the government.

### 6.3.3 The GMP (Global Mercury Project) approach on regional legislation

Besides this complex scenario of laws, the authority and jurisdiction of the Federal, State and Municipal governments that regulate and control the activities which may impact the environment are not always clear. There are some agreements between Federal and State levels, and between State and Municipal levels. One of the main problems preventing these agreements from functioning properly is the lack of proper communication between the three levels of power and between agencies at the same level. One of the contributions to Brazil by the UNIDO/GMP to reduce this gap was the promotion of events where representatives of diverse agencies could debate the ASGM issues in light of the existing legislation and the situation in the field. The advantage of these meetings with the main stakeholders was to promote an overall integration of mechanisms to improve communications and find feasible solutions to formalize artisanal miners. The GMP advocated principles and guidelines (GMP, 2010) for the simplification of laws and above all, for more official presence in the field.

GMP explored the idea of working locally, at the municipal level, and supporting decentralization of roles from the Federal (IBAMA/DNPM) and State (SECTAM) levels to provide more power to the Municipal mining and environmental agency (SEMMA). An example of this was the formal agreement between SECTAM (State of Para Environmental Secretary) and SEMMA (Secretary of Environment and Mining of Itaituba). Through this agreement SEMMA can establish criteria and issue an environmental license for many activities undertaken within Itaituba's regional limits. Environmental licensing for mining activities is still under review, but it has produced a Municipal law n° 1.834/2006 – the Itaituba Environmental Code (SEMMA, 2006). This may allow more presence of officials in the field.

The GMP proposal embraced by SEMMA and discussed with DNPM and SECTAM considers replacing the conventional Environmental Impact Assessments in "garimpos" through the use of the evaluations implemented by the GMP, encompassing the 5 main objectives and the 20 performance indicators of the program as presented by Sousa and Veiga (2009). By this proposal, a "garimpo" would have an environmental license based on the degree of conformity to its practices, and according to evaluation by the SEMMA.

This municipal law also requires that gold shops in Itaituba and its districts have fume hoods installed with filters for mercury vapour abatement. The GMP worked in partnership with the USEPA (US Environmental Protection Agency) and SEMMA to promote fume hoods in gold shops. This promotion encompassed testing new prototypes, implementing solutions, monitoring new and existing systems, training local gold shop owners on using and cleaning these filters, awareness campaigns about the fumehoods and development of a local supplier.

By the time the GMP was implemented in the Tapajos Region from 2006 to 2008, the following were some of the alternatives proposed to authorities to simplify the ASGM formalization:

- The integration of environmental and mineral licensing within a single agency which would take care of the whole licensing process. In the case of the Tapajos region, for instance, eventual conflicts between IBAMA, SECTAM, DNPM and SEMMA would be resolved through agreement and delegation among these divisions, but the miners would have a single interlocutor. Ideally, this should be at the most local level, in this case, the Municipal branch, SEMMA;

- SEMMA would receive financial support from the federal government as compensation for the transfer of responsibilities and in order to equip and train its personnel properly;
- Itaituba could be a pilot project for such an initiative, and SEMMA would grant licensing to “garimpos”, analysing both the mineral rights and the environmental requirements, based on guidelines from IBAMA and DNPM. Licensing of medium size and large scale mining companies would remain as it currently is;
- The environmental licensing process should be significantly simplified. As an example, by adopting the training proposed by the GMP and proceeding with the evaluation of the 5 macro objectives and 20 indicators of performance as suggested by Sousa and Veiga (2009). “Garimpos” would receive training and would be evaluated and re-evaluated as required. The grade of the evaluations would determine the issuance of the environmental licence.
- In the GMP pilot project, the 5 macro objectives covered: formalization of mines; technological improvement: gold recovery; environmental improvement: protection of water and forest; safe use of mercury and cyanide plus the gradual replacement of mercury; health and sanitation improvement, as detailed in Sousa and Veiga (2009).
- In the context of “garimpos”, refilling of old pits with the tailings from a new excavation has to be seen as huge step in mine reclamation; use of retorts, regardless of efficiency,

are to be applauded; mercury recovery, reactivation and reuse, use of amalgamation pools, use of latrines, proper garbage disposal and other very simple but feasible steps cannot be undervalued or seen as insufficient environmental protective measures. These simple but practical measures can be assimilated by the "garimpeiros" and this kind of approach may represent the reasonable balance between the stringent requirement that does not work and the simple one that works better;

- The amount of paper work in this new approach is minimum compared with the current requirements, yet necessary as controls must be in place to identify the area and to keep basic records regarding training, evaluation, re-evaluation and progress tracking.
- Re-evaluation of "garimpos" and re-training of miners by SEMMA would be an annual activity, and the garimpo's environmental licence would be based on these standards;
- Incentive for mining associations and cooperatives and implementation of a microcredit project to benefit "garimpos" attaining the environmental standards under the new terms;

To this date, none of these recommendations have been effectively implemented.

## 6.4 Conclusions and Recommendations

The examples presented in this study show that some important environmental laws designed to protect the natural resources of the Amazon are stringent on paper and weak in their application and enforcement. They are derogatorily known as "Leis para Ingles ver". Although legislators usually defend the idea that the creation of laws and law enforcement are two distinct figures, for the purpose of this study these figures were considered as part of a unique integrated system. If the enforcement fails, the law as a whole is ultimately failing to produce its expected purpose.

Following an international trend, environmental legislation became more severe worldwide, but their applicability is debatable in the context of areas with a vast territory like the Amazon. As the level of compliance has been very low, in some cases negligible, it would be more beneficial to the environment if a more realistic legislation (lower level of requirements) with higher level of compliance was enacted and enforced.

In order to solve the environmental and technological problems of ASGM in the Amazon, the Government's preferred approach has been clear: enact laws, but without providing mechanisms to enforce their application. Unfortunately, this is not unique of the Brazilian government. Many international agencies also promote environmental programs with minimal effort in the field.

In this context, ASGM has been the "elephant in the room" as the existing regulatory framework has never been effective in solving the problems associated with it. The Brazilian government created reserves where artisanal miners can work. In these areas miners must obtain a mining permit which requires an elaborate environmental impact assessment. As the process and requirements are beyond the miners' capability and there is no educational program in place, most miners remain illegal. This limits them from accessing bank credit, incentives, proper training and technology.

It seems clear that the existing regulations have failed to solve or at least alleviate the environmental, technological and socio-economic problems associated with the "garimpos".

Simplification of the laws and processes is badly needed. This would make the mining and environmental legislation enforceable and compatible to the ASGM reality. Mechanisms should be implemented in the law to raise the environmental standards progressively so the ASGM could absorb them.

Most of the amendments made by the government in recent years aiming to simplify the legislation to improve compliance were cosmetic changes and have failed to succeed. Very few recommendations were made for the legislation to be modified to accommodate the miners' most crucial limitations, such as illiteracy, lack of confidence in authorities, fear of bureaucracy, etc. In addition to legislation, training, awareness and government presence in the communities are absolutely necessary. Overall, legal requirements should not be so stringent as to keep compliance at the current minuscule level, nor soft to the point they may become ineffective as environmental protection.

The principle of "Lei para Ingles ver" is getting close to its 200$^{th}$ anniversary and it is time to exterminate the bad habit. New laws should be proposed only if provisions exist to ensure their implementation. In the meantime, while Brazil creates more stringent laws and plans "para Ingles ver", the Amazon forest loses on average 24,400 $km^2$/ annum (INPE, 2008).

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## CHAPTER 7 – DISCUSSION AND GENERAL CONCLUSIONS

This study was conducted in the Tapajos Region, the most important ASGM location in Brazil, and also one of the highest concentrations of artisanal miners in the world. In this region, with the high price of gold (US$1,100/oz in Dec/2009) (Kitco/2010), gold mining is more profitable to miners than alternatives such as agriculture and livestock. Artisanal gold mining activities started around 40 years ago and it will persist for many years. As most alluvial and colluvial deposits have been depleted, miners are now mining either lower grade surficial deposits or new high grade primary quartz veins or reprocessing tailings accumulated in the last decades (Sousa and Veiga, 2009).

The main environmental problems in ASGM in the Tapajos Region are associated with mercury contamination, water siltation and deforestation. The uncontrolled use of cyanide in the last years has increased considerably the risk of environmental contamination and human intoxication. Other health and safety problems posing serious threats to miners and communities are malaria and accidents, as miners have no training and very little concern about safety issues. On the social side, ASGM is strongly associated with family disruption as miners leave their families in their original towns to seek gold. Moreover, they have very limited access to education and the overall infrastructure of the mining villages is very rudimentary.

The international price of mercury is US$0.017/g (Metalprices.com, 2009) but this can be 11 times higher (US$0.20/g) at the mining sites in the Tapajos region. Nevertheless, this is still very cheap compared to the price of gold sold by local miners (US$35/g). This indicates that even if mercury price increases, it is unlikely that this would discourage miners to use mercury to amalgamate gold, once mercury is still easily available to miners in supply stores. Mercury use in ASGM has been regulated in Brazil since 1989 (Ministry of Environment, 1989) and legal restrictions only have proven not to be a solution for the pollution problems.

At the current price of gold, it is unlikely that ASGM activities will reduce soon. According to Hilson and Banchirigah (2009), studying ASGM in Ghana, despite the attempts to implement alternative livelihoods projects in ASGM areas, most have failed to succeed. The evidence of this view is the fact that illegal ASGM activities continued to escalate after the alternative livelihood projects had been in place. Hilson (2002), approaching the future of ASGM, points out that "it is likely that governments will continue to be lackadaisical in addressing the ASGM related problems".

## 7.1 Key findings - addressing research questions

The main research questions presented in Table 1-1 were discussed in the chapters 2 to 6 of this thesis, and the main points are summarizes as follows:

**Chapter 2: Matrix of environmental impacts**

• <u>The most relevant activities affecting the environment in typical ASGM sites in the Amazon</u>

The matrix of environmental impacts allowed the classification of the most critical activities in ASGM based on the DoB (Degree of Belief) or risk they can cause significant environmental impacts. The variables that generated "substantial" (60-80%) or "extreme" (>80%) DoBs for environmental impacts (such as vegetation removal, excavation, mercury use, manual amalgamation, etc) were focused on during miner training and were monitored and controlled to mitigate their adverse impacts. The variables with “substantial” or “extreme” beneficial environmental impacts (such as mercury reactivation, use of retorts, backfilling pool for amalgamation, backfilling old pit, etc) were promoted in the program for 4,200 artisanal miners and their community members in the Tapajos Region.

- <u>The interaction among stakeholders to set the objectives of an intervention program</u>

The matrix of environmental impacts is a simple tool that can be understood by the local stakeholders (the implementing agency - GMP, government, miner’s association representatives), and can support discussions among them. This allowed a participatory process to define the main concerns to be addressed in an intervention program.

- <u>Alignment of the objectives of an intervention program with ASGM</u>

By considering the pyramid of vision, mission, objectives and goals and performance indicators as shown in Figure 3-2, the stakeholders assured that each variable addressed in the interventional program was contributing to the attainment of the objectives towards the mission.

The simplicity of the matrix process made it feasible for the miners to understand it, reduced subjectivity and increased the interested parties’ participation and commitment.

**Chapter 3: Training of miners**

- <u>Best practices for creating programs to address environmental problems caused by ASGM</u>

The best approach should involve the local community representatives and give credit to the locals for successes. As example, the GMP was known locally as "Cuide de seu Tesouro" (Take care of your treasure) and became a local trademark. The commitment of local stakeholders with the results of the intervention program was assured as they were part of the process since the beginning.

- <u>Objectives, goals, and understanding stakeholders' motivations and needs</u>

Overall, interventions must be applied where they are welcomed. When implementing intervention programs in ASGM an initial phase of introduction to miners and trust building was required. In the Tapajos program, the main stakeholders were involved in the problem formulation phase, when the mission of the program, objectives and different perspectives were considered. Government, for instance, generally prioritizes the need of legal compliance by the miners, as the latter generally prioritize gold recovery. It is useless to address environmental programs without taking into consideration the miners' motivations and needs, which are not necessarily the ones considered by the projects' implementers. It is not possible to dissociate technical and economical objectives from the environmental goals. An effective way to get miners interested in environmental issues is by providing them with solutions that improve their gold recovery and/or reduce costs. Environmental and health awareness must be introduced when the basic economic needs are addressed and when miners become confident that new proposed methods will be beneficial for them.

• Effectiveness of interventions and implementation of preventive and corrective actions

The use of balanced scorecard through measurable performance indicators has proven to be an effective way to evaluate an intervention case effectiveness. In the GMP case, the mission of the project was supported by 5 macro objectives (formalization of mines, technology / gold recovery, water protection, use of mercury, health and sanitation) and 20 performance indicators were created to address these objectives. These indicators have shown the strengths and weaknesses of the program, allowing proper decision on preventive and corrective actions. Overall, in the 141 mines evaluated, the conformity expressed by the indicators before the training program started was 22.2% (Table 3-3). The average goal was set to 40% and the overall result was 51.0% after 120 days, leading to an Absolute Improvement (AI) of 29% and a Degree of Accomplishment (DA) of 110.0%.

**Chapter 4: Rehabilitation of degraded areas**

• The extent of the impacts caused by ASGM in deforestation and water contamination

The area and volume of soil material disturbed by the miners were estimated based on gold production and grade of the deposits, which allowed the estimation of the amount of material displaced by ASGM. Around 600 large pits (with volume above 10,000 $m^3$) are open annually in the Tapajos Region, generating more than 6 million tonnes of sediments, which are generally disposed into local rivers

• Suitable techniques for miners to reclaim degraded areas

Simple techniques were implemented involving refilling old pits with the sediments of new pits, followed by natural revegetation or reforestation with native species, as demonstrated in Chapter 4. Refilling open pits is a crucial step in the rehabilitation of these degraded artisanal mines. In Garimpo Canaan, the use of triple barriers made of palm leaves was efficient to retain sediments. The loss of material (not retained by the barriers) varies according to the particles size, the slurry flow and the quality of these simple barriers. Although reforestation is not always a feasible option for artisanal miners, refilling old pits represents a significant progress in comparison to the common practice of abandonment.

- The miner's incentives to reclaim degraded areas

The demonstrated reclamation method to refill old pits is simple and does not represent significant extra costs for miners, as it can be performed with materials already available at the sites, such as palm tree leaves. The presence of government officials in the field to provide assistance to miners is fundamental for the success of the reclamation activities. In the ASGM, reclamation needs to be applied with high level of simplification. Sometimes the reclamation work is considered terminated as soon as the pit is refilled. Revegetation, however, has proven to be a viable step and for mine owners as this represents a source of fruit for local consumption and wood for future use. In Garimpo Canaan, the owner expects that his Mahogany plantation will generate future gross revenue of US$3,200/ha.annum (4 $m^3$/ha.annum).

It is easier to convince miners that reforestation not only is an environmental activity, but a profitable business involving wood, fruit, seeds and vegetal oil. Miners are more motivated by economical approaches than by the environmental appeals.

**Chapter 5: Pre concentration and cyanidation of gold**

- Miners engagement to programs addressing environmental protection

Miners embrace environmental programs if these are associated with technical solutions that improve gold recovery or reduce costs, in either case representing economical gains for them.

- Alternative technical solutions with higher chances of assimilation by miners

Any initiative in ASGM must be previously discussed and welcomed by miners in order to be sustainable. The proposed method of concentration of gold followed by cyanidation of concentrate is not the only solution but it has proved to be simple as well as technically and economically viable for ASGM. This is particularly true for those miners reprocessing tailings through heap-leaching or vat-leaching, as they already have experience with cyanide and can convert their process more easily.

The results of concentration of old gravity concentration tailings (sluice boxes) in a small centrifuge (iCon) followed by intensive cyanidation (NaCN 20 g/L + $H_2O_2$ 0.3 g/L) in a ball mill shown a considerable reduction of the leaching time. While the current vat-leaching process at GOR takes over 20 days per cycle with 50% of gold recovery, the new ball mill leaching process requires less than 24h. Intensive cyanidation has proven to be effective, resulting in gold recoveries from concentrates of up to 98%, which results in overall recovery (centrifuging + intensive cyanidation) around 50%.

• <u>Cyanide as a suitable chemical for ASGM</u>

Intensive cyanidation of concentrates in ball mill is very convenient for ASGM as the amount of material to be treated with cyanide, compared to the conventional vat-leaching, is up to 700 times less due to the previous gravity concentration. The residual cyanide can be treated with bleach or peroxide after natural degradation in a small pool before final disposal in the tailing pond.

Full replacement of the current vat leaching process in Garimpo Ouro Roxo with the proposed concentration and cyanidation method would reduce the annual consumption from 22,000 kg NaCN to 980 kg. Cyanide from local suppliers cost to the miners US$6/kg. The economic and environmental components of such cyanide reduction are a great incentive for the implementation of the new process. Both the capital and the operating costs for implementing a plant to leach the whole ore are generally higher than the costs for those processes based on pre-concentration followed by cyanidation of concentrates only. In addition, the cost of treatment of contaminated tailing is significantly reduced when only concentrates are leached. The gravity concentration plant followed by intensive cyanidation implemented in the Tapajos was well accepted by miners and other similar plants are currently being installed.

**Chapter 6: Policy and legislation**

• <u>The efficiency of mercury prohibition in reducing mercury pollution</u>

Despite the legal controls, mercury is still largely misused in the gold mines. The cost of mercury in ASGM represents less than 1% of the price of gold. When alternatives to mercury are not available, the best approach is mercury reduction through the use of gravity concentration of gold followed by amalgamation of the concentrates, elimination of copper plates for whole ore amalgamation, use of retorts to recover mercury, use of electrolytic process to reactivate and reuse mercury, and the use of confined amalgamation pools. The combination of these processes can reduce the use of mercury drastically.

- <u>The effectiveness of the existing regulations to protect the environment in the ASGM sites</u>

This study analysed the impact of 20 different regulations that affect the ASGM. Overall, the Brazilian environmental laws are very stringent but the government does not provide realistic mechanisms for miners to comply with the legal requirements. In addition, miners believe that there is no major consequence of being illegal as the government does not enforce the law properly.

In order to solve the environmental and technological problems of ASGM in the Amazon, the government's preferred approach has been clearly enacting laws, without providing mechanisms to enforce their application. Unfortunately, this is not unique to the Brazilian government. Many international agencies also promote environmental programs with minimal effort in the field

- <u>Ways to improve the current level of effectiveness / compliance with legislation</u>

Compliance with legislation is not a simple process, and involves a combination of actions. It requires the simplification of administrative processes and requirements to implement regulations in the field. It also requires a strong presence of the government in the field, providing training and technical assistance to the miners. When conditions are in place, government also has to provide capacity to enforce the law. The combination of training, awareness and enforcement is the most effective approach to increase the current negligible level of compliance with legislation.

In the light of these key findings, the main objectives of this study have been achieved. The following questions have been answered: 1) how to evaluate environmental impacts; 2) how to address prevention in an intervention program; 3) how to measure effectiveness of results; 4) how to address rehabilitation of degraded areas; 5) how to improve technology and; 6) how to address the main ASGM issues with realistic policies and regulations.

## 7.2 Recommendations on future studies and actions

Among all the studies and actions addressing ASGM, there are many more studies related to environment and health assessments than appropriate demonstration and implementation of technical solutions. Although the present study has provided relevant information on rehabilitation of degraded areas, cyanidation of concentrates and legislation, there are still many other questions to be answered.

In rehabilitation, for instance, topsoil salvation is a crucial step to assure that a layer of organic matter will be available to recap the pit when refilled with tailings. However, a viable technique to remove and save the topsoil for posterior use is still a challenging task in the field. As miners use hydraulic monitors for excavation, both topsoil and soil are revolved and mixed. Future studies should consider alternatives to separate these layers when miners open a new pit, as well as to return the topsoil when the refilling is complete.

In the pilot plant of gold concentration followed by cyanidation, the emphasis was given to gold recovery but without considering the mercury fate in this process properly. The pilot plant was primarily intended to reprocess tailings accumulated by many years of operation. In general these tailings are contaminated with mercury. When miners use vat-leaching, for instance, mercury can react with cyanide and form mercury cyanide, more toxic and more bioavailable than metallic mercury (Veiga and Baker, 2004). In the pilot plant, this risk is also present, however, due to gravity concentration, the mass of material is reduced up to 700 times, and the amount of material exposed to cyanide is reduced significantly. The ball mill tailings are treated with bleach to destroy cyanide before final disposal. As an opportunity for future study, a mercury balance should be conducted step by step in the process, and mercury should be removed from the material before cyanidation, for instance by using silver plates (Veiga et al., 2005). Although cyanidation in ball mill has shown very positive results (98% of gold recovery in less than 24 h), the gravity concentration of gold is still low (50% of gold recovery). In future studies other alternatives should be tested, which could include the use of 2 or 3 centrifuges in series, as preliminary tests in the lab have shown that a 2$^{nd}$ concentration stage can recover between 10 to 20% of the residual gold from tailings and a 3$^{rd}$ stage recovers between 5 to 10%. The decision, in this case, becomes economic, depending on the costs of the additional recovery steps and its respective benefits. In addition, flotation of tailings can be an alternative to centrifuge, or a complementary process to recover gold from centrifuge tailings.

Regarding policy and regulation, future studies should explore even more the opportunities to simplify the administrative processes to legalize artisanal miners and organize miners into cooperatives. This would also be a key condition for miners to have access to microcredit programs, allowing them to improve their technology and environmental compliance. Overall, the problems on policies and regulation for the ASGM sector in Brazil are related to lack of practical implementation. Most of the amendments to the Brazilian legislation made by the government aiming at simplification or improvement of compliance were cosmetic changes and have failed to succeed. These regulations have failed to accommodate the miners' most crucial limitations, such as illiteracy, lack of confidence in authorities, fear of bureaucracy, etc.

In addition to improvements in legislation, training and awareness campaigns for miners and the government presence in the communities are badly needed. Overall, legal requirements should not be so strict to the point that they hinder compliance. These regulations should be realistic to provide a way to miners easily understand and comply with effective environmental protection.

## 7.3 Methodological contributions and claim to originality

Each chapter of this thesis brings original contributions to research and practical implementation in the field. The matrix of environmental impacts presented in Chapter 2 represents an original approach in the artisanal mining context, and replaces conventional and more complex environmental risk assessment methodologies which are incompatible with the ASGM reality.

The use of Balanced Scorecard to evaluate and prove the effectiveness of an intervention program represents an original approach to ASGM. This tool brought clarity to the results, allowing a critical analysis of the effectiveness of the intervention, serving as a historical database of comparison and allowing the identification of opportunities to improve future programs.

The mine reclamation methods demonstrated in chapter 4 are simple and compatible with the ASGM context in the Amazon. Miners can afford to implement these simple yet effective practices if they receive proper training and incentives from government authorities. The innovation of this method is the use of barriers made of palm tree leaves to filter the tailings and retain sediments, refilling old pits, while clean water returns to the rivers. This prevents millions of tonnes of mercury-contaminated tailings to reach the aquatic system, where it can contaminate the aquatic biota.

In chapter 5, the pilot plant to pre-concentrate gold and leach the concentrate in a batch ball mill is a considerable innovation. This process uses a PVC capsule with activated carbon that can extract 98% of the gold in the concentrate in less than 24h.

Chapter 6 was devoted to discuss policies and legislation rather than proposing more legislation to resolve the existing problems. The original approach was pointing out why the current legislation does not work well on the ground and offering alternatives to simplify the requirements. This also includes supporting the miners with training and technical assistance. Simple processes and presence of the government in the field would considerably increase the miners' current negligible level of compliance with the environmental legislation.

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# APPENDIX A – LIST OF PAPERS PUBLISHED / TO BE PUBLISHED

| Chapter | Publications related to the Thesis |
|---|---|
| Chapter 2 – Evaluation of environmental impacts: the use of a matrix of E.I. | • **Sousa R.N**; Veiga M.M; Meech J; Sousa A.J. A simplified Matrix of Environmental Risks to Support an Intervention Program in a Small Scale Mining Site. Submitted to *Journal of Cleaner Production*, in Mar/2010 |
| Chapter 3 – Intervention programs in ASGM | • **Sousa R.N**. and Veiga M.M., 2009. Using Performance Indicators to Evaluate an Environmental Education Program in Artisanal Gold Mining Communities in the Brazilian Amazon. *Ambio,* 38(1): 40-46<br>• **Sousa R.N**; Veiga M.M; Frederico D.S. 2009. Sustainability of ASM in the Amazon: Shortening the gap between theory and practice (In Portuguese: Sustentabilidade do garimpo de ouro na Amazonia: encurtando o caminho entre a teoria e a prática). *Revista Meio Ambiente Industrial*. Brazil. Feb/09 - p.36-41<br>• **Sousa R. N**. and Veiga M. M, 2007. Implementing Programs to Improve Gold Recovery and Reduce Environmental Impacts by Artisanal Gold Mining in Brazil. *Proc. 31st Annual British Columbia Mine Reclamation Symposium*. Squamish, BC, Sep/2007. TP20. 10p |
| Chapter 4 – Rehabilitation of degraded areas in ASGM | • **Sousa R. N**. and Veiga M. M, 2008. Garimpo Canaan - A successful Case of Reclamation of an Artisanal Gold Mine in the Amazon. *Proc. 32nd Annual British Columbia Mine Reclamation Symposium*. Kamloops, BC, Sep/2008. TP15. 12p<br>• **Sousa R.N**; Veiga M.M; Rehabilitation of Degraded Areas in Artisanal Mining: a Case Study in the Tapajos River Basin. In Portuguese: "Recuperação de áreas degradadas pela mineração artesanal de ouro na Amazônia – um estudo de caso na bacia do Rio Tapajós". Submitted to *Revista Arvore* in Oct/2009. |
| Chapter 5 – Alternative method for gold recovery without using mercury | • **Sousa R.N**; Veiga M.M; Klein, B.; Telmer, K., Gunson A.J.; Bernaudat, L. Strategies for Reducing the Environmental Impact of Reprocessing Mercury-Contaminated Tailings in the Artisanal and Small-Scale Gold Mining Sector: Insights from Tapajos River Basin, Brazil. Accepted for publication by the *Journal of Cleaner Production*, in 19/Jun/2010<br>• Veiga, M.M, Nunes, D. Klein, B., Shandro, J., Velasquez, C., **Sousa, R.N**. 2009. Mill-Leaching: A Viable Substitute for Mercury Amalgamation in the Artisanal Gold Mining Sector? *Journal of Cleaner Production* 17(15): 1373-1381 |
| Chapter 6 – Policy and regulations for ASGM in the Brazilian Amazon | • **Sousa R.N.;** Veiga M.M.; Van Zyl D.; Telmer, K.; Spiegel, S. Selder, J. Policies and regulations for the artisanal gold mining sector. A Brazilian case study: analysis and recommendations. Submitted to the *Journal of Cleaner Production* in Apr/2010<br>• Spiegel, S.; Ribeiro, C., Veiga, M.M., **Sousa, R.N**., et al. Mapping Spaces of Environmental Dispute: GIS, Mining and Surveillance in the Amazon. (to be published, awaiting review)<br>• **Sousa R.N**; Veiga M.M; Spiegel, S. The use of mercury in artisanal gold mining: the ineffectiveness of prohibition. (to be published, awaiting review) |

## APPENDIX B – BOOKLET FOR TRAINING OF MINERS (CHAPTER 3)



Bom pessoal à turma do

**"CUIDE DO SEU TESOURO"**

Está aí para te ajudar
Ande sempre com esta cartilha
ela não pode faltar.
O Seu Sobrinho esta lá na SEMMA
de portas abertas é só procurar.

O Zé Carneiro fica lá pelos lados do CANAÃ é um grande parceiro e pode muito orientar.
A ARARAN e o JUBA
Ah estes pode acreditar vai ter sempre um deles voando por aí pronto para te Apoiar.

## Reativação do Mercúrio

AGORA É A HORA, PRESTE ATENÇÃO PARA VOCÊ APRENDER DIREITINHO COMO DEVE FAZER PARA ATIVAR ESTE SEU MERCÚRIO FRAQUINHO. ESSE É AQUELE QUE VOCÊ RECUPEROU NA RETORTA E NA PISCINA. PRESTE A ATENÇÃO E DEPOIS FAÇA VOCÊ MESMO.

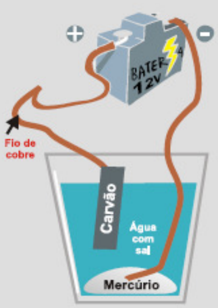
RECEITA DE ATIVAÇÃO DO MERCÚRIO

1 KG DE MERCÚRIO
100G DE SAL
½ LITRO DE ÁGUA

MODO DE FAZER
LIGUE O POLO POSITIVO NA GRAFITE, COLOQUE ESTA EM CONTATO COM A ÁGUA E A PONTA DO OUTRO FIO LIGADO NO NEGATIVO EM CONTATO COM O MERCÚRIO. DEIXE REAGIR POR 20 MINUTOS.

PRECAUÇÕES
A) UMA VEZ ATIVADO O MERCÚRIO, DEVERÁ SER CONSERVADO EM QUEROZENE, O QUE O MANTERÁ POR ESSA CONDIÇÃO POR TEMPO INDEFINIDO; OU

B) GUARDE O MERCÚRIO ATIVADO COM UMA FINA CAMADA DE ÁGUA E NUNCA FECHE O RECIPIENTE TOTALMENTE, POIS A REAÇÃO CONTINUA ACONTECENDO GERANDO HIDROGÊNIO, E SE ESSE GÁS NÃO SAIR PODERÁ EXPLODIR O RECEPIENTE. LAVE O MERCÚRIO ATÉ A ÁGUA FICAR LIMPA E USE A ÁGUA SANITÁRIA PARA LIMPAR E DESINFETAR OS AMBIENTES.




RESULTADO: MERCÚRIO COM MAIOR PODER DE AMALGAMAÇÃO E ÁGUA SANITÁRIA

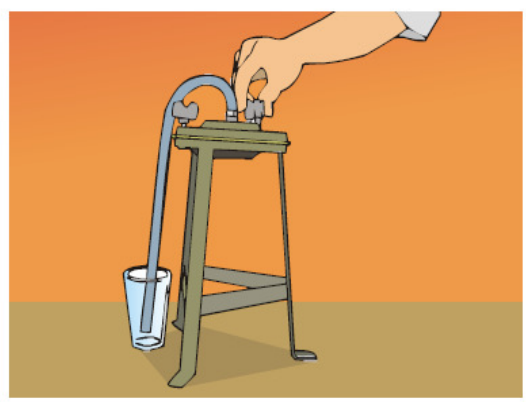

MODULO I - SAÚDE e SANEAMENTO

## CUIDE DA SUA SAÚDE

### Não respire a queima do azougue


## Retorta

A RETORTA VOCÊ PODE FAZER AÍ MESMO COM OS RECURSOS QUE VOCÊ TEM, AGORA CASO QUEIRA MANDA FAZER AÍ NA CIDADE MAIS PERTO, OLHA NAS FIGURAS E VOCÊ VAI VER COMO FAZER.



## Amalgamar

NÃO ESQUEÇA DE USAR A LUVA
PRA AMALGAMAR.
LEMBRA VOCÊ RECUPERA O MERCÚRIO
E NÃO PERDE A SAÚDE.

A COR DA LUVA NÃO É IMPORTANTE, O IMPORTANTE É QUE O MATERIAL DA LUVA POSSA VEDAR TOTALMENTE A SUA MÃO PARA QUE ELA NÃO ENTRE EM CONTATO COM O MERCÚRIO

## Vai usar mercúrio? Ponha a luva


## Use o mosquiteiro, fora mosquito!!!

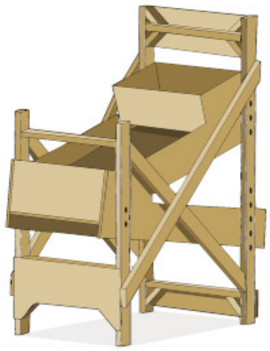

## Despesca na piscina

FAÇA A PISCINA QUANDO FIZER A DESPESCA NA PISCINA. LEMBRA VOCÊ RECUPERA O MERCÚRIO, O PEIXE AGRADECE E VOCÊ NÃO ADOECE.

COMO VOCÊ VÊ NO DESENHO ACIMA FAZER UMA PISCINA NÃO DARÁ MUITO TRABALHO, E O MATERIAL TAMBÉM NÃO É MUITO CARO E FÁCIL DE ACHAR.

## Calha em Zig Zig

SABE QUAL É O PROBLEMA DAQUELA CALHA? QUASE TUDO, ELA É FINA DEMAIS, É ÁGUA DEMAIS, SUJA DEMAIS, E RÁPIDA DEMAIS, ASSIM MEU AMIGO GARIMPEIRO NÃO DÁ TEMPO DO OURO CONCENTRAR. E O QUE CONCENTRA A ÁGUA QUE VEM ATRÁS LEVA EMBORA.



A CALHA DO SEU SONHO, TEM QUE SER MAIS LARGA, A ÁGUA TEM QUE VIR MAIS DEVAGAR E MAIS LIMPA, E EM ZIG ZAG, DESTA FORMA ELA VEM MAIS DEVAGAR. E PRO SEU OURO DEITAR E FICAR, PÕE UM CARPETE FINO NA PRIMEIRA CURVA E UMA PLACA COM IMÃ NA SEGUNDA.
VOCÊ JÁ DEVE TER VISTO ISTO A PRIMEIRA FAZ TCHAN!!!! A SEGUNDA FAZ TCHUN!!!! E TCHAN - TCHAN - TCHAN OLHA O OURO AÍ, LIBERADO E CONCENTRADO NA SUA CALHA EM ZIG E ZAG.

## Água é vida, tem que ser limpa


## Saia do mato e use a casinha


## Moinhos de bola

VAMOS COMEÇAR A GANHAR MAIS DINHEIRO, TRABALHAR MENOS E MUITO MELHOR.
SABE POR QUE VOCÊ SÓ FICA COM 30% DO OURO QUE ESTA PASSANDO NAQUELA SUA CALHA LÁ? OLHA PARA ELA, É BONITA PARECE UMA CACHOEIRA. OS GROSSO DO OURO FICA NO GROSSO DA LAMA QUE VAI PRO BURACO, QUE A GENTE AGORA COMEÇAR A TAMPAR, LEMBRA.

Ilustração de um Moinho De Bola

O MOINHO DE BOLA VAI FAZER O TRABALHO QUE A ÁGUA SOZINHA NÃO FAZ E MUITO MELHOR QUE O MOINHO DE MARTELO. E JÁ QUE É PARA GANHAR DINHEIRO, CÁ PARA NÓS QUEM AGÜENTA TROCAR O MARTELO DO MOINHO DE MARTELO. ENTÃO ESTA PRONTO PARA LIBERAR.


CUIDE DO SEU OURO
POIS ENTÃO, ACHO QUE ESTAMOS INDO MUITO BEM, VOCÊ JÁ ESTÁ CUIDANDO DA SUA SAÚDE. SUA FAMÍLIA E SUA CASA JÁ ESTÃO FICANDO UMA BELEZA, TODA LIMPA. A GENTE JÁ NÃO VÊ MAIS MOSCA, MOSQUITO, RATO E BARATA. JÁ É POSSÍVEL ATÉ AVISTAR AS PRIMEIRAS MUDAS BROTANDO. É BEM POSSÍVEL QUE QUANDO O SEU SOBRINHO E O ZÉ CARNEIRO VIREM AQUI PARA VISITAR JÁ VAI TER ALGUMA FRUTA NO PÉ. QUEM SABE!
BOM AGORA É HORA DE CUIDAR DO SEU OURO E AS PALAVRAS DE ORDEM SÃO ... LIBERAR PRA CONCENTRAR.


Não vacile, use camisinha nele.
VOCÊ JÁ CHUPOU BALA COM O PAPEL? NÃO? POIS É TA HORA DE APRENDER.
PROTEJA A SUA VIDA E A DELA, PÕE A CAMISINHA NELE.
USE CAMISINHA

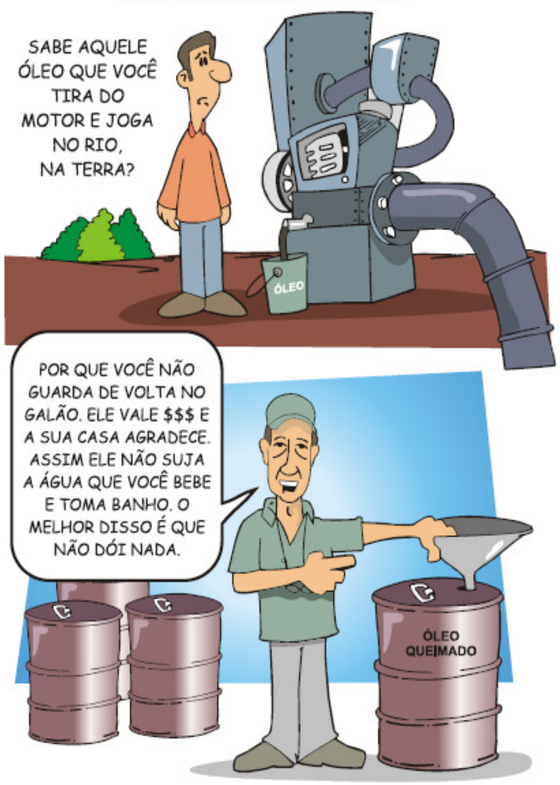

CUIDE DA SUA CASA
Jogue o lixo no lixo
ESTE ACAMPAMENTO ESTÁ UM LIXO, É LATA PRA TODO LADO, PAPEL, PLÁSTICO, GARRAFA DE PINGA É O QUE NÃO FALTA. COMO! PINGA. É, AH! ACABO DE TER UMA BOA IDÉIA.
JOGUE O LIXO NO LIXO


Use abatadores para conter a terra
SÓ PARA TERMINAR ESTA PARTE, VOU REPETIR MAIS UMA VEZ PARA VOCÊ NÃO ESQUECER. ÁGUA É VIDA ... E PARA FICAR BONITO MESMO, SABE AQUELA LAMA SUJA QUE VAI SAINDO LÁ DA CALHA, POIS ENTÃO, ELA VAI INDO PRO REGO, QUE TÁ INDO PRO RIO. E VOCÊ? TEM ANDADO UM BOCADO PRA PEGAR ÁGUA DE BEBER E DE COZINHAR?
PESCAR NESSE BARRO NEM PENSAR! O PEIXE ATÉ QUE É BONZINHO, MAS NÃO USA ÓCULOS.
VAMOS RESOLVER ESTA SITUAÇÃO AGORA. É MUITO, MUITO FÁCIL E NÃO DÓI NADA. SABE AQUELE BURACO ENORME QUE ESTA ALI, É DO ÚLTIMO BARRANCO QUE VOCÊ TRABALHOU. ENTÃO, PÕE SUA CALHA VIRADA PARA LÁ, APROVEITA, E JÁ VAI TAMPANDO ELE. NA SAÍDA DESSE, VOCÊ PÕE UMAS TRÊS OU QUATRO LINHAS DE ABATADORES. ASSIM ELAS VÃO SEGURANDO A TERRA. SABE A ÁGUA? É AQUELA QUE É VIDA, VAI SAINDO LIMPINHA DE VOLTA PARA O RIO.

## Recupere o azougue use a retorta

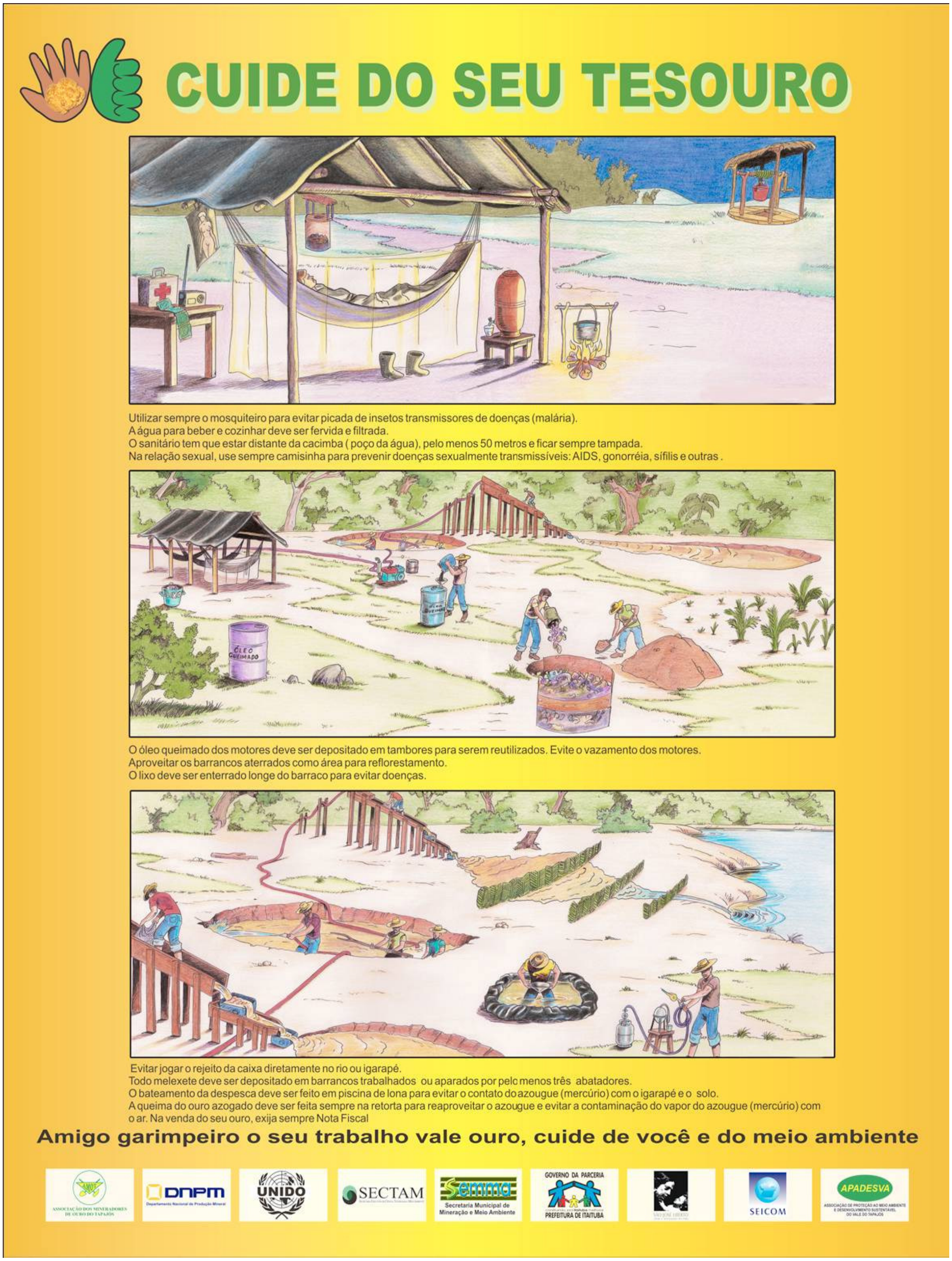

## Replante as áreas que você não usa mais


## Reutilize óleo utilizado




## Use a piscina para despesca

# APPENDIX C – POSTER TO PROMOTE THE TRAINING PROGRAM



# APPENDIX D – FORM FOR EVALUATION OF MINING SITES (CHAPTER 3)

**GMP Program / "Cuide de seu Tesouro"**
**Evaluation of Garimpos**

| | | | |
|---|---|---|---|
| Garimpo name | " ORIGINAL VERSION IS IN PORTUGUESE, THIS IS ONE AN EXA | Date | |
| Monitor / evaluator | | Signature | |
| Garinpo's owner | | Signature | |

| Theme of evaluation | N | Evaluated Item | Compliance to requirements | | |
|---|---|---|---|---|---|
| | | | Yes | Partially | No |
| Legalization of garimpo | 1 | Environmental License available (SECTAM)? | | | |
| | 2 | Mining Permission available (DNPM)? | | | |
| | 3 | Invoice issued for selling gold? | | | |
| Gold Production | 4 | Use scientific method for finding gold? | | | |
| | 5 | Right equipment and process available? | | | |
| | 6 | Equipment and process recover fine gold? | | | |
| | 7 | Equipment maintenance and stock of supplies OK? | | | |
| Protection of water and forest | 8 | Reffling of old pits OK? | | | |
| | 9 | Reforestation of degraded areas? | | | |
| | 10 | Quality of water returned to the river / sediment containment OK? | | | |
| Use of Mercury | 11 | Evidences of minimization of mercury? | | | |
| | 12 | Use retorts safely during the burning process? | | | |
| | 13 | Amalgamation is confined (pool for concentrate)? | | | |
| | 14 | Evidence of first steps for technology free of mercury? | | | |
| Quality of life | 15 | Use of latrines OK? | | | |
| | 16 | Use of filtered drinking water? | | | |
| | 17 | Use of methods for prevention and treatment of malaria? | | | |
| | 18 | Hygiene, cleanness and comfort of the area OK? | | | |
| | 18 | Exposition to risks and safety OK? | | | |
| | 19 | The waste disposal OK? | | | |
| | 20 | Use practices of environmental education, health and awareness? | | | |
| | | Sum of points: | | | |
| | | Final Grade (sum points and multiply by 5, result in %): | | | |

| | | |
|---|---|---|
| Improvement opportunities, causes of problems, corrective actions and time for execution | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| General comments | | |

Information

1) Evaluation based in objective evidences (not only in interviews)
2) For non-conformities, present corrective actions and required time for compliance
3) If necessary, attach maps and schemes
4) The responsible person for the garimpo should escort the monitor
5) The evaluation will be analysed and filed at SEMMA. A copy will be kept with the garimpo owner

## APPENDIX E – LIST OF 141 MINING SITES IN THE TRAINING PROGRAM

| # | "Garimpo" name | Person in charge | Date of 1st evaluation | % Conformity to standards in the 1st and 2nd evaluations (after 120 days) | | | |
|---|---|---|---|---|---|---|---|
| | | | | 1st (%) | Class | 2nd (%) | Class |
| 1 | Canaã | Paulo Henrique M. Carneiro | 17/01/2007 | 75.0 | B | 75.0 | B |
| 2 | Rio Criporizao | Antonio Jose Tavares Da Luz | 29/01/2007 | 60.0 | C | 65.0 | B |
| 3 | Castanheiro | José Roberto Dias Da Silva | 12/01/2007 | 57.5 | C | 65.0 | B |
| 4 | Samaúma | Francisco De Assis P. | 14/01/2007 | 50.0 | C | 62.5 | B |
| 5 | Castanheiro (Filão) | Antonio Pedro G. Teixeira | 12/01/2007 | 50.0 | C | 67.5 | B |
| 6 | Samaúma | Ademir V. Da Silva | 14/01/2007 | 47.5 | C | 62.5 | B |
| 7 | Samaúma | João De Deus Oliveira P. | 14/01/2007 | 45.0 | C | 65.0 | B |
| 8 | Filao Do Para | Dinaldo Marques Almeida | 28/01/2007 | 42.5 | C | 62.5 | B |
| 9 | Rio Surubim G.Do Haroldo | Haroldo Oliveira Pereira | 25/02/2007 | 40.0 | D | 65.0 | C |
| 10 | Garimpo Do Sr Chacal | Chacal | 22/02/2007 | 40.0 | D | 62.5 | B |
| 11 | Rio Marupa G. Grotão Do Buriti | Gilmar Ferreira (Fofoca) | 23/01/2007 | 37.5 | D | 65.0 | C |
| 12 | Baixao Do Corima | Edimilson Mathus De Sousa | 23/01/2007 | 35.0 | D | 62.5 | B |
| 13 | Rio Surubim G. Dominginho | Lorival Rodrigues Da Silva | 23/02/2007 | 35.0 | D | 57.5 | C |
| 14 | Garimpo Surubim | Sr. Claudio | 26/02/2007 | 35.0 | D | 62.5 | B |
| 15 | Santa Rita 1 | Manoel Severino Da Silva | 10/01/2007 | 32.5 | D | 62.5 | B |
| 16 | Santa Rita 2 | Manoel Severino Da Silva | 10/01/2007 | 32.5 | D | 62.5 | B |
| 17 | Samaúma | Agnel Santos Pereira | 14/01/2007 | 32.5 | D | 57.5 | C |
| 18 | Draga Do Arthur | Arthur Gomes Da Silva | 28/01/2007 | 32.5 | D | 62.5 | B |
| 19 | Creporizão | Ivan/Massafra | 30/01/2007 | 32.5 | D | 65.0 | B |
| 20 | Alto Alegre 1 | José Maria Felix | 11/01/2007 | 32.5 | D | 67.5 | B |
| 21 | Alto Alegre 2 | José Maria Felix | 11/01/2007 | 32.5 | D | 67.5 | B |
| 22 | G. Morro Alto Neguinho | José Raimundo Alves | 27/01/2007 | 30.0 | D | 65.0 | B |
| 23 | Do Sr. Zé Goiano | Goiano | 23/02/2007 | 30.0 | D | 62.5 | B |
| 24 | União | | 07/02/2007 | 30.0 | D | 65.0 | B |
| 25 | G. Senhozinho | Francisco Vidal Da Penha | 16/02/2007 | 30.0 | D | 65.0 | B |
| 26 | Rio Crepori Massafra | Ivan/Massafra | 30/01/2007 | 27.5 | D | 65.0 | B |
| 27 | Pista Do Goiano | Canela | 28/01/2007 | 27.5 | D | 65.0 | B |

| # | "Garimpo" name | Person in charge | Date of 1st evaluation | % Conformity to standards in the 1st and 2nd evaluations (after 120 days) | | | |
|---|---|---|---|---|---|---|---|
| | | | | 1st (%) | Class | 2nd (%) | Class |
| 28 | Samaúma 3 | Ceará Das Medalhas | 14/01/2007 | 27.5 | D | 67.5 | B |
| 29 | G. Do Tavari | Gilmar Marques Filho | 16/02/2007 | 27.5 | D | 67.5 | B |
| 30 | Baixão Do Janau 1 | Noé Carvalho Alves | 23/01/2007 | 25.0 | D | 65.0 | B |
| 31 | Baixão Do Janau 2 | Noé Carvalho Alves | 23/01/2007 | 25.0 | D | 65.0 | B |
| 32 | Fofoca Do Amapá | Macelo Santos | 18/01/2007 | 25.0 | D | 65.0 | B |
| 33 | Rio Surubim | | 27/02/2007 | 25.0 | D | 65.0 | B |
| 34 | Rio Surubim G. Chacal 1 | José Ribamar Rodrigues | 23/02/2007 | 25.0 | D | 62.5 | B |
| 35 | Garimpo Vila Nova | José Jorje De Lima | 25/02/2007 | 25.0 | D | 62.5 | B |
| 36 | Santa Isabel Paulo Jandaia | Antonio Ferreira | 26/02/2007 | 25.0 | D | 62.5 | B |
| 37 | Rio Surubim G.Chacau 2 | Neto Do Zé Da Ripa | 23/02/2007 | 25.0 | D | 62.5 | B |
| 38 | Tauari | Aroudo De Lima Silva | 17/02/2007 | 25.0 | D | 62.5 | B |
| 39 | Agua Suja | Raimundo Pereira Dos Santos | 19/02/2007 | 22.5 | D | 62.5 | B |
| 40 | Paraizo | José De Arimateia Lira | 25/01/2007 | 22.5 | D | 62.5 | B |
| 41 | Rio Marupá 21 | Reginaldo Alves P.Roxo | 16/01/2007 | 22.5 | D | 55.0 | C |
| 42 | Rio Surubim G. Do Zinho | Zinho | 02/03/2007 | 22.5 | D | 62.5 | B |
| 43 | Rio Surubim G. Chacal | Zeca Gaúcho | 23/02/2007 | 22.5 | D | 62.5 | B |
| 44 | Pista Vvelha | Elde Brado E Zé Pereira | 19/02/2007 | 22.5 | D | 55.0 | C |
| 45 | Baixão Do Cajueiro | G. Careguinha | 20/02/2007 | 22.5 | D | 55.0 | C |
| 46 | G. Ubaldino | Ubaldino Rodrigues Borges | | 22.5 | D | 62.5 | B |
| 47 | Fofoca Do Castanheiro Marupá | Celinaldo | 17/01/2007 | 22.5 | D | 55.0 | C |
| 48 | G Pissarreira | José Ferreira Lima Neto | 17/02/2007 | 22.5 | D | 57.5 | C |
| 49 | G. Cachaçal | Zé Baiano | 13/02/2007 | 22.5 | D | 62.5 | B |
| 50 | Patrocinio G, Japão | Jorje Taveres Dos Santos | 20/02/2007 | 22.5 | D | 62.5 | B |
| 51 | Pedra Alta | Dineval Silva Sousa | 17/02/2007 | 22.5 | D | 62.5 | B |
| 52 | Fofoca Lagoa Do Difunto | | 20/01/2007 | 22.5 | D | 62.5 | B |
| 53 | Alto Alegre | Fabricio José Groff. | 11/01/2007 | 20.0 | E | 62.5 | B |
| 54 | Castanheiro | Cristiano M. Sousa | 12/01/2007 | 20.0 | E | 52.5 | C |
| 55 | Santa Rita | João Benedito Simão | 10/01/2007 | 20.0 | E | 52.5 | C |
| 56 | Novo Horizonte | Edson Gomes Coelho | 11/01/2007 | 20.0 | E | 62.5 | B |

| # | "Garimpo" name | Person in charge | Date of 1st evaluation | % Conformity to standards in the 1st and 2nd evaluations (after 120 days) | | | |
|---|---|---|---|---|---|---|---|
| | | | | 1st (%) | Class | 2nd (%) | Class |
| 57 | Rio Marupa Baixão Janau | Francisco Da Silva Leite | 23/01/2007 | 20.0 | E | 55.0 | C |
| 58 | Baixão Do Janau | João Batista Dos Santos | 23/01/2007 | 20.0 | E | 52.5 | C |
| 59 | Fazenda Paraiso | Lurdes | 25/01/2007 | 20.0 | E | 62.5 | B |
| 60 | Goiano Maquinario Canela | Canela | 24/01/2007 | 20.0 | E | 52.5 | C |
| 61 | G.Morro Alto B. Chicão | Francisco Bispo Dos Santos | 27/01/2007 | 20.0 | E | 62.5 | B |
| 62 | Baixão Do Buriti | Alcenor | | 20.0 | E | 52.5 | C |
| 63 | Rio Surubim | Batistão | 01/03/2007 | 20.0 | E | 62.5 | B |
| 64 | G. Do Gauca Rio Surubim | Marimbondo | 01/03/2007 | 20.0 | E | 62.5 | B |
| 65 | Fazenda Primavera | Manuel Do Nascimento Silva | 17/02/2007 | 20.0 | E | 52.5 | C |
| 66 | Patrocinio Isca Fola | Gilmar Nogueira Martins | 17/02/2007 | 20.0 | E | 62.5 | B |
| 67 | Fazenda Paraiso | Ivan Mendonça | 25/01/2007 | 20.0 | E | 62.5 | B |
| 68 | Garimpo do Albino | Albino Dos Santos | 28/01/2007 | 20.0 | E | 57.5 | C |
| 69 | Rio Surubim 4 | Veronica Zé Da Ripa | 02/03/2007 | 20.0 | E | 62.5 | B |
| 70 | Rio Surubim João Nogueira | Gerente Jamil | 25/02/2007 | 20.0 | E | 52.5 | C |
| 71 | G. Surubim 5 | João Nogueira | 27/02/2007 | 20.0 | E | 52.5 | C |
| 72 | Rio Surubim G. João Nogueira | Daniel R P L José Teixeira | 28/02/2007 | 20.0 | E | 62.5 | B |
| 73 | Garimpo do Jaú | Gerente Jaú | | 20.0 | E | 55.0 | C |
| 74 | Baixão Da Padaria | Jose adrelino | 13/02/2007 | 20.0 | E | 52.5 | C |
| 75 | G. Da Dona Margarete | José Raimundo R. | 20/02/2007 | 20.0 | E | 52.5 | C |
| 76 | G. Da Agua Suja | Everaldo Silva Dos Santos | 20/02/2007 | 20.0 | E | 60.0 | C |
| 77 | Alto Alegre | Isaqueu Teles Pereira | 11/01/2007 | 17.5 | E | 60.0 | C |
| 78 | Castanheira | Rosi Araújo Baia | 12/01/2007 | 17.5 | E | 52.5 | C |
| 79 | Vila Nova | Francisco Peres | 25/02/2007 | 17.5 | E | 52.5 | C |
| 80 | Criporizinho | Luiz Preto | 16/02/2007 | 17.5 | E | 52.5 | C |
| 81 | B. Chico Brabo | Nay Alves Cardoso | 14/01/2007 | 17.5 | E | 52.5 | C |
| 82 | Samaúma 6 | José Arnaldo Oliveira | 14/01/2007 | 17.5 | E | 52.5 | C |
| 83 | B.Morro Alto .P.M. Alcino | Alcino Da Costa Cardoso | 27/01/2007 | 17.5 | E | 42.5 | D |
| 84 | Garimpo Do Bruno | Bruno Andrade | 18/01/2007 | 17.5 | E | 42.5 | D |
| 85 | Barranco Do Cabeça | Jose Henrique | 25/02/2007 | 17.5 | E | 37.5 | D |
| 86 | João Nogueira | Ineslo Catarina Sousa | 25/02/2007 | 17.5 | E | 52.5 | C |
| 87 | Rio Surubim 8 | João Nogueira | 28/02/2007 | 17.5 | E | 52.5 | C |
| 88 | Rio Surubim 9 | Rosilene Da Rosa | 01/03/2007 | 17.5 | E | 52.5 | C |

| # | "Garimpo" name | Person in charge | Date of 1st evaluation | % Conformity to standards in the 1st and 2nd evaluations (after 120 days) | | | |
|---|---|---|---|---|---|---|---|
| | | | | 1st (%) | Class | 2nd (%) | Class |
| | | Trado | | | | | |
| 89 | Garimpo Pedra Nova | Garibaldo | 10/02/2007 | 17.5 | E | 30.0 | D |
| 90 | Rio Criporizão | Albino Alves | 26/01/2007 | 17.5 | E | 52.5 | C |
| 91 | Pista Filho Do Piaui/Pista Velha | Fernando Crines Silva | 16/02/2007 | 17.5 | E | 52.5 | C |
| 92 | Patrocinio Grota Velha | Miguel Pereira Da Silva | 16/02/2007 | 17.5 | E | 55.0 | C |
| 93 | Novo Patrocinio 1 | Manoel Vieira Dos Santos | 19/02/2007 | 17.5 | E | 52.5 | C |
| 94 | Novo Patrocinio 2 | Antonio Alves De Sousa | 19/02/2007 | 17.5 | E | 52.5 | C |
| 95 | Novo Patrocinio 3 | Valmir Ferreira Da Conceição | 19/02/2007 | 17.5 | E | 30.0 | D |
| 96 | Morissoca Patrocinio | Antonio Filho De Oliveira | 20/02/2007 | 17.5 | E | 55.0 | C |
| 97 | Do Manezinho | Raimundo José De Sousa | 28/01/2007 | 17.5 | E | 55.0 | C |
| 98 | Santa Isabel B.Do Rabico | José Silva Ferreira Rabico | 26/02/2007 | 17.5 | E | 30.0 | D |
| 99 | Rio Surubim G. Raimundo | Raimundo Nonato Silva | 23/02/2007 | 17.5 | E | 52.5 | C |
| 100 | G. Luiz Preto | Luiz Preto | 13/02/2007 | 17.5 | E | 55.0 | C |
| 101 | Vicinal Tabocal | G. Do Tolentino | 03/03/2007 | 17.5 | E | 30.0 | D |
| 102 | Patrocinio Isca Fola | Luiz Silva Santos | 17/02/2007 | 17.5 | E | 30.0 | D |
| 103 | Patrocinio 7 | Salatiel Mendonça | 17/02/2007 | 17.5 | E | 30.0 | D |
| 104 | Forro Pesado G. Lorival | Renato Alves Ferreira | 16/02/2007 | 17.5 | E | 30.0 | D |
| 105 | G. Do Agua Suja | G. Do José | 22/02/2007 | 17.5 | E | 30.0 | D |
| 106 | Garimpo Vila Nova | Waldemar Bondaranco | 25/02/2007 | 17.5 | E | 25.0 | D |
| 107 | G. Zé Rodrigues | José Macedo Magalhaes | 26/01/2007 | 15.0 | E | 52.5 | C |
| 108 | B. Morro Alto | Albano Da Silva Pereira | 27/01/2007 | 15.0 | E | 52.5 | C |
| 109 | G. Do Chacão | Avelino Almeida Lima | 23/02/2007 | 15.0 | E | 30.0 | D |
| 110 | G Do Hospital | Altamir Batista De Sousa | 12/02/2007 | 15.0 | E | 30.0 | D |
| 111 | Patrocinio Pista Velha | José Alves Da Silva | 17/02/2007 | 15.0 | E | 30.0 | D |
| 112 | Pedra Alta | Vilson Vieira Carvalho | 17/02/2007 | 15.0 | E | 52.5 | C |
| 113 | Patrocinho Novo/Manelão | Manoel Pereira Dos Santos | 19/02/2007 | 15.0 | E | 22.5 | D |
| 114 | João Nogueira | Tito Martins | 05/02/2007 | 15.0 | E | 30.0 | D |
| 115 | G. Do Sr. Claudio | Bié | 26/02/2007 | 15.0 | E | 52.5 | C |
| 116 | G. Do Cabeça | Cabeça | 26/02/2007 | 15.0 | E | 30.0 | D |

| # | "Garimpo" name | Person in charge | Date of 1st evaluation | % Conformity to standards in the 1st and 2nd evaluations (after 120 days) | | | |
|---|---|---|---|---|---|---|---|
| | | | | 1st (%) | Class | 2nd (%) | Class |
| 117 | Rio Surubim G. Chacal | Noemia Ferreira De Sousa | 23/02/2007 | 15.0 | E | 30.0 | D |
| 118 | Luiz Preto 2 | Luiz Preto | 13/02/077 | 15.0 | E | 30.0 | D |
| 119 | Grota Pista Velha | Raimundo Pereira Dos Santos | 18/02/2007 | 15.0 | E | 52.5 | C |
| 120 | Rio Criporizao | Daniel Dos Santos Gato | 27/01/2007 | 12.5 | E | 30.0 | D |
| 121 | Patrocinio Novo | Manoel Oliveira Silva | 19/02/2007 | 12.5 | E | 30.0 | D |
| 122 | Novo Patrocinio | Antonio Brito | 19/02/2007 | 12.5 | E | 30.0 | D |
| 123 | Neguinho Do Artur | Reginaldo | 27/01/2007 | 12.5 | E | 52.5 | C |
| 124 | Filho Do Henrique | | 09/02/2007 | 12.5 | E | 25.0 | D |
| 125 | G. Do Tabocal | José Lorenco De Oliveira | 16/02/2007 | 12.5 | E | 25.0 | D |
| 126 | Estrada Tabocal | Zé Baiano | 16/02/2007 | 12.5 | E | 52.5 | C |
| 127 | Zé Baiano | Zé Baiano | 13/02/2007 | 12.5 | E | 25.0 | D |
| 128 | Balsa Da Fatima | Maria De Fatima De Sousa | 29/01/2007 | 12.5 | E | 25.0 | D |
| 129 | Patrocinio 8 | José Alvino Martins | 18/02/2007 | 12.5 | E | 52.5 | C |
| 130 | Tauari | Francisco Mesquita Da Silva | 17/02/2007 | 12.5 | E | 25.0 | D |
| 131 | Patrocinio Isca Fola | Francisco De Assis [a] | 17/02/2007 | 12.5 | E | 25.0 | D |
| 132 | Baixão Do Amazonas Buriti | | 14/02/2007 | 10.0 | E | 52.5 | C |
| 133 | Novo Patrocinio | Raimundo Rodrigues De Sousa | 19/02/2007 | 10.0 | E | 22.7 | D |
| 134 | Isca Fola G. Mão De Onça | Antonio José Gaspar Silva | 16/02/2007 | 10.0 | E | 27.5 | D |
| 135 | Agua Suja | Sebastião Silva Santos | 20/02/2007 | 10.0 | E | 52.5 | C |
| 136 | Novo Patrocinio | (Doutor) Edimundo | 19/02/2007 | 10.0 | E | 27.5 | D |
| 137 | Patrocinio Garimpo Zé Da Rosa | José Do Nascimento Santos | 20/02/2007 | 7.5 | E | 22.5 | D |
| 138 | Garimpo Serra Morena | Ribamar De Jesus | 20/02/2007 | 7.5 | E | 22.5 | D |
| 139 | Grotão Da Madeira | Joel Pequeno | 21/02/2007 | 7.5 | E | 22.5 | D |
| 140 | Serra Morena | João Gago | 25/01/2007 | 7.5 | E | 27.5 | D |
| 141 | Agua Suja | Abimael Dutra | 20/02/2007 | 7.5 | E | 22.5 | D |
| | | | | 22.2 | | 51.0 | |