Evaluation of Environmental Impacts of Riverbed Dredging: A Proposed Project on the Lower Caroni River, Venezuela

By

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We accept this thesis as conforming to the required standard

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Department of **MINING ENGINEERING**

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Date **April 25th 2003**
ABSTRACT
The purpose of this research thesis is to identify social, economic and environmental impacts associated with dredging in riverbed settings and potential preventive actions. This project uses a mining dredging project (Caroni Project), currently at an early stage, as a case study. Increases in river water turbidity, changes in drinking water quality for the nearby cities, and increased mercury mobilization are the main environmental impacts this thesis project evaluates. A diversity of non-environmental factors also influence the feasibility of the Caroni Project, and for that reason an integrated environmental, social and economic approach is required.

It was found that increases in river water turbidity during dredging operations can be prevented by using a combination of pneumatic high density suction dredging methods and an underwater crusher or a cutterhead dredger where hard pan layers are located. Regardless of the low fines content expected in the river, these procedures must be accompanied by preventive measures against turbidity like turbidity curtains and low impact cutterheads, due to the extreme sensitivity of the dredging area. It was also found that the main potential environmental impacts are linked to mercury recovery, waste water and sludge treatment. The removal of metallic mercury contained in the sediments can be achieved during the processing stage by gravity concentration and retorting. The residual mercury is expected to be associated with fine concentrates that could be treated by electrochemical methods if required. Encapsulation of metallic mercury and organic mercury bearing sludge is possible by commercially available methods.

The development of a Sustainable Business Case and the implementation of the Mining, Minerals and Sustainable Development - Seven Questions Methodology as a tool for monitoring sustainability would both contribute to better foreseen opportunities to negotiate mutually beneficial agreements among stakeholders of the Caroni Project, and reduce the risk of land use conflict with hydro-electric company (EDELCA), former artisanal miners and other potential actors not yet identified. This research project provides an opportunity to propose specific sustainable practices not only applicable to the mineral dredging industry but also to junior mining company project.
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<td>ASTM</td>
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<td>CONAPRI</td>
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1 INTRODUCTION

1.1 Statement of the Problem

The Caroni River (located in the State of Bolivar of Venezuela) has an extensive history of environmental degradation associated with mineral extraction by artisanal gold and diamond dredgers, whose rudimentary techniques have resulted in widespread mercury pollution and mobilization of sediments throughout the river. Artisanal miners in the Caroni used simple suction dredgers to recover gold contained in sediments. Diluted pulps (about 5% solids) were sent to on-board sluices where they were concentrated. Tailings from sluices were directly discharged back to the river.

These tailings were spreading mercury along the riverbed. Prior to 1991, the more than 200 barges dredging the Caroni River released an estimated 5 tonnes of mercury into the river as a result of these poor practices. A 1991 decree prohibiting mercury amalgamation was established. Around the same time, CVG EDELCA\(^1\) was starting the construction of the Caruachi hydro-electric dam in the Lower Caroni River forcing dredging operations out of the flooding zone; (although it is likely that these dredging practices continued illegally in other sections of the river). The flooding itself has brought environmental impacts to the region. A precedent of mercury mobilization triggered by new reservoirs has already occurred upstream in the same river, on the Guri hydro-electric reservoir (Veiga, 1996). This issue may overlap with possible environmental impacts of any new mining dredging project operating in the zone.

The granting of an extraction permit to a foreign dredging company may generate some discomfort among those who feel their interests are threatened by such a dredging project. EDELCA’s concerns about turbidity generation affecting their turbines, former concession holders’ concerns about new rules favouring foreign companies, and environmentalists that perceive all dredging as contamination are some of the issues that new dredging projects must address.

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\(^1\) CVG EDELCA Government own Company in charge of the Caroni Hydro-electrical Complex that operates several dams along the river.
There is a need to reduce the amount of sediments accumulated around some reservoirs without jeopardizing the performance of the hydro-electric complex located along the river, which provides 75% of the country's electricity, and without compromising the water quality of the river.

The current political situation in Venezuela is another issue that requires careful consideration. The highly polarized and unstable situation can discourage foreign investors and shareholders. Alternatively, it can enable the Venezuelan government to generate a welcoming and permissive attitude towards foreign investment, mostly during the crucial upcoming 2003 election season.

In summary, there is a wide diversity of factors influencing the viability of this dredging project that necessitate an integrated approach. Land use conflict, social conflicts, quality and use of the water, sediment disturbance and mobilization, and political conflict are some of the main issues to consider in planning reclamation programs.

1.2 Objectives of the Work

To assess potential impacts of dredging technologies on the lower Caroni Region, specifically to:

- Identify social, economical and environmental impacts associated with dredging in riverbed settings.
- Identify potential mitigation techniques.
- Propose an action plan for dealing with environmental uncertainties in a future feasibility stage of the project.

1.3 Outline of the Work

Cadre Resources Ltd., a Canadian junior mining company, is proposing to recover sediments from the Lower Caroni River (referred to hereafter as the Caroni Project). The Caroni Project is in the process of obtaining a permit for a pilot operation as part of a feasibility study that would confirm reserves, test appropriate technologies, and conduct a socio-environmental impact assessment.
This research thesis begins with a comparative description of the dredging technologies currently available for mining riverbed deposits, followed by an overview of the Lower Caroni region, and a detailed description of the dredging project used as a case study. Once the main perceived problems have been identified, a detailed analysis of each one is undertaken from an environmental point of view. The thesis provides a preliminary impact assessment based on the information currently available.

1.4 Thesis Hypothesis

The aggregates and mineral dredging industry can, from early the stages of a project, adopt methodologies for forecasting social and environmental impacts similar to those used in reclamation dredging and traditional mining. New methodologies are needed in order to ensure that dredging practice is in line with the principles of sustainable development. The following impacts emerge from dredging: increase in river water turbidity, changes in drinking water quality for nearby communities, and increased heavy metals mobilization. To adhere to principles of sustainable development, this dredging project should have the following objectives: minimize increases in water turbidity, minimize or have no impact on drinking water quality, and achieve reduced heavy metals (notably mercury) levels in the soil profiles of the Caroni River.

1.5 Study Methodology

The results presented in this thesis are mainly based on the review of scientific literature and the evaluation of data from previous feasibility studies conducted in the Lower Caroni region since 1990. The mineralogical analytical data was generates by Cannon Microprobe (1997) and UBC - CIMI² (2002). Some qualitative mineralogical evaluation was also undertaken by the author. Information for this research was also provided by experts from different fields involved in the project, using the ENTA ³ guidelines for evaluation of perceived impact assessment.

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² UBC - CIMI – University of British Columbia - Center for Industrial Minerals Innovations
³ ENTA: United Nations' proposed methodology for Environmental Technology Assessment.
1.6 **Significance of the Work**

Dredging is the oldest and most prevalent extraction technology for riverbed minerals. In developing countries, the use of rudimentary dredging practices significantly affects local biota and the livelihoods of surrounding communities. In the last 10 years, a great deal of research has been undertaken on reclamation dredging practices, but little attentions has been centered on evaluating dredging for the purposes of mineral extraction. In fact, there is no substantial regulation anywhere in the world for implementing improved sustainable practices in exploitation dredging. This is despite the fact that a wide range of potential problems related to dredging can be identified as early as the pre-feasibility stage of a dredging project, by forecasting the impact of implementing the project.

Using the Caroni Project as a case study, this research contributes to the dredging industry by bringing tools for environmental evaluation widely used in other mining sectors and adapting them to specific dredging concerns. This should contribute to the development of better practices within the minerals dredging industry. This also provides an opportunity to incorporate specific sustainable practices into a junior mining company project, and creates the opportunity for further monitoring of successes and challenges in implementation.

1.7 **Structure of the Thesis**

**Chapter One** – Introduction:
Contains a justification for this work, describes the hypothesis, proposes objectives and presents an overview of the content and distribution of the information within the thesis.

**Chapter Two** – Review of River Dredging Technologies:
Defines basic concepts of dredging. This chapter groups the dredgers as mechanical or hydraulic with a special attention to low impact dredgers and pumping systems.

**Chapter Three** – Lower Caroni Region:
Provides background information about Eastern Venezuela, particularly the Lower Caroni region of the State of Bolivar, where the dredging project under evaluation would be located. This chapter contains a brief description of local geology and mineralogy as well as preliminary considerations on local biology. An overview of current economical conditions in the region is also presented.

Chapter Four – Dredging System Design:
Describes in detail the proposed Caroni Project for river dredging in the previously mentioned location. This chapter also contains detailed information on the three types of dredgers most likely to be used in this project and the processing operation suggested by Bateman Eng.\(^4\). This chapter ends by evaluating the economical viability of the project.

Chapter Five – Potential Environmental Impact Assessment:
This chapter presents an evaluation of Caroni Project from the environmental point of view. Even though the evaluation will be focused on the hypothetical impacts, it is not limited by them. An evaluation of potential environmental impacts of the Caroni Project based on expert judgment is also presented in this chapter.

Chapter Six – Mercury Contaminated Sediments.
This chapter presents extensive background information about mercury reactivity on aquatic systems. The background is followed by the evaluation of mercury bioaccumulation in the Lower Caroni River. Finally this chapter presents a review of possible encapsulation treatments for mercury containing sludge.

Chapter Seven – Integration of Sustainability Practices into the Project
Evaluates the Lower Caroni Project from the sustainability point of view and presents some scenarios for better practices that could be considered by the proponent. Perceived social impacts are also evaluated in this chapter. Finally, this chapter contains a sustainability business case exercise that evaluates the potential business opportunities for the Caroni Project derived from identifying and addressing sustainability risk factors since the early stages of the project.

\(^4\) Engineering company contracted by the project proponent for the design of the mineral processing facilities
Chapter Seven: Conclusion:

Discusses the findings derived from the environmental, social, technological, and economical assessment of the Lower Caroni dredging project. It also summarizes the main potential impacts and confirms the initial hypothesis of this work. Recommendations are included in this chapter.
2 REVIEW OF RIVER DREDGING TECHNOLOGIES

This chapter presents a basic background of dredging technology in the context of environmental and energy efficiency performance. There are numerous options for dredging in the market, and dredging support technologies have been successfully applied in operations around the world. A conscious evaluation of the working conditions, adequate monitoring of such conditions and operational flexibility to adapt to changes will determine the likelihood of success of a dredging operation.

Dredging may be defined as raising material from the bottom of a water covered area to the surface and pumping or transporting it over some distance (Herbich, 2000). It may involve mechanically penetrating, grabbing, raking, cutting, or hydraulically scouring the bottom of the water body to dislodge the sediment. There are differences in the operation and environmental performance of most of the commercial available dredgers. This chapter will discuss those differences.

Dredgers can be categorized as either mechanical or hydraulic, depending on the basic means of moving the dredged material. Some of the hydraulic dredgers employ pneumatic systems to pump the sediments out of the water body (USEPA, 1994). Another difference between mechanical and hydraulic dredging has to do with the nature of the sediments removed. Mechanical dredgers usually remove the sediments at nearly the same solids content as the in situ material because little additional water comes with the sediments when removed, making the volume of the sediments essentially the same before and after dredging. Hydraulic dredgers remove and transport sediment in slurry form. The total volume of water is greatly increased, because the solids content of the slurry is considerably less than that of the in situ sediments (USEPA, 1994). Suction dredger suppliers like Dredging Supply Inc., (2002) claim solid content in the slurry from 25 to 30 % in weight. Hydrostatic dredgers like Pneuma®, (2002) claim slurry water content up to 50% in weight when loose, fine sediments are dredged.
Dredging equipment (dredgers) vary widely, coming in many sizes and types. The majority are water-based machines, although there are a significant number of land based machines. For the purposes of clarity, dredgers have been classified (according to the method of excavation and operation used) into the following main categories (IADC, 2002):

- Mechanical dredgers;
- Hydraulic dredgers;
- Hybrid dredgers;
- Special, low-impact dredgers; and
- Other types of dredgers.

Within the above categories further subgroups can be identified on the basis of propulsion (i.e. self-propelled versus stationary - IADC, 2002). The selection of dredging equipment for a particular project depends upon a combination of factors, including:

- Type of physical environment;
- Nature, quantity and level of contamination of the material to be dredged;
- Method of placement; and
- Distance to the placement site.

2.1 Mechanical dredgers

Mechanical dredgers were the first type commercially developed. The three main subgroups of mechanical dredgers are bucket-ladder dredgers, backhoes, and grab dredgers. These dredgers are well suited to removing hard-packed material or debris, and to working in confined areas. Mechanical means are used for excavation – material is dislodged and then raised to the water surface - in a way similar to dry land excavation methods. Mechanically dredged sediments are generally transported by barges. Cohesive sediments dredged and transported this way usually remain intact, with large pieces retaining their in-situ density and structure through the whole dredging and placement process (IADC, 2002).
Mechanical dredgers are all characterized by their inability to transport the dredged material over long distances, lack of self-propulsion, and relatively low production. Their advantage lies in their ability to operate in locations with restricted mobility and to treat and de-water the dredged material in placer mining operations.

The most common types of mechanical dredgers are:

- **Dipper Dredger:** A floating version of the land-based mechanical excavation shovel frequently found on construction sites or mining operations due to its great leverage and carrying capacity. It is most commonly used in hard, compacted material and sediments.

- **Bucket Dredger:** This term is used to represent all types of mechanical dredgers that use buckets or scoops to excavate and lift the material. According to their design they can be also subdivided as Bucket-Grapple, Bucket-Dragline, Bucket-Dipper and Bucket-Ladder dredgers (USACE, 2001). One good example is the cable arm clamshell.

- **Backhoes:** Used more as excavating rather than dredging equipment, backhoes can nonetheless be used for removing sediments under certain circumstances. Backhoes are normally land based, but may be operated from a barge, and sometimes have been used for navigation dredging in deep-draft (e.g., 20-ft [6-m]) – channels (Fitzpatrick 1994, taken from USEPA, 1994). Specialized backhoes include closed-bucket versions and pontoon-mounted models especially adapted to dredging.

### 2.2 Hydraulic Dredgers

Hydraulic dredgers are self-contained units which handle both phases (suction and discharge) of the dredging process. They loosen and mix the material using cutter heads or agitation. These dredgers not only dig up the material but also dispose of it usually by pumping the material through a floating pipeline to a sorting area. This is what has made them more efficient, versatile and economical to operate than mechanical dredgers in most cases.
These dredgers use hydraulic centrifugal pumps to provide the dislodging and lifting force and remove the material in a slurry form. They usually work well in loose, "unconsolidated" silts, sands, gravels and soft clays. In more cohesive materials, teeth or water-jets have to be applied to break up the material (IADC, 2002).

According to the ARCS\textsuperscript{5} Remediation Guidance Document (1994), there are four key components of a hydraulic dredger:

- *The dredge-head*: the part of the dredger submerged into the sediment.
- *The dredge-head support*: usually a ladder, a simple cable or a sophisticated hydraulic arm.
- *The hydraulic pump*: provides suction at the dredger head and propels the sediment slurry through a pipeline (The pump can be submerged or deck-mounted).
- *The pipeline*: carries the sediment slurry away from the dredge-head to the receiving area.

Hydraulic dredgers are often classified in the following categories:

- *Agitation Dredger*: Commonly used for channel maintenance, agitation dredgers consist of a ship-type hull with hoppers housed within to hold material dredged from the bottom. The material is brought to the surface using a suction pipe and drag-head (end of the suction pipe usually conically shaped). A classical example is the Hopper Dredger. New designs are capable of handling compact material, and can have a hopper capacity of up to 33,000m\textsuperscript{3} (Herbich, 2000). They also have new features like submerged pumps, drag-head winch control, and other process-improving technologies. Hopper dredgers can reach down to 21m in depth without submerged pumps and as deep as 40m with submerged pumps. Drag-heads can re-suspend the sediments and overflow of water containing fine sediments will generate a turbidity plume that could affect the

\textsuperscript{5} USEPA Assessment and Remediation of Contaminated Sediments (ARCS) Program
quality of the water body and mobilize contaminants (although some improvements have been made to reduce turbidity generation).

- **Side-casting:** This is done from a shallow-draft seagoing vessel, especially designed to remove material from the channels of small coastal inlets. Similar in design to the hopper dredger, sidecasting dredgers pump the dredged material directly overboard through an elevated discharge boom instead of storing them in a hopper.

- **Pipeline:** All suction dredgers fall under this classification. Depending on the head mechanism, they can be sub-classified as:
  
  o **Plain suction**, where the suction pipe does not have any dislocating mechanism.
  
  o **Cutter-head**, where a rotating dented apparatus surrounds the intake end of the suction pipe. Cutter-head suction dredgers are equipped with a cutting device to increase their dislodging force. These "cutter" dredgers are suitable for use in high strength materials such as clays, packed or compacted sands, and rocks. The cutter heads most commonly found in the market are: soft silt cutters, serrated edge cutters, cutter heads with cutting teeth, and viscous sludge cutters. Modern cutter suction dredgers have improved capabilities, including:
    
    - Electric (rather than hydraulic) control systems that are more sensitive to changes and decrease the reaction time
    - Rams to control ladder movement and provide downward force on the ladder,
    - Variable speed cutters and the ability to reverse direction.
    - Swing winches with dynamic hydraulic braking.
    - Automation of functions.

- **Bucket wheel:** Utilizes a wheel of shovel-like buckets that loosen, collect, and deposit the sediments directly into the suction pipe.
- **Dustpan**: Employs pressure water jets mounted along a widely-flared suction head to loosen and agitate the sediments before the suction intake.

- **Portable Hydraulic Dredgers**: These are relatively small machines that can be transported over land. These dredgers can be as simple as a hose connected to a vacuum truck, such as the one used to remove PCB-contaminated sediments from the Shiawassee River in Michigan (USEPA 1985 cited by USEPA, 1994). In another example, diaphragm sludge pumps were used by the USEPA's Inland Response Team to remove PCB-contaminated sediments from the Duwamish River Waterway in Seattle, Washington (Averett et al., cited by USEPA, 1994). The primary application of such dredgers is the removal of small volumes of contaminated materials that can be easily accessed from the surface or by divers (USEPA, 1994).

- **Self-Propelled Hopper Dredgers**: This type of dredger operates hydraulically, but it is often described as a separate type of dredger because the dredged material is retained onboard rather than being discharged through a pipeline. Self-propelled hopper dredgers are well suited for dredging large quantities of sediments in open areas. However, they are not well suited for small dredging projects, especially in close quarters (USEPA, 1994).

Table 1 below shows the general appearance of the main commercially available dredgers previously discussed in this chapter.
Table 2.1: Commercially available dredgers

<table>
<thead>
<tr>
<th>Type of Dredger</th>
<th>Profile</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mechanical Dredgers</strong></td>
<td></td>
<td><strong>Bucket wheel</strong> <em>(after EuDA, 2003)</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Deeper (backhoe) Dredger</strong> <em>(after EuDA, 2003)</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Bucket (grab) dredger</strong> <em>(after EuDA, 2003)</em></td>
</tr>
<tr>
<td><strong>Suction Dredgers</strong></td>
<td></td>
<td><strong>Hydraulic Dredger</strong> <em>(after Dredging Supply Company Inc., 2002)</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Pneumatic Dredger with an Hydraulic Crusher</strong> <em>(after S.M.S, 2002)</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Pneumatic suction</strong> <em>(after Pneuma, 2003)</em></td>
</tr>
<tr>
<td><strong>Sub-aquatic Dredgers</strong></td>
<td></td>
<td><strong>Tracked underwater dredging</strong> <em>(after Boskalis, 2002)</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Remote-controlled underwater dredging</strong> <em>(after Boskalis, 2002)</em></td>
</tr>
</tbody>
</table>
2.3 Special low-impact dredgers (environmental/restoration)

Dredging of riverbeds has been used for navigation improvement, construction, and mining for a long time. The mass production enabled by the industrialized culture of the early 20th century, and the subsequent indiscriminate use of fertilizers and pesticides and other types of contaminants that have been mobilized by water streams, has greatly contributed to the contamination of sediments in river and seaside ports. During the last 30 years, a great deal of research has been focused on finding safer ways to dredge contaminated sediments in an environmentally acceptable manner. Contaminants are generally bound to the fine particles, which are those most easily re-suspended; most efforts are focused on minimizing the amount of re-suspension of fine particles. All this has stimulated the development of new kinds of dredging equipment that optimize operations. They do this by reducing over-dredging and/or minimizing the suspension of riverbed material. In some cases existing dredger types have been modified; in other cases completely new dredgers have been designed.

The philosophy behind these innovations is to ensure that contaminants are not re-mobilized and/or released into the water column, where they may detrimentally affect aquatic life. Some of these improvements include: encapsulated bucket lines for bucket chain dredgers; closed buckets for backhoes; closed clamshells for grab dredgers; auger dredgers, disc cutters, scoop dredgers and sweep dredgers and in general, all modified cutter dredgers (IADC,2002). In addition, innovative design of operational control and monitoring systems have contributed to the development of dredging technology.

2.4 Other types of dredgers

There are suction dredgers available in the market that operates using less traditional approach or pumping systems. Some of these dredgers are:

- **Airlift crusher**: This suction dredger operates using a hydraulic pump unit (variable displacement). The dredge-head does not have rotary cutters but instead has an underwater jaw type crusher capable of handling feed particles up to 800 mm in diameter.
- **Pneumatic Dredgers**: Operates with compressed air in shallow waters and uses the hydrostatic water column at deeper waters. For instance, Pneuma a three stage (three cylinder) system that alternates the suction of the sediments into the cylinders with their discharge.

- **Underwater dredgers**: Recently, seabed-based and remote-operated dredging technologies have been developed by Boskalis. Applications are mostly in mining seabed minerals under adverse weather conditions and very deep waters. Other attempts have been made to commercialize underwater vessels to this end, but these have been at a much smaller scale (although this technology has been proposed by several dredging companies). A good example of this is the "Track dredger 4" discharge designed by the Dredging Supply Company Inc. (2002). Unfortunately, the current high cost of R&D and construction for these technologies puts them beyond the financial capacity of most dredging operations to implement them.

### 2.5 Pumping systems

A very important aspect in the selection and performance of a dredging system is the type of pump used to operate it. An efficient pump has to be able to retrieve the minimum amount of water within the slurry (low dilution) and be energy efficient at the same time. This determines the amount of waste water that has to be treated and returned to the water bodies at the end of the process. This is a main issue concerning environmental impacts.

There are several types of dredging pumps available on the market. The classification presented by the USEPA (1994) is detailed in Table 2, with associated advantages and disadvantages of different systems.
Table 2.2: Commercially available pumping systems for dredging operations

<table>
<thead>
<tr>
<th>Pump Type</th>
<th>Application</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air lift</td>
<td>Operates by releasing compressed air into a riser pipe with open top and bottom. The slurry is dragged into the pipe and later discharged.</td>
<td>No moving parts, easy to fabricate. Slurries with up to 25% solids typically achieved, with some achieving 30% solids (Neptun, 2002). Relatively efficient from the environmental point of view due to low turbidity generation.</td>
<td>Sensitive to suction and discharge head variation. Not economically viable at greater than 7 m depths. Not suitable for long distance discharge piping. High water content in the slurry.</td>
</tr>
<tr>
<td>Water Eductor</td>
<td>Operated by a suction force (vacuum) passing pressured water through a streamlined confinement (venturi effect).</td>
<td>No moving parts, can handle solids within the slurry. Similar environmental performance that of Air lift.</td>
<td>Can not slurry particles bigger than 5 cm.</td>
</tr>
<tr>
<td>Radial Flow</td>
<td>Impeller vanes capture the influent slurry and throw it to the outside of the pump casing where the velocity imparted by the vanes is converted to pressure energy.</td>
<td>Has a screened suction intake. Capable of passing large solids without clogging. Small enough to prevent over-dilution (Lindeber 1992 cited by EPA).</td>
<td>Operates well only in a relative narrow range of particle sizes (USEPA 1979 cited by EPA, 1994).</td>
</tr>
<tr>
<td>Axial Flow</td>
<td>Uses rotating impellers to impart a spiraling motion to the fluid entering the pump.</td>
<td>High reliability. Lasts longer.</td>
<td>Less efficient than radial flow centrifugal pumps. Limited particle sizes.</td>
</tr>
<tr>
<td>Reciprocating Diaphragm</td>
<td>Uses a flexible membrane that opens on a two stroke cycle that contracts and enlarges an enclosed cavity (pump chamber).</td>
<td>Can be mechanically or hydraulically operated. Few moving parts. Two or more pumping stations.</td>
<td>Power required for hydraulic driven pump is typically double than the required for a mechanically driven pump of similar capacity.</td>
</tr>
<tr>
<td><strong>Pump Type</strong> (cont.)</td>
<td><strong>Application (cont.)</strong></td>
<td><strong>Advantages (cont.)</strong></td>
<td><strong>Disadvantages (cont.)</strong></td>
</tr>
<tr>
<td>-----------------------</td>
<td>------------------------</td>
<td>-----------------------</td>
<td>--------------------------</td>
</tr>
<tr>
<td>Pneumatic (hydrostatic pump)</td>
<td>Uses compressed air to convey sediments though a pipeline. Three submerged pressured vessels (a collector, an air compressor and a compressed air distributor) are used.</td>
<td>Widely and successfully used. Claim a solid content up to a 80%[^6] on the slurry making it environmentally attractive (Pneuma, 2002).</td>
<td>A crane and cable systems required suspending and pulling the pump. Lower power efficiency when compared to conventional centrifugal pumps.</td>
</tr>
<tr>
<td>Oozier (hydrostatic pump)</td>
<td>Japanese version of Pneuma with two pressure vessels rather than three.</td>
<td>Maximum production rate of 350m³/h. Similar environmental performance than Pneuma.</td>
<td>Lower power efficiency when compared with conventional centrifugal pump.</td>
</tr>
<tr>
<td>Plunger</td>
<td>Pistons driven by an exposed drive crank.</td>
<td>Variable stroke length, hence a variable positive displacement pumping action. Low maintenance costs (USEPA, 1979 cited by EPA).</td>
<td>Requires a daily routine servicing.</td>
</tr>
<tr>
<td>Piston</td>
<td>Cable guide and fluid powered piston (similar to plunger).</td>
<td>Capable of generating high pressures at low flows.</td>
<td>More expensive than other positive displacement pumps. Used for special applications only (USEPA, 1979 cited by USEPA, 1994)</td>
</tr>
<tr>
<td>Progressive cavity</td>
<td>Single-threaded rotor that spins inside a double-threaded helix rubber stator.</td>
<td>Flow rates are easily controlled, pulsation is minimal and operation is clean (USEPA 1979 cited by USEPA, 1994).</td>
<td>Due to the high wear on the rotors, the maintenance cost is highest of any slurry pump.</td>
</tr>
<tr>
<td>Lobe</td>
<td>Uses two rotating synchronous lobes to push the slurry trough the pump.</td>
<td>Variable lobe configuration according to the type of slurry. Rotational speed and shearing stresses are low.</td>
<td></td>
</tr>
</tbody>
</table>

[^6]: Much less water to treat and separate from contaminated sediments.
It can be concluded from Table 2.2 that the best option for retrieving loose, shallow, fine material like sand banks is the Pneuma pump due to its capacity to retrieve slurry at up to 50% solids content. A dust control type head should be selected once the amount of fines in the sediments is determined. Air lift pumping systems are suitable for deeper gravel and hard pan containing sediments in combination with a crusher or a cutter head.

2.6 Turbidity and Dredging

Kaneco et al., (1984) was one of the first researchers to study turbidity generation during dredging and ways to prevent it\(^7\). These studies concluded that lower turbidity is achieved when the dredging system has the following characteristics:

- *A spiral gathering head* that facilitates the flow of sand and cuts different kinds of sediments.
- *The use of cover and shutter*, to avoid the escape of fines and control the water flow.
- *The use of check valves* in the suction and the discharge sides. This prevents backflow when the system stops, and sends the backflow to the discharge pipe in the case of an emergency.

As previously mentioned, support technology has improved dredging performance but it is unrealistic to think that zero turbidity can be guaranteed under all conditions. In many cases, not all contaminated sediments can be removed, even with the most sophisticated equipment.

Equipment is not the only factor affecting the efficiency of a dredger. There are many factors that influence contaminant losses, according to the St. Lawrence Center (1993 cited by USEPA, 1994), the main factors of which are:

- *Sediment Type and Quality*: Grain Size, density, cohesion, organic matter concentration, and volatile substance concentration.

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\(^7\) *Turbidity* is a function of total suspended solids (TSS). TSS may be attributed to phytoplankton, particulate matter or organic detritus. Increased turbidity, particularly for extended periods of time, may decrease light penetration, modify channel dimensions, stimulate algal growth or interfere with biological processes.
- **Method**: Type, capacity, and condition of the equipment; equipment modifications; reliability under different circumstances; operating precision of the equipment; sediment lost during operation; and the training and skills of operators.

- **Water Quality**: Temperature, salinity, density, and dissolved organic matter.

- **Hydrodynamic conditions**: Water depth, morphology, flows, suspended solids concentration, waves, tides and direction, wind speed, and changes in hydrogeological conditions due to the dredging process itself.

Monitoring of turbidity throughout operation of the dredger would confirm whether the equipment is operating as anticipated. Two instruments have been identified as potential options for monitoring at the Lower Caroni site:

- **Sensor OBS-3** (D & A Instrument Company) evaluates total suspended solids and turbidity by measuring light dissipation. It generates a near linear response to particle concentration and can calculate and correct for environmental light.

- **OBS-3A** combines the optical sensor previously described with pressure, electric, and conductivity measurers. This sensor will also send the information to a computer program that can record data hourly for up to nine months.

This equipment can measure a range of turbidity (0 to 4000 UTF\(^8\) to a high degree of accuracy (+/- 0.1 to 5 UTF, depending on the turbidity range measured). Figure 2.1 shows the above mentioned turbidity monitoring equipment.

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8 UTF, Turbidity unit of formazine, is calculated by measuring the light dispersion though a liquid sample. The turbidity of tap water is usually less than 1 UTF, and pristine water bodies measure 5 UTF. One UTF is equivalent to approximately 30mg/L of suspended fines.
3 LOWER CARONI REGION

The project used as a case study is a planned development in the lower section of the Caroni River in the State of Bolivar in Venezuela. In order to better understand the general context for this project, it is important to describe the area of interest, its socio-economical condition as well as its historical and geographical aspects. The project proponent is planning to invest around US$60 million in a large-scale river dredging project that intends to recover sands, gravel, gold, diamonds, rare earths and ilmenite, as well as reclaim the mercury deposited by previous concession holders. The proponent expressed its commitment to operate in a sustainable, sound manner. Using cutting-edge dredging and processing technologies, the project intends to extract 10 million tons of material annually with estimated gross revenues of US $211.1 million per annum. Preliminary information suggests that the project may be viable for more than 100 years. In order to further evaluate the Project, a pilot operation would be conducted along the river to establish the best locations, evaluate dredging and processing methods and validate laboratory data.

3.1 Site Description

The Lower Caroni region, as shown in Figure 3.1, is located in the State of Bolivar in eastern Venezuela. It is situated 600 km southeast of Caracas and can be accessed by air (50 minute flight from Caracas) on a corridor well serviced by two domestic airline companies.

The Lower Caroni River, the main tributary of the Orinoco River, is located between the Guri Dam and the Caroni River’s confluence with the Orinoco River at Puerto Ordaz. Approximately 70 km in length, the Caroni River is the principal drainage system for the Gran Sabana and Guayana Highlands, which cover much of State of Bolivar. It receives water from the Upper Caroni, Paragua, Oris, and other rivers.

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9First from upstream and bigger Hydro-electrical dam, part of the hydro-electrical complex operated by the Venezuelan state company CVG - EDELCA
Ciudad Guayana, a major Venezuelan industrial centre, is located at the junction of the Lower Caroni and the Orinoco Rivers. Several smaller cities (Puerto Ordáz, San Félix, and Upatá, etc) are located around Ciudad Guayana. In 2000, the estimated population of Ciudad Guayana and surrounding metropolitan areas was 620,000 and the total population of the State of Bolivar was estimated at 1.2 million (Venezuelatuya.com, 2001)

The first phase of the dredging operation would be located about 25 km upstream from Puerto Ordáz on the Lower Caroni River and the processing plant would be situated in an industrial zone on the Orinoco River near Matanzas in Puerto Ordáz, adjacent to a large
steel mill and shipping terminal. The Orinoco River is a major transportation corridor with an annual shipping capacity of 100 million tonnes bulk cargo.

The Lower Caroni regional climate is moderately tropical with temperature fluctuations between 20°C and 30°C throughout the year. The average annual rainfall is 111.5 mm, with highest average monthly precipitation in June (201.3 mm, with a relative humidity of 83%) and the lowest monthly average precipitation in February (21.8 mm, with a relative humidity of 64%).

3.2 Regional Geology

The Lower Caroni River runs roughly parallel to a mountain chain. These approximately east-west oriented mountains consist of Precambrian formations underlying a quaternary mesa, and lie to the northwest of the river (Carlesi, 1990). The Imataca Complex, which predominantly consists of granitic gneiss, metabasic rocks and quartzite, dominates the region. More recent superficial deposits are composed of clays, and alluvial and illuvial deposits. The lithologies of the Ciudad Bolivar Belt, consisting of quartz-feldspathic intrusions into ferrous formations, amphibolite, and granodioritic gneiss, are of comparable composition to the coarse alluvial deposits.

Structurally, the Lower Caroni region is located between two main faults: the “El Pao” to the north, and the “Guri” to the south, which separates the Imataca Complex from the Pastora Super-Group. The “El Merey” fault cuts both primary faults.

3.3 Local Geology

Successive tectonic events were responsible for the early development of the Caroni River. Originally, the river channel was narrow, but displacement by the El Merey fault resulted in upward thrusting of units in the Imataca Complex, followed by their erosion and distribution throughout the channel. Deposition was controlled by topography and the influence of conjugate faults (oriented N 60° W), in conjunction with rock characteristics (Caromin, 1995).
Degerstrom (1994) describes the geological mineral occurrence of the Lower Caroni River. The basic stratigraphy of the river bottom is shown in Figure 3.2. An upper layer of recent sand, gravel and igneous boulders overlies a ferrous crust locally known as “capa”. The low-permeability capa consists of a cemented sand and gravel mixture that can vary in thickness from a few centimetres up to a metre. This crust is made of a mix of hematite, magnetite, and manganese oxide (Degerstrom, 1994), and was probably formed during dry seasons over the last ten thousand years. Gold and diamonds are enriched in the capa and near to bedrock, and have been associated with gravel and basic rocks with high magnetic susceptibility. The capa overlies additional layers of weakly consolidated sands and gravels. Up to three layers of capa are intermittently located between sands and gravels in some locations. Bedrock material is composed of the granitic gneiss characteristic of the Imataca Complex.

As the Lower Caroni River bed predominantly consists of coarse materials (sand and gravel), suspension of sediments is minimal. Further to this, the capa material underlying the upper sand and gravel is believed to be well cemented (Bradbury, 1994), and would likely be somewhat resistant to scouring. As the distribution of fines has not been well characterized, this potential for sediment suspension should be further evaluated.
Riverbed material is predominantly derived from igneous and, to a lesser extent, sedimentary rocks. Petrographic studies done by Walker (1994) indicate the presence of quartzite, granite, pegmatite, mafic igneous rock and ferrous arenites, among others. A study done in the region (Degerstrom 1994) evaluated gold and diamonds in the Delta, Rosita I, and Gorrin concessions along the Lower Caroni River (Figure 3.3). The following minerals are abundant: quartz, chlorite, ilmenite, magnetite, monazite, goethite and feldspar. Minor minerals include: cassiterite, garnet, pyrite and rutile.

The Lower Caroni River flows through a slightly steep valley situated between two low mountain ranges. On average, the Lower Caroni grades 1.15 m/km towards the Orinoco basin. This section of the River has a variable width of 700 to 4000 meters, an area of 15,000 km² and a flow rate of the River below the Guri Dam¹⁰ of approximately 4800 m³/s. Highest and lowest flow rates observed in the Caruachi Reservoir are 12,996 m³/s and 218 m³/s, respectively (Leal, 1995). The significant water flow and steep grade make the Caroni River an ideal environment for hydro-electrical power generation.

¹⁰ Guri Dam is the bigger hydro-electrical structure located in the upper section of the Lower Caroni River.
Studies done by Bradbury (1994) described the size distribution of sediment samples taken from the Delta and Rosita concessions (Table 3.1). The percentage of fines (particles passing #200 mesh, 0.074 mm in diameter) in samples taken from three dredgers in these concessions was low. Less than 1% of the sediments extracted by the Delta Roja dredger were below 200 mesh. The proportion of fines from the Delta Blanca and Rosita Star dredgers were 4.58% and 2.08%, respectively. Based on the lack of fines, very little turbidity generation through the dredging process is anticipated.
Figure 3.3: Location of Previous Concessions and Poso Hojero-Santa Rosa Zone
Table 3.1: Particle size distribution of sediments in the Caroni River
(after Degerstrom, 1994)

<table>
<thead>
<tr>
<th>Mesh size</th>
<th>Delta Blanca dredger %w</th>
<th>Delta Roja dredger %w</th>
<th>Rosita Star dredger %w</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\frac{3}{4}$ &quot;(19 mm)</td>
<td>1.51</td>
<td>0.76</td>
<td>0</td>
</tr>
<tr>
<td>$\frac{1}{2}$ &quot;(12.7 mm)</td>
<td>6.45</td>
<td>0.64</td>
<td>0.02</td>
</tr>
<tr>
<td>$\frac{3}{8}$ &quot;(9.51 mm)</td>
<td>6.14</td>
<td>0.36</td>
<td>0.10</td>
</tr>
<tr>
<td>$\frac{1}{4}$ &quot;(6.35 mm)</td>
<td>11.24</td>
<td>0.49</td>
<td>0.30</td>
</tr>
<tr>
<td>4 (4.76 mm)</td>
<td>4.60</td>
<td>0.19</td>
<td>0.10</td>
</tr>
<tr>
<td>6 (3.36 mm)</td>
<td>6.24</td>
<td>0.39</td>
<td>0.12</td>
</tr>
<tr>
<td>8 (2.38 mm)</td>
<td>6.08</td>
<td>0.50</td>
<td>0.17</td>
</tr>
<tr>
<td>10 (1.68 mm)</td>
<td>5.67</td>
<td>0.68</td>
<td>0.37</td>
</tr>
<tr>
<td>14 (1.19 mm)</td>
<td>7.04</td>
<td>1.50</td>
<td>0.97</td>
</tr>
<tr>
<td>20 (0.841 mm)</td>
<td>7.84</td>
<td>5.57</td>
<td>2.15</td>
</tr>
<tr>
<td>28 (0.595 mm)</td>
<td>7.68</td>
<td>14.31</td>
<td>4.59</td>
</tr>
<tr>
<td>35 (0.420 mm)</td>
<td>9.11</td>
<td>34.90</td>
<td>17.58</td>
</tr>
<tr>
<td>48 (0.297 mm)</td>
<td>8.07</td>
<td>27.86</td>
<td>41.01</td>
</tr>
<tr>
<td>65 (0.210 mm)</td>
<td>4.80</td>
<td>8.63</td>
<td>22.65</td>
</tr>
<tr>
<td>100 (0.149 mm)</td>
<td>2.95</td>
<td>2.31</td>
<td>7.80</td>
</tr>
<tr>
<td>200 (0.074 mm)</td>
<td>2.50</td>
<td>0.73</td>
<td>1.81</td>
</tr>
<tr>
<td>-200 (-0.074 mm)</td>
<td>2.08</td>
<td>0.19</td>
<td>0.27</td>
</tr>
</tbody>
</table>

3.3.1 Estimated Reserves

The thickness of the alluvial deposits is variable, and the stratigraphy of the area of interest, as well as the distribution of the various commodities within these geologic units, requires further characterization for a more detailed reserve estimate. Previous studies have indicated that the placer deposits containing gold and diamonds range between 1-50 m. Between 1 and 3 capa layers may be present in a given location. Some prior studies (Minproc, 1991; Caromin, 1995) have indicated that the capa may be enriched in gold and diamonds, but higher grades are believed to be located beneath these layers, in particular near bedrock.
Several geologic units in the region have been identified as probable sources of gold and diamonds. These include greenstone units of the Pastora Group and the El Callao Formation. Diamonds are found in the Roraima Formation (Degerstrom, 1994), whose erosion has resulted in mobilization of diamonds into major drainages, such as the Caroni. A biogenetic source of gold has also been proposed, but its contribution to the total gold resource is unknown.

In the Poso Hojero-Santa Rosa zone alone, a 20 km long stretch of the river, possible reserves have been estimated and are presented in Table 3.2. Based on average dimensions of the river\textsuperscript{11}, an area of about 20 km\textsuperscript{2} was evaluated in the Poso Hojero – Santa Rosa zone. It should be noted that this zone represents only 25\% of the material in the Lower Caroni River that appears to be suitable for dredging. Figure 3.4 shows the region used to evaluate the preliminary reserves for the Caroni Project. Exploitable sediments have been estimated around 252 million tonnes. Pilot studies must confirm those grades.

Table 3.2: Estimated Possible Reserves - Lower Caroni Project

<table>
<thead>
<tr>
<th>Category</th>
<th>Sand and Gravel</th>
<th>Gold</th>
<th>Diamonds</th>
<th>Ilmenite</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tons (x 10\textsuperscript{6})</td>
<td>g/t</td>
<td>Ounces\textsuperscript{1} (x 10\textsuperscript{6})</td>
<td>ct/tonne</td>
</tr>
<tr>
<td><strong>Poso Hojero-Santa Rosa Zone:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower estimate</td>
<td>222</td>
<td>0.5</td>
<td>3.6</td>
<td>0.02</td>
</tr>
<tr>
<td>Upper estimate</td>
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<td>1.0</td>
<td>10.7</td>
<td>0.04</td>
</tr>
<tr>
<td>Average</td>
<td>278</td>
<td></td>
<td>7.1</td>
<td></td>
</tr>
<tr>
<td><strong>Other zones\textsuperscript{2}:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower estimate</td>
<td>666</td>
<td>0.5</td>
<td>10.8</td>
<td>0.02</td>
</tr>
<tr>
<td>Upper estimate</td>
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<tr>
<td>Average</td>
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<td>20.1</td>
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<tr>
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</tr>
<tr>
<td>(Lower Estimate)</td>
<td>889</td>
<td></td>
<td>14.4</td>
<td></td>
</tr>
<tr>
<td>(Upper Estimate)</td>
<td>1334</td>
<td></td>
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<tr>
<td><strong>Average</strong></td>
<td>1111</td>
<td></td>
<td>28.6</td>
<td></td>
</tr>
</tbody>
</table>

1. Troy ounces.
2. Reserves in "Other Zones" were estimated based on the areal relationship between Poso Hojero-Santa Rosa zone (25\%) and the remainder of the river that is presumed to be viable for dredging (75\%).

\textsuperscript{11} The width of the river ranges between 700 - 4000m. A conservative width of 1km was used in this estimate. Thickness of alluvium ranges from 1-50 m. A thickness of 10m was used to calculate possible reserves.
3.4 Mineralogy of River Sediments

As previously mentioned, the riverbed is predominantly composed of quartz sand and igneous-derived coarser materials (gravel to boulders) imbedded with ferruginous layers, or “capa”. The capa (about 1 to 100 cm thickness) consists of sand and gravel particles cemented in limonite, hematite, magnetite and magnesium oxide (Bradbury, 1994). The capa covers additional layers of weakly consolidated sands and gravels. Previous studies have shown that up to three layers of capa inter-bedded with sands and gravels can be found in some locations. Bedrock is composed of granitic gneiss.

Riverbed material is composed of the following minerals: quartz, quartzite, chlorite, ilmenite, magnetite, monazite, goethite and feldspar. Minor minerals include: cassiterite, garnet, and rutile. Some pyrite has been identified in previous studies (Carlesi, 1990; Bradbury, 1994) as a trace mineral.
The Centre for Industrial Minerals Innovations (CIMI) at UBC conducted a metallurgical evaluation of the use of centrifuge technology on the recovery of sands of the Caroni River taken from different places on the Lower Caroni former concessions. Those tests confirmed the presence of ilmenite, cassiterite, tantalite, monazite, gold and mercury. They found that most of the black sands are significantly finer than 28 mesh (600µm). Gold cassiterite and tantalite can be separated from the rest of the sands (mostly silicates) by gravity concentration. The magnetic properties of a head sample from the Caroni sands were evaluated using a Rare Earth Separator by exposing the sample to dry high-intensity magnetic separation. A size distribution of the separated fractions was also conducted. It was found that the non magnetic material in the feed is significantly coarser than the magnetically susceptible (MS) material. As shown in Figure 3.5, ilmenite (a MS sand) can be easily separated from the rest of the sands using a 35 mesh screen. The middling fraction of this separation was mostly cassiterite (Gunson et al, 2002).

In order to get a visual sense of the mineral association and distribution within concentrated the dark sands sample from the Lower Caroni River, a qualitative SEM mineralogical evaluation was also conducted by the author. Using a Philips XL-30

Figure 3.5: Grain Size Distribution of Magnetically Separated Sands from the Lower Caroni (after Gunson et al, 2002)
Scanning Electron Microscope (SEM), it was confirmed that the main minerals present in the sample were those identified in previous analyses (ilmenite and cassiterite are the most abundant heavy minerals). Figure 3.6a and 3.6b show highly liberated minerals, as is expected in a riverbed placer deposit. The bulk of the sample is well liberated ilmenite grains. In a significant lower proportion there are well-defined casserite grains. The brightest minerals found in this sample appear to be a thorium and uranium bearing oxide (possibly thorianite) (Figure 3.6b). The sands agglomerated by the “cemented capa” were not evaluated. The degree of comminution required to liberate them has not been establish.

Figure 3.6a: SEM image of black sands
Between the late 1800’s and 1994, an estimated 200 tonnes of gold were extracted in Venezuela, the majority being from the State of Bolivar (Rodriguez, 1994). In the late 1980s a new gold rush was experienced in the State of Bolivar, stimulated perhaps by the economic recession that the country was experiencing at that time. According to estimates by CVG (Venezuelan Corporation of Guayana), approximately 30,000 to 40,000 people in State of Bolivar were involved in gold and diamond mining in 1995, with 7,000 to 10,000 operating illegally (Veiga, 1996).

Many of these informal miners were involved in dredging in the Caroni River. Dredged material was concentrated on-board using inefficient sluices and mats, and occasionally using locally-made jigs and centrifuges. Gold amalgamation, on-board or on-shore, was commonly performed using amalgamation plates. Mercury-laden tailings were returned to the river prior to a 1991 government decree prohibiting mercury amalgamation. This practice, nevertheless, continues illegally, although on a smaller scale. Local miners and
CVG estimate that at least 5 tonnes of mercury has been discharged into the River prior to and since the 1991 decree. Inefficient dredging technology, particularly at depths greater than 20 meters, combined with frequent and extensive ‘down-time’ and poor recovery methods, has resulted in at least 60% of the gold being returned to the river with tailings (Veiga, 1996).

Despite the resource potential, most miners have operated under individual one-year contracts obtained from CVG at the local level. These short-term permits did not guarantee renewal for the subsequent year, but miners were released of any legal environmental responsibility (Veiga, 1996). As a result of recent environmental regulations, short-term operating licenses are no longer granted to these small scale miners.

According to Olmore (1994), earlier dredging operations focused on the recovery of diamonds rather than gold. It has also been estimated that over four million carats of diamonds have been recovered from the Caroni, with the majority coming from the upper portion of the Guri Reservoir. Diamonds as large as 20 carats have been reported. Despite the extraordinary potential, diamond recovery was relatively laborious, particularly in comparison to gold. Consequently, when the price of gold increased in the late 1970’s and early 1980’s, the focus shifted to gold. In 1994, CVG estimated that approximately 200 dredge operations were producing 1,000 ounces of gold per day from the Caroni River.

Due to the recent construction of the Caroni Dam’s complex, concessions for dredging operations have not been granted in the Caroni River. Nevertheless, illegal dredging operations have been reported in the middle Caroni region. There are no precedents for commercial sand and gravel production in conjunction with other commodities (i.e. gold, diamonds) from the river, although it is possible that unauthorized co-extraction has occurred.
3.6 The money cycle

In order to better understand the influence that a new economic activity would bring to the local community it is important to understand to some extent the economical balance of the region. With this understanding, it will be easier to integrate the new project to the existing money cycle of the region. This analysis will also contribute to an early identification of possible detrimental effects that the project would have on a particular economic sector and ideally allow measures to be taken at an early stage to prevent them.

As mentioned at the beginning of this document, the Caroni Project would take place on the lower section of the Caroni River. This section is located within limits of the municipality of Caruachi, in the State of Bolivar. The immediate region of influence of the proposed operation would be the communities of Caruachi, Caruachito, and the region known as Santa Rosa (see Figure 3.3). This region is located about 20 km southwest of Puerto Ordaz and Ciudad Guayana, the mayor urban center of the state.

According to a 2001 INE\(^{12}\) census, the Caroni municipality has 646,541 inhabitants, 77.2% of the state population. The unemployment rate measured by November 2002 (INE, 2003) was a 15.7%. Ciudad Guayana, also located in the Caroni municipality (542,707 inhabitants, 50.66% male, 49.34% female) it is located at the confluence of the Orinoco and Caroni Rivers (west to the Lower Caroni River, see Figure 3.3). Its economic activity heavily depends on the metallurgical and chemical industries, alongside cement production.

Puerto Ordaz (6900 inhabitants) is also a port city located in the same confluence of the Orinoco and Caroni Rivers (east side of the Caroni) with a strongly industrial economy. The total area would include the newly-named metropolitan sector of Santo Tomé de Guayana.

A gold rush, started in 1961, followed by the discovery of diamond deposits in the Lower Caroni Region, created the small community of Caruachi (around 200 inhabitants by

\(^{12}\) INE, Venezuelan National Institute of Statistics (Instituto Nacional de Estadísticas)
1994). This small community was located nearby the area of interest for the Caroni Project, its main characteristic was its labor instability, with an unemployment rate of 22.6%. With the new legislation that banned mercury uses for gold extraction and the construction of a new dam (and consequently the partially flooding of the sector) this community was order out decreasing the temporarily mining population around the mining zone.

3.6.1 Government Investment

Initially with funds from the Inter-American Development Bank, and later on with capital generated from the national oil industry, the government has created public companies that are among the bigger employers of the country. Under the umbrella of the “Corporación Venezolana de Guayana (CVG)” are a number of mining, metallurgical, chemical and agro-industrial companies such Alcasa, Carbonorca, Conacal, Bauxilum, Edelca, Minerven, Ferrocasas, Ferrominera, Proforca, Venalum, Tecmin and Alunasa. These government run operations provide 19,287 direct jobs in the lower Caroni Region (personal communication, information service CVG), and indirectly support about the 40% of the population. The oil industry also has several ongoing projects, including a heavy oil refinery in the region that would provide significant direct employment benefits. The operation of the ports on the Orinoco is another source of government income and employment.

3.6.2 Informal Sector

In 1994 the informal sector\(^{13}\) (51.3% of employable population) exceeded the formal sector for the first time in recent Venezuelan history. In 1999 the economic growth of the country started to decrease for the first time in 50 years (COINDUSTRIA, 2003). By November 2002 the informal sector in the country represents a 52.2% of employable population (INE, 2003). Even if this proportion is assumed to be lower for the Caroni Region due to its industrial nature, it can be concluded that at least 300,000 inhabitants of

\(^{13}\) Defined according to the INE as labour of non registered enterprises with less than 5 employees (owner included), house keeping, non professional self employees (artisans, drivers, painters, carpenters, etc.) and non remunerated family helpers with more than 11 h per week.
the Caroni region belong to this sector. In the State of Bolivar, small scale mining and
dredging are a significant part of this sector.

By 1996, CVG estimated the number of small scale miners nationally to be around
30,000 to 40,000, almost all located in the State of Bolivar, of which between 7,000 and
10,000 were illegal (Veiga, 1996). Based on information provided by local artisanal
miners, and local gold and diamond dealers, there is a strong informal economy related to
gold production in the region. At least 25 dredging barges are still operating in the middle
Caroni in the Guri Dam region near the village of El Manteco. These barges provide
direct income to at least 100 dredge workers and services providers, and income for
dredger owners and dealers (personal communication with local gold traders, 2003).
There are some indications of artisanal mining activities at the upper Caroni River near
Ikabaru. It is estimated that an average of 12 grams of gold per month are recovered by
each operation (Zsupanek, 2003).

3.6.3 Private Investment

Since 1997, foreign investment in the country has been drastically reduced from
Nevertheless, foreign investment in the mining sector in the State of Bolivar during the
period between 2000 and 2002 has been estimated at US$1,196 million, (CONAPRI,
2003) represented in ongoing projects by Elkem Group, Pechiney, Glencore / Palmat,
Hecla, Vanessa Venture Ltd. Yankuang Group-CVG and Shandon-CVG, and Cristallex
(with the Las Cristinas mining project formerly owned by Placer Dome). Some are
represented by partial ownership of state companies. There is also a Swedish power
producer (ABB) and a Chilean timber company which produces fiberboard, timber and
wood products for export markets. Japanese, Korean and American iron reduction plants,
Acidos y Minerales de Venezuela with a cast iron plant, and Odebrecht civil engineering
(constructing a second bridge over the Orinoco River) are also operating in the region.
Local investment is mainly represented by service provider companies and retail stores. There are also local quarry operations, furniture builders, restaurants and hotels and entertainment sectors. In the industrial sector, some cement companies are also owned and operated by local investors. Figure 3.7 summarizes the economic “cycle” of the Lower Caroni region.
Figure 3.7: Economic Cycle of the Lower Caroni Region
It can be concluded from this section, that the incorporation of the Caroni Project to the economical cycle of the region will be beneficial to most economic sectors. It can be seen in the generation of direct employments, taxes and royalties paid to the country, and creation of a demand for local services and supplies. Even though there are other aggregates exporters in the region, there does not seem to be a conflict because the Caroni Project targets a different market.

Although a direct impact on former concession holders can not be considered because those concessions expired long before the proposal of the Caroni Project and because there are no artisanal dredgers operating on the region of interest, granting a concession to a foreign company will promote a reactivation of dredging within the river under higher social and environmental standards. Former local operators will have to strongly invest to upgrade their equipment and socio-environmental practices in order to meet the new standards. This sector may be affected by the new circumstances but at the same time the Caroni Project would open the door for new concessions being granted to local operators with the capacity for raising such standards. Nevertheless, there is a potential opportunity for the Caroni Project to subcontract part of the operation to local dredgers while contributing to the upgrade of technical and managerial skills of local operators. This will be further evaluated in Chapter 6

4 DREDGING SYSTEM DESIGN

This chapter contains detail information about the project proposed by Cadre Resources Ltd. It is based on the current available knowledge, followed by a preliminary economic analysis of the project in order to determine the possible economic capabilities of the enterprise.

Cadre Resources Ltd.

With headquarters in Vancouver, Cadre Resources was founded in 1988 and registered under the Canada Business Corporation Act of the Province of British Columbia. Cadre is listed on the Canadian Venture Exchange under the symbol “CSL.T” with 8,971,715 shares issued. In the United States, Cadre has a 12g registration and an Over the Counter
Bulletin Board (OTCBB) symbol of CDRUF, although OTCBB trading and market making has not yet been pursued (Sandner, 2001). Cadre has been actively involved in the Lower Caroni region since 1994 and has identified several unexploited and partially exploited areas of interest on the Caroni River from Guri Dam to Puerto Ordáz. All are previously, poorly worked concessions (Sandner, 2001).

As briefly mentioned in Chapter 1, Cadre is proposing to invest in a large-scale river dredging project for the recovery of sands, gravel, ilmenite, gold and diamonds in the Lower Caroni River, Venezuela. The Lower Caroni region has been a known producer of gold and diamonds for over a century. In the past, production has been dominated by small and medium sized companies and individuals using somewhat inefficient and environmentally destructive techniques.

The Caroni Project intends to extract 10 million tons (9.1 million tonnes) of material annually with estimated gross revenues of US$200 million. Initial resource estimates indicate the operation is viable for more than 100 years. All dredged material is to be slurry-piped to a processing plant located adjacent to the Orinoco River. Unique characteristics of the project include the absence of tailings (it was estimated that about 95% of the material extracted will be sold as product) and the remediation of mercury contamination already present in the river. This represents a significant cost savings and benefit to the local environment, respectively. Figure 4.1 shows the general layout of the proposed operation.

The upper section of the figure shows a map of the Caroni municipality and in particular the region of confluence of the Caroni and Orinoco Rivers. At the west side of the confluence there is the city of Puerto Ordáz, where the CVG-EDELCA complex, among other industrial companies and the airport, are located. Along the east side of the Orinoco River, a series of industrial piers are operating for the iron industry. The city of Ciudad Guayana and some farming developments are located at the east side of the confluence.
The lower part of Figure 4.1 shows a tentative layout of the complete operation from left to right. Initially, the sediments from the Lower Caroni River would be extracted by the selected dredging methods and pumping using a 12 inch diameter floating pontoon pipeline into an on-shore temporary storage/homogenizing tank. From the tank (that could be replaced with a storage barge), the homogeneous slurry would be transported to the processing plant by a piping system of 18 inches external diameter reinforced iron along about 13 km. More details about the processing and material handling processes are presented later in this Thesis.
Figure 4.1:
Preliminary Operation Layout
4.1 The Proposed Dredging Technology

Selection of a single dredging technology is a complex issue due to the variable characteristics of water depth, type of sediment and accessibility. As shown in the profile of the Lower Caroni River (Figure 4.2), the series of dams in the river, combined with the initial topography of the area, have resulted in deep water in some locations, particularly in the reservoir located between the Guri and Caruachi Dams. Thus, at least three dredging technologies with variable characteristics have been considered.

![Figure 4.2: Profile of the hydro-electrical dams’ complex at the Lower Caroni River (Veiga, 1996)](image)

4.1.1 Cutter suction (CS) dredger

CS dredging systems are suitable for depths to 20 m. However, when these dredgers are equipped with underwater pumps, they can reach up to 35m in depth (Figure 4.3). Shallow-depth dredging systems are specially designed for maximum efficiency with low turbidity. The specific design, cutter head, tooth types and general operating configurations can be selected according to the sediment characteristics and production requirements. According to manufacturer tests, the CS dredger can handle on average
20% sand by weight and 15% gravel by weight. Two 14 in., CS at each dredging site are envisioned by the proponent for some sections of the river in order to have flexibility without compromising throughput. Figure 8 shows an electrically driven, cutterhead 14 in., suction dredger similar to the one described in this section. Figure 4.4 shows the current flexibility in the designs of cutter heads, the different sizes and configuration of the teeth depending on the composition and degree of compaction of the sediments to remove.

Figure 4.3: Electric Suction Dredge (DCS) (taken from manufacturer catalogue)
4.1.2 Hydrostatic dredger with hydraulic underwater airlift crusher

These dredgers utilize the hydrostatic pressure of the overlying water column and compressed air to force material at depth through a suction head to the surface. If the hydrostatic head is too low, a vacuum system is activated to guarantee that suction into the cylinder is maintained. As the pressure gradient is continuous into the cylinder, turbidity generation is negligible.

A number of pneumatic dredgers are available, including the Neptun 253, which can efficiently operate at depths of up to 50 m, dredging material containing up to 25-30% solids. Figure 4.5 shows a profile of the Neptun 253 dredger. It consists of a barge carrier of hydro-suction and drainage chambers and a crane-like structure that supports the sub-aquatic hydraulic crusher head and suction pipe. In this system, the underwater airlift crusher can reduce boulders up to 800mm in diameter to 30 mm size, which can then be lifted along with sand and fines using the hydraulic system. Although this pneumatic system is not a rotary crusher, the shovel-like form and strong suction facilitates the extraction of large stones, sands and clays without generating significant turbidity. Based on project requirements, a 300-350 mm dredger discharge line is recommended by the suppliers (S.M.S, 2001)
4.1.3 Pneumatic pump and dredger (Pneuma®)

Another system likely to be used in the proposed project is the Pneuma® S.R.L. manufactured pump and dredge. This system uses static water head and compressed air inside special cylinders in a piston-like manner. The hydrostatic force fills each cylinder sequentially with sediment slurry (Figure 4.6 stage 1). While the cylinder is being filled, compressed air supplied by a distribution device attached to a compressor that acts as a piston and the slurry is forced through a valve to the discharge pipeline (Figure 4.6 stage 2). As the cylinder empties, the compressed air is discharged while releasing the internal pressure of the cylinder (Figure 4.6 stage 3) (Orchard, 2001).

The manufacturer claims that for loose materials like sand and gravel, the solids content in the dredged mixtures varies from 50% to 90% in volume. The higher efficiency is due to the high inlet velocities reached by the pneumatic pump and to the effect of the hydrostatic head.

Figure 4.6: Operation of the Pneuma® Pumping System (After www.pneuma.it)

According to evaluation conducted by the manufacturer (Pneuma, 2002), when compared with cutter head dredger (CHD centrifugal pump) for similar size equipment (dredging
depth of 10 m), Pneuma pumps present a higher performance in relation to reflux distance (3500m with Pneuma vs. 3000 with CHD), a better output of solids (750 m³/hr with Pneuma vs. 400 m³/hr with CHD) with a higher slurry concentration (50% versus 20%, respectively). The power requirements on the other hand were higher for the Pneuma system (2240HP versus 2120 HP)

Hydrostatic pumping systems, particularly Pneuma can be operated in two ways:

- **Hole Dredging:** This method is frequently used to dredge loose materials like sand and gravel embankments. As shown in Figure 4.7a, the pump body is suspended by shears and lifted by a winch. The pump starts operating when the three inlet pipes are in contact with the bottom of the water body (Pneuma, 1983).

- **Trailing Dredging:** This method is more suitable for compacted materials such hard clay, sandy silt or mud. As illustrated in Figure 4.7b, this method uses the same standard pumping system, but the three inlet valves are connected to a disintegrating and leveling shovel (or set of shovels) (Pneuma, 1983)

A closer look of the standard array for the pumping system is shown in Figure 4.7c. Their size varies from 3.66 m high by 2.63 m in diameter to 6.2 m high by 4.6 m in diameter. The lower section of Figure 4.7c shows a profile of the shovels.

This dredging system has been successfully used in reclamation dredging since 1976, when it was used by USACE in the clean up operations of the Duwamish Waterway in Seattle Harbor. In 1993, Pneuma system was also used to dredge hydro-electric basins under varying levels of depth from 5 m to 20 m as was the case during the reclamation of PCB-laden silts and clay from Collingwood Harbor, Ontario (Orchard, 2001, Buchberger, 1993). From 1982 to 1986 Pneuma pumps were used at Gibraltar Lake (Santa Barbara California) in the de-siltation of the water reservoir. Similar cases can be cited at Shimen Dam in Taiwan where Pneuma dredges were used in the removal of sediments 80m below the water surface. In 1982 the Ofima reservoir at the Palagnedra hydro-electric basin (Switzerland) also utilized a 50m dredging operation operated by Pneuma Dredging Systems.
Figure 4.7a: Hole Dredging System

Figure 4.7b: Trailing dredging System

Figure 4.7c: Hydrostatic pump standard arrangement
(taken from www.pneuma.it)
It is suggested the implementation of a dredging program that uses different dredging systems for recovery of different type of materials within the same site. An initial hydrostatic/pneumatic system could remove the loose sediments (sand and gravel) and most of the anthropogenic mercury with a lower uptake of water. After the loose material is dredged, a dislocating dredging system (i.e. cutter headed) capable to crush hard pan layers can be use. The number of stages for this program should be implemented according to the distribution of sand and gravel embankments and hard pan layers within the riverbed. In any case, the dredging system should be tested at a pilot scale. Uncertainties like the behavior of gold and mercury on the bottom of a Pneuma cylinder (and how to recover it if necessary) can be resolved at this stage.

Most dredgers can be located on a 30 m long, 15m wide, deep barge equipped with 20-ton winches for use in lifting/pulling anchors, moving piping and other equipment. The dredged material is more likely to be transported to a container barge floating beside the dredger from where a second arrangement of hydrostatic pumps would be able to transport by pipeline highly dense slurry to the processing facilities.

Another option evaluated was the use of a pipeline transport system using a centrifugal pumping arrangement with a densifier tank located on the riverbank. This densifier tanks would increase material density to 30% (Hagler, 2000) solids while homogenizing the slurry to avoid cavitations and pressure losses in the piping network. This second option will not be applicable if high slurry density (50 -90% solids by volume is achieved.

A service boat will also be required for transport of heavy equipment and for use by mechanical maintenance personnel. A welding machine/cutting unit, tools, and other supplies, located aboard a small floating deck would also be required for dredger maintenance.

4.2 Containment Systems

Best practices programs like the one proposed by Hartman, (1996) for the dredging industry, highly recommend the use of containment barriers in order to prevent or
minimize the consequences of dredging activities into the water body. Among these measures, nonstructural containment barriers as silt curtains and/or gunderbooms\textsuperscript{14} are widely used at sediment remediation sites. The selection of silt curtains is primarily determined by the hydrodynamic conditions at the site. Conditions that reduce the effectiveness of barriers include: strong currents, high winds, changing water levels, excessive wave height (including ship wakes) and drifting ice and debris (EPA, 1994). Silt curtains and screens are most effective in relatively shallow, quiescent water. It is not recommended to use silt curtains in water deeper than 6.5 m or in currents greater than 50 cm/sec (St. Lawrence Centre (1993 cited by EPA, 1994). The cost of implementing turbidity curtains is relatively low; it ranges from US$13 to US$30 per square foot depending of water flow conditions and the expected life time the curtain would be in operation. A maintenance kit of US$400 would be required. Transport and maintenance will depend of the project location and labor cost (personal communication with Elastec\textsuperscript{®} sales representative).

The quantity and type of suspended solids, the mooring method\textsuperscript{15}, and the characteristics of the barrier (JBF Scientific Corp. 1978 cited by EPA, 1994), all have to be taken into account when selecting containment barriers. To be effective, barriers need to be deployed around the dredging operation and must remain in place until the operation is completed at that site. For large projects, it may be necessary to relocate the barriers as the dredger moves to new areas. They may also be used to protect specific areas (e.g., valuable habitat, water intakes, or recreational areas) from suspended sediment contamination (EPA, 1994).

In the particular case of the Lower Caroni, it is important to consider that the Caroni Project would operate in the same region where the tap water intake for the Caroni municipality is located. This is also the region of influence of the Caruachi Hydro-electrical Dam. These two factors make the Lower Caroni River a very sensitive working

\textsuperscript{14} Similar to silt curtains but constructed of permeable geotextile fabrics designed to extend from the water surface to the sediments bed. They are also designed to allow water to flow trough the curtain while filtering suspended dredging sediments (Hartman, 1996)

\textsuperscript{15} Method to tie it together
area that creates concerns on EDELCA, local population and authorities about mobilization of contaminants (heavy metals like mercury or lead) and siltation.

The series of hydro electrical dams controls the water flow in the Caroni River between the Guri Lake and the Orinoco River, so there is a low probability of unexpected drastic changes on the water regime in the dredging area. Low sediment suspended in the Caroni waters and the low content of fine particles in its sediments suggests that the use of a silt curtain as a preventive measure is sufficient.

4.2.1 Delivery System

Depending on the type of dredging system in operation different water content in the slurry would be achieved. In any case, a temporarily slurry containment would be required to homogenize\(^{16}\) the slurry to be pump to the processing facilities. The first option evaluated was the Hagler® piping system that includes a homogenizing/densifier tank (size can be customize) and an arrangement of two booster pump stations along the delivery pipe. According to the manufacturer (Hagler®), the main pipeline would handle up to 2000 t/h (1814 tonnes/h). Approximately 5 km of secondary piping would be required as dredging progresses north-east and south-west of the central homogenizing tank. These lower capacity pipelines (12” ID) would handle approximately 880 t/h (798 tonnes/h) of slurry. The homogenized material could be pumped 10 km to the processing plant via a steel pipeline (17”ID). A Hagler® system\(^{17}\) if sludge density is kept under 30% solids in volume. If simultaneous dredging operations are feasible, a bigger piping arrangement would be required.

The second option is the pneumatic pumping system (also requires two pneumatic booster stations) from a stationary barge just beside the dredger. Barges with a liquid carrying capacity from small barges of about 100m\(^3\) to more than 1500m\(^3\) can be anchor

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\(^{16}\) Homogenization is needed in order to improve the performance of the pumping system and to avoid changes in pressure that can lead to cavitations (when applicable) and malfunctioning of the pumps.

\(^{17}\) The Hagler® system consist of a 17” ID pumping system using 2 main variable speed pumping stations on the beginning and mid-section of the pipeline, and two constant speed auxiliary stations along the pipeline (personal communication with supplier).
close to the dredger to receive the dredged material and from there to be piped to the processing plant. An example of these barges is shown in Figure 4.8. The pipeline could be operated under all slurry density conditions using a hydrostatic system (i.e. a Pneuma® “re-flow” and booster pumping arrangement). A pneumatic pumping system for piping is suggested due to lower footprint and lower water content. Nevertheless, security issues have to be considered.

![Figure 4.8: Storage barge for dredged material. (after Pneuma, 2003)](image)

4.3 Processing Plant

The processing facilities would consist of two adjacent 850 t/h processing plants, a stockpile area and a material handling system for dredged material and concentrate. Those would likely consist of pipelines and conveyor systems respectively. According to Bateman (2000), the processing plant would most likely contain feed preparation units, a spiral plant for gold and ilmenite separation, and Gemini table for gold recovery, a furnace with scrubber for mercury recovery, and a DMS plant and X-ray sorter for diamonds recovery (Figure 4.9). A gravity concentrator has been also evaluated and appears to be effective for gold and mercury recovery (Gunson et al, 2002). The need for a major tailings impoundment is not anticipated based on the current available information. A slimes and waste water treatment facilities would be needed.
4.3.1 Land Based Facility

The land-based facility would be comprised of two 850 t/h processing plants and a material blending/stockpile area. The estimated cost of the first processing plant and blending/stockpile area is estimated at US$ 18 million, including shipping, erection and civil engineering costs. The second plant is estimated at US$ 9 million. The processing plants are likely to contain the following units:

- feed preparation,
- a spiral plant for gold and ilmenite separation,
- a concentrator and Gemini table for gold recovery,
- a furnace with scrubbers for mercury recovery, and,
- a DMS plant and X-ray sorter for diamond recovery.

Based on a preliminary sediments distribution (Table 3.1), the plant input approximately consists of 545 t/h of sand and 305 t/h of gravel (495 and 280 tonnes/h, respectively). With the addition of the second 850 t/h plant, the total feed rate would increase to 1090 t/h of sand and 610 t/h of gravel (990 and 560 tonnes/h, respectively). Figure 4.9 shows Bateman’s (2000) proposed flow diagram for the processing plant. The need to recover metallic mercury from others processing outputs different that concentrates (-1mm +0) has to be evaluated.
Figure 4.9: Flow Diagram of the Processing plant for the Caroni Project (Batewman, 2000)
4.3.2 Water Treatment

From the solid material feed to the processing plant, it is assumed that a maximum of 53% by weight (753.8 t/h) of water will be input to the processing facilities. By the time the two plants are fully operational, about 1507.6 t/h of water will be input to the process. Even though some of this water will be recycled to the processing operations, storage and treatment is required for excess water before using it for agricultural or industrial proposes or before discharging it to the Orinoco River.

The size of the containment facilities would depend of the retention time of the water treatment operation that in turn will strongly depend of the content of fine particulate in suspension and heavy metals compounds in solution. For these reason it is strongly suggested to implement a high density dredging and piping systems to reduce the amount of water to treat.

In relation to the waste water treatment itself, in case of high concentration of dissolved heavy metals or mercury compounds are present in the water, it is technically possible to treat them using a settling pond where a polymeric flocculants\textsuperscript{18} or metal sequestering agents may be used to precipitate heavy metals. Metal sequestering\textsuperscript{19} can be made using dithiocarbamates forming highly insoluble compounds (with solubility far below that of the corresponding hydroxides) Flexsys (2003). A thiol-based chelating agent also has been developed and successfully used in the removal of heavy metals including mercury on the Great Lakes Watershed where effluents of many industrial processes, as well as surface and groundwater from historically polluted sites, often contain unacceptably high levels of mercury and other toxic trace metals. (Hensman and Bloom, 2001).

\textsuperscript{18} http://www.generalchem.com/soldering_fluxes/Aqua-Floc_3300.htm
\textsuperscript{19} http://www.water-technology.net/contractors/water_chem/flexsys_nv/
4.4 Sludge Containment Facilities

It is considered sludge the fine sediment particles below 200 mesh that could be either dredged or generated as result of piping and processing friction. This material is usually separated after processing and waste water treatment. Based on the current flowsheet and size distribution of the sediments shown in Table 3.1 (4.58% to 0.92% by weight) and also assuming that, a major tailings storage facility will not be required. A small impoundment for slimes with an estimated final capacity of approximately 1 million m³ is anticipated. In the event that the process designs change, a larger impoundment may be needed.

In order to reduce volume requirements of a slimes containment facility, techniques for slimes densification should be evaluated in subsequent project studies. According to (USTDA, 2000) these include the following:

- Stacked disk centrifuges;
- Decanter centrifuges;
- Drum and/or disk vacuum filters;
- Pressure filters
- Geo-textile filters; and
- VSEP\(^{20}\) screens.

A comprehensive review of these and other technologies should be conducted in detail once more information about the nature and quantities of particles bellow 75 microns will be in the water effluents from the processing plants. The use of a geo-textile as a containment-filtering process would be highly attractive. Wangensteen et al (2002) have developed a fairly new technique for draining fine contaminated sediments using a geo-textile pipes to filter and storage sediments highly contaminated with mercury (up to 12mg/kg), copper (up to 277 mg/kg) and lead (up to 1,220 mg/kg) as major contaminants from Grubers Grove Bay, Baraboo, Wisconsin.

Based on current information, which indicates that the acid generation potential for material from the Lower Caroni is low, a sub-aerial slimes facility would be sufficient. Due to the intensity of seasonal rainfall in the region (1-2 m/a), the potential for metals mobilization should be considered. If further geochemical test work indicates a potential for acid rock drainage (ARD) generation or mobilization of metals through neutral drainage, an alternative slimes facility design may be required.

As the topography is relatively flat, many locations in close proximity to the proposed processing plant site appear to be suitable for a small impoundment. A detailed evaluation of potential sites should be conducted in the future. A potential also exists in the region for shallow earthquakes (0-33 km depth) (USGS, 2001). Therefore, seismicity hazards, as well as the potential for flooding and other natural hazards, should be assessed in a more detail.

4.5 Product Shipping

4.5.1 Conveyor system

Once the product is ready for shipment, it would be transported to the shipping terminal and loaded on 50,000 - 60,000 DWT21 capacity Seabulk Systems Inc22., self-unloading ships using a conveyor system. Based on the proposed processing plant location, approximately 3 km of conveyors would be required. Based on information provided by potential suppliers, (Eastern Machine and Conveyors Inc. Dorona, PA., direct communication) and using a 250-300 HP, 48 inches wide conveyor with a 400 ft/min loading rate (approx 5000 t/h).

4.5.2 Blending/Storage Area

An estimated 250 m by 250 m storeage and blending area would be required for storage of sands, gravel, black sands and ilmenite concentrate. This should be sufficient to stock

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21 Dry Weight Tonnes
22 Involved exclusively in Bulk Materials Handling Systems since 1989, the main focus of Seabulk is the development of proprietary new Material Handling Systems for the waterborne shipment industry. Seabulk is currently involved as a co proponent of the Caroni Project.
piles up to 300,000 tons (about 225,000 tonnes) of material. Fine-grained products must be kept in a covered structure to inhibit dust generation and erosion. Prior to construction (if feasible) of an ilmenite recovery circuit and smelting plant, a larger storage area (180m x 180m for 150,000 tons, or 135,000 tonnes) may be required for ilmenite containing black sands.

In order to provide products that meet client specifications, storage facilities can be underlain by an automated feed bin system with bulk flow gates, in order to control the release of required volumes of material and facilitate blending. Sand and gravel of specified grain size and quality would be combined in an underlying bin and transported via conveyor to the ship loading terminal. A number of process control systems are available for accurate aggregate blending in continuous mix or batch plants. Most systems can control the ratio blending of more than 10 feed bins to exact mix formulas. Analog or digital proportioning controllers would be used to accurately release required ratios of specified materials.

The potential for Lower Caroni River aggregates to compete within existing markets primarily hinges on the availability of an efficient and economic means of waterborne product transport. Seabulk Systems Inc. is currently engaged in ship loading, marine transportation using self-unloading vessels, and other bulk materials handling equipment around the world.

Seabulk has proposed the installation of a high capacity ship loader (4000 tonnes per hour) at a loading site on the southern bank of the Orinoco River. The loader would service bulk carriers customized to suit the receiving ports and to be self-unloading at a high rate. A proprietary self-unloading system has recently been demonstrated by Seabulk Systems Inc. for the export of construction aggregates from Western Canada to California. Conversion of 50,000 to 60,000 DWT ships to self-unloading vessels, as well as detailed design of the shipping terminal (e.g. dock, loading system, etc). Figures 4.10a and 4.10b show a British Columbia base Seabulk Operation.
With the third highest flow volume in the world \(1.1 \times 10^{12} \text{ m}^3\) per year, the Orinoco River transports only one-fifth of its maximum shipping capacity of 100 million tonnes per annum. The Orinoco accepts ships with an 80,000 DWT load capacity in the rainy season (May-October) and a 50-60,000 DWT capacity the remainder of the year. This Project intends to use 50,000 to 60,000 DWT capacity vessels.

Figure 4.10a: Seabulk’s ship loading system in action (www.seabulkinternational.com)
In Puerto Ordaz, the Ferrominera Orinoco C.A. operates a large port facility that is currently utilizing only 10% of its capacity, and could be temporarily used prior to construction of a permanent facility. Alternately, as there is a natural basin at the confluence of the Orinoco and Caroni Rivers, there are a number of locations suitable for the construction of temporary (i.e. floating) or permanent loading facilities.

4.6 Health and Safety

Potential health impacts to the community primarily relate to the potential for: contamination of food sources or drinking water through metals mobilization enhanced (e.g. Hg, Pb) by dredging or slime deposition, exposure to metals and other constituents from dust, and impacts from noise pollution. Oil spills may be another source of potential impact.

A health and safety program should be required for all employees, permanent and contract, of the project. This program should include consideration of chemical handling, emergency response procedures, first-aid, and corresponding training for employees. Material Safety Data Sheets (MSDS) should be compiled for all potentially hazardous
materials. First aid training will be required for a specified number of employees, with a minimum number of trained personnel per shift. First aid supplies should be located at accessible, well-labelled locations in the plant and on dredgers, and contact information for more extensive emergency response should be posted. Measures to limit effects of dust, noise, or other irritants should be well distributed to personnel and their use enforced. Preventive measures such as turbidity curtains with oil containment pads would reduce the risk of lubrication oil spills.

4.7 Economic Feasibility of the project

Exploitable sediments have been estimated around 252 million tonnes, as shown in Table 3.2. Assumptions used in this preliminary estimate are considered to be conservative, particularly the value used to represent the deposit thickness (10m). Most data derived from existing studies suggest the thickness of the alluvium is in excess of 20m. More reliable determination of reserves is recommended further in this project. Figure 3.4 also shows the assumptions made for the estimation of preliminary reserves.

The long-term reserves and assessment of this region’s mineralogical potential are important, as they can guarantee the economic feasibility of the project and the generation of long lasting employment for at least two generations.

4.7.1 Cash Flow Analysis

Expected profits, capital and operating costs were estimated using data provided by the proponent and equipment and services providers. Table 4.1 shows the estimated grades and production of the project. Table 4.2 contains the prices of the commodities also used. The rationale for the selecting these prices is primarily based on the results of the Market Evaluation conducted by (Sandoval and Hinton, 2002- unpublished). This information is used to evaluate the cash flow of the project for the first 10 years of operation (see Appendix I for details). Working capital of $16.4 million (half of operating cost for a year) was considered necessary at the start of operation.
Table 4.1: Assumptions: Productivity and Grades

<table>
<thead>
<tr>
<th>General assumptions</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Production first year</td>
<td>3,500,000</td>
<td>ton</td>
</tr>
<tr>
<td>Total Production second year</td>
<td>7,000,000</td>
<td>ton</td>
</tr>
<tr>
<td>Total Production third year on</td>
<td>10,000,000</td>
<td>ton</td>
</tr>
<tr>
<td>Percent of Sand and Gravel</td>
<td>85.0%</td>
<td></td>
</tr>
<tr>
<td>Gold Grade (95% recovery)</td>
<td>0.71</td>
<td>g/ton</td>
</tr>
<tr>
<td>Diamonds (95% recovery)</td>
<td>0.03</td>
<td>cts/ton</td>
</tr>
<tr>
<td>Ilmenite concentrate (1.5% @ US$70/tonne)</td>
<td>1.50%</td>
<td></td>
</tr>
</tbody>
</table>

Table 4.2: Estimated Prices of the Commodities

<table>
<thead>
<tr>
<th>Estimated Prices</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand and Gravel</td>
<td>10.00</td>
<td>US$/ton</td>
</tr>
<tr>
<td>Gold</td>
<td>300.00</td>
<td>US$/ounce</td>
</tr>
<tr>
<td>Diamonds</td>
<td>100.00</td>
<td>US$/ct</td>
</tr>
<tr>
<td>Ilmenite concentrate</td>
<td>93.00</td>
<td>US$/ton</td>
</tr>
</tbody>
</table>

As royalties associated with the various commodities have not been determined, royalties have been included within an estimated 45% of total taxation after profits. It was also assumed an investment on equipment update after ten years of operation. According to this evaluation, at current commodity prices (March 2003) the proposed project estimates an internal rate of return of 60%, a Net Present Value of US $248.4 Million and a Cash Flow Index of 3.3. Figure 4.11 summarizes the project cash flow for twenty years of operation.

The operating costs were sub-divided as per the capital cost (dredging, material handling, processing and services). Where other information was not available, estimates were developed in accordance with the SME guidelines (1992). Table 4.3 summarizes the estimated operating costs.
<table>
<thead>
<tr>
<th>Operating Cost</th>
<th>Value</th>
<th>Imperial</th>
<th>Metric</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dredging</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dredge operating cost (incl. spare parts)</td>
<td>$0.47</td>
<td>US$/ton</td>
<td>$0.52</td>
</tr>
<tr>
<td><strong>Material Handling</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pipeline maintenance and spare parts</td>
<td>$0.25</td>
<td>US$/ton</td>
<td>$0.28</td>
</tr>
<tr>
<td>Conveyor maintenance and spare parts</td>
<td>$0.01</td>
<td>US$/ton</td>
<td>$0.01</td>
</tr>
<tr>
<td>Ship loading</td>
<td>$0.75</td>
<td>US$/ton</td>
<td>$0.83</td>
</tr>
<tr>
<td>Shipping (assume to port in Florida)</td>
<td>$6.00</td>
<td>US$/ton</td>
<td>$6.61</td>
</tr>
<tr>
<td><strong>Processing Plant</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Processing plant maintenance and spare parts</td>
<td>$0.64</td>
<td>US$/ton</td>
<td>$0.71</td>
</tr>
<tr>
<td><strong>Services</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Administration</td>
<td>$0.01</td>
<td>US$/ton</td>
<td>$0.01</td>
</tr>
<tr>
<td><strong>Waste Management Facilities</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water treatment</td>
<td>$0.15</td>
<td>US$/ton</td>
<td>$0.17</td>
</tr>
<tr>
<td>Slimes pond</td>
<td>$0.09</td>
<td>US$/ton</td>
<td>$0.10</td>
</tr>
<tr>
<td><strong>Total Operating Costs</strong></td>
<td>$8.36</td>
<td>US$/ton</td>
<td>$9.22</td>
</tr>
</tbody>
</table>
Figure 4.11: Estimated Cash flow for 20 years of the Lower Caroni Dredging Project
Figure 4.12: Sensitivity analysis of the Lower Caroni River Project
4.7.2 Sensitivity Analysis

The Caroni Project appears to achieve a financial stability as soon as the second year of operation. The economic capacity and relatively fast investment recovery of this project, indicates that the enterprise would be able to undertake voluntary initiatives and assume preventive or possible remedial measures. Figure 4.12 shows an IRR base sensitivity analysis\(^{23}\) of the project. It suggests that the project success highly depend of the price and grade of commodities (lines with steeper angle in relation to the X axis on Figure 4.12). It is interesting to see how in this case the increase in environmental and social investment (community funding, slimes and water facilities) do not appear to have a significant impact on the economics of the project at this point. This may be due to the rapid recovery of initial capital expected for this project can afford a bigger initial investment (i.e more costly and efficient water and slimes treatment facilities).

The size of this proposed venture, compared with the several extractive projects happening simultaneously elsewhere in the region around the Caroni Project, show it to be relatively small among the big projects, nevertheless influential in relation to employment generation. Initially 145 direct employments in the dredgers and processing plant would be created, with an increase while increase of production. The shipping and loading contractors have not been included.

The heavily industrialized manufacturing base of the region, as well as the fairly diversified local economy, is factors that would contribute to the potential for sustainability of the project. The implications of economical aspects in the integration of the project in a sustainable way to the surrounding community will be discuss more in detail further in this thesis.

\(^{23}\) Evaluation of the performance of the project when the main economical variables are change in terms of Internal Rate of Return (IRR)
5 POTENTIAL ENVIRONMENTAL IMPACTS

For the development of this preliminary environmental impact assessment, a group of experts (geologists, anthropologists, engineers and business developers) who have been involved with the development of the Caroni Project were invited to participate in an Environmental Technology Assessment (EnTA). Their expertise on riverbed dredging technologies, mineral processing, environmental impacts on tropical ecosystems, exploration development and community liaisons was consulted during the EnTA half-day session.

The methodology for the Environmental Technology Assessment is an initiative of the United Nations Environment Program (UNEP), designed to facilitate the selection of appropriated technology to suit environmental social and economic circumstances and priorities of a region (UNIDO, 2000). The EnTA methodology promotes the participatory multi-stakeholder evaluation of possible impacts derived from the implementation or transfer of technology mainly in developing countries. There is a strong social component imbedded within the methodology, therefore, social aspects that may or may not be influenced by environmental impacts will also be taken into account. In this particular case the impact assessment component of the EnTA methodology is used in the evaluation of possible impacts of implementing the Caroni River dredging project from an expert’s perspective.

The concept of judgments from experts has been widely used in decision analysis in a qualitative or semi-quantitative way. At this point it will not be developed as a multi-stakeholder approach; rather, the intension was to brainstorm possible negative impacts of the proposed project. Basically, after providing the participants with basic information about the proposed project, a team of seven people with different fields of expertise meet in a 5-hour session to identify possible impacts.

After discussing the topics, a conclusion was reached about the more important issues that they suggest must be evaluated during the feasibility study. These issues were rated,
and an average was calculated in terms of how important each issue was considered by the participants. Note that this average is just a perceived value. The impacts were divided into five categories, the same categories used in the EnTA methodology.

5.1 Perceived potential impact on local natural environment

- Hg-mobilization and system contamination (21.1%): 
- Permanent impact in aquatic biota within the dredging area (20.0%): 
- Contamination due to poorly treated water (18.9%): 
- Generation of siltation due to dredging (18.9%): 
- Modification of river morphology (14.3%): 
- Hg in residual sand (3.4%): 
- Suspended solids on water discharged into the Orinoco River (2.9%): 
- Pipelines crossing existing migratory routes (0.6%):

In relation to the dredging operation, a concern was expressed of finding fine sediments under the hard pan in some locations, generating turbidity. Turbidity generated by possible overflow from temporary storage facilities was articulated. The oxidation and transport downstream of water soluble mercury compounds was also a concern. Also, the removal of a big portion of the sediments within the dredging area would affect the local benthic fauna and flora and the spawning behavior of local fish species. These species were recently affected by the flooding of the Caroni reservoir. Concerns were voiced about the change of the water regime nearby the sediments, resulting from the creation of pits or irregular voids that may be influential in the transport of remaining sediments during the dam flushes. It was agreed that construction of land based infrastructure is not affecting wildlife migratory routes because it would be located in the perimeters of an urban industrial setting. About the processing plant, the concerns relates to quality of the waste water, especially in relation to suspended solids. Uncertainty issues were raised about residual mercury in low quality sands and its implication in case this sand starts being used as landfill.

5.2 Perceived potential impact on Human health

- Hg in the food chain (59.1%):
• Turbidity of water for human consumption (30.3%):
• Impact on labor health – Hg handling (18.2%):
• Hg contamination of drinking water (7.6%):

It was concluded by the group that the main issue regarding human health was the possibility of alteration of the quality of the water uptake by the downstream communities. This alteration would occur by an increase in river turbidity or by mobilization/transformation of the mercury contained in the sediments into water-soluble compounds that can reach tap water. Possible increase of Hg mobilization may be occurring after the flooding created while construction of the hydro electrical dams. The dredging operation may increase the problem if turbidity is generated.

5.3 Perceived potential impact on the sustainability of the resources

Sustainability related impacts were also evaluated by the same group of people. The perceived potential impacts identified by the group were:

• Potential conflict with former or illegal artisanal miners (41.6%):
• No significant impacts on aboriginal communities (31.9%):
• Impact to farmers (19.4%):
• Removal of sediment from the river bed (6.9%):

This section deals with the unavoidable mining fact of resource depletion. Sediments would be taken from a sector of the river between two major dams; therefore, no new sediments would replace the extracted ones. The capacity of extraction of a bigger company will reduce the availability of the placer resources for future generations, therefore the mining operation itself can not be considered sustainable. The Caroni Project could develop investment programs that contribute to increase the long term livelihood in the region. Some of those programs could become an investment opportunity for the proponent as well.

The mining operation would be located fairly close to a mid-size industrial city, there are not aboriginal communities located near the area of potential negative impact in their way of leaving, making this concerns less relevant. At the eastern side of the Caroni River
there are some agricultural and farmer activities. At this point there is no evident potential impact on local farmers.

5.4 Potential Impacts on Social Equity

- Potential conflict with former or illegal artisanal miners (51.7%):
- Attitude towards foreign industry (25.9%):
- Redistribution of taxes revenue (17.2%):
- Local quarries may be affected if project covers local markets (5.2%):

The artisanal miners concerns were raised once again, this time under the possibility of alienation of opportunities in order to favor foreign investment. It was mentioned that local population may dislike that a foreign company would be running a traditionally local business like sand and gravel. There are local quarries that are currently serving the local market as well as exporting aggregates to Italy. Even though the projected market of the project would be US and the Caribbean, competitive positions may be perceived. The distribution of taxes and revenues was mention as a possible impact, it was also mentioned that at present there exist no controls over government distribution of royalties or taxes derived from the operations.

Many of the potential impacts mentioned in this session can be addressed by an adequate engagement of the people and a careful selection of the communication strategy. For this a deep understanding of the opinion and concerns of the local and regional people is recommended. In relation to the distribution of taxes and rent, the company may try to negotiate some tax reduction that may be reinvested in local development programs but ultimately this is a decision of the Venezuelan government.

5.5 Other Potential Impacts

- Influence of dredging generated siltation on turbine performance (100%):

This is one of the most sensitive issues due to the influence of the Hydro-electrical Company EDELCA in the approval and development of the Caroni Project. An increase of turbidity due to the dredging operation could even effect the cancellation of the project.
As was mentioned at the beginning of this Thesis it was hypothesized that the main environmental concerns for a Caroni Mining Project would be: increase in river water turbidity, changes in drinking water quality for the nearby cities, and increased mercury mobilization. This section evaluates these possibilities by reviewing available information and by proposing measures that could mitigate or prevent them from happening.

In March 1991, the consulting company Minproc Canada Inc. generated a detailed report on mercury pollution in the Lower Caroni, proposed processes for recovery of diamonds and gold, and offered an assessment of geophysical methods to be used in detailed exploration of the area. This work, which was commissioned by Randes Desarrollos Mineros (Rademin), C.A. involved a field sampling program with collection of sediments, fish and plants in the Lower Caroni, in order to establish the levels of mercury in the environment and to determine the suitability of future placer mining. Throughout all phases of the investigation, eighty-six sediment samples (approximately 1500 kg in total) were taken from locations between Playa Blanca and the Zona de Balneareos in the outskirts of Puerto Ordaz. One 300 kg bulk sample was collected to assess potential processing techniques and grades. A major conclusion derived from the Minproc report was that mercury contamination in the river and bank sediments is widespread and heterogeneous in nature. Elevated mercury levels were detected in various species of biota, indicating the entrance of mercury into the food chain.

An Environmental Impact Assessment of gold and diamond extraction in the Rosita I concession in the Lower Caroni River was conducted by Ambiente Consultores e Inversiones Guayana, C.A. Leal in 1995. This study evaluated the impacts of current mining practices in the river, characterized the biophysical environment, and assessed the potential impacts of a large-scale extraction project. Although Leal indicated that social benefits (e.g. employment, tax base) could be derived from the Project, some environmental concerns were identified. These primarily related to the potential of the use of dredgers to re-mobilize available mercury into the water column, exacerbating its
incorporation into the food chain. It is important to clarify that the dredging technology evaluated in this study was comparatively rudimentary and lacked measures to inhibit sediment re-suspension. Mercury mobilization continues, however, to be a significant environmental consideration of this project. This was mainly associated with the practice of discharging tailings directly into the water. Biological activity in the river was, however, deemed by surveys to be relatively low. This report also expressed concerns pertaining to concentrations of petroleum products (e.g. oil, gas), presumably derived from active dredgers, which were measured on the river surface in excess of the national regulatory limit of 0.3 mg/L. Although an evaluation of sediment transport phenomena was also conducted, results were inconclusive.

*Turbidity and River Water Quality*

Due to the widespread use of dredgers to remove contaminated sediments, many dredging technologies exist that can minimize the suspension of sediments. The proposed dredging technologies for the Lower Caroni operation were partially chosen for their high suction capacity and demonstrated ability to reduce the potential to increase turbidity. The pneumatic dredger with hydraulic underwater airlift crusher, which is suitable for depths greater than 20m, is equipped with a special suction head that minimizes sediment suspension. The Cutter Suction dredger, which is appropriate to 20m depths, can also be outfitted with a special cutter cone and suction mouth to inhibit re-suspension of sediments. The Pneumatic dredging system, as mentioned in chapter four has been widely recognized as the more efficient method for recovery of loose contaminated sediments at any depth with very low generation of turbidity.

As previously reported, the expected levels of fine sediments are low. Therefore a significant increase in the water turbidity is not expected. Nevertheless preventive measures as turbidity curtains around the dredging area would lower the risk of turbidity mobilization due to unexpected fines embankments. From the operator’s safety point of view, the expected concentration of organic mercury in water and fine sediments is very low, nevertheless, standard procedures for mercury and organic mercury compounds
handling are widely available and easy to implement. The possibility of oxygenation of sediments due to dredging is low.

The potential for mobilization of metals (e.g. Hg, Cr, Pb) through dredging practices should be determined in a detailed geochemical study, particularly as the Lower Caroni River is an important water source for the region, serving Puerto Ordáz, Upata, San Felix and Ciudad Bolivar. Sediment samples collected at seven locations along the Lower Caroni indicate that elevated levels of mercury, lead and chromium are present in riverbed material. Table 5.1, shows the concentration of the metallic elements of concern found on the Lower Caroni sediment samples, using ICP analysis. The table also compare those concentrations with current US guidelines. More detailed study is required, however, to evaluate the distribution and potential for mobilization of metals through dredging and associated risks to biota.

Table 5.1: Metal Concentrations in Lower Caroni Sediments

<table>
<thead>
<tr>
<th>Metal</th>
<th>Sample</th>
<th>Sediment Guideline</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>As</td>
<td>&lt;0.5</td>
<td>&lt;0.5</td>
</tr>
<tr>
<td>Cd</td>
<td>0.1</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Cr</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Cu</td>
<td>8.0</td>
<td>3.4</td>
</tr>
<tr>
<td>Hg</td>
<td>76</td>
<td>2</td>
</tr>
<tr>
<td>Ni</td>
<td>5.3</td>
<td>5.6</td>
</tr>
<tr>
<td>Pb</td>
<td>189</td>
<td>78.9</td>
</tr>
<tr>
<td>Zn</td>
<td>17</td>
<td>23</td>
</tr>
</tbody>
</table>

1. All concentrations in mg/kg (ppm)
2. US National Oceanic and Atmospheric Administration Sediment Quality Guidelines for the protection of aquatic life:
   TEL = threshold effect level; PEL = probable toxic effect level; UEL = upper toxic effect level
3. Samples 5, 6, and 7 were collected from the dry bed of the River near the Caruachi Dam

The sediments more likely to be oxygenated are the ones pumped into the process; the rate of this oxidation has to be tested on site.
Treatment of waste water has to be included as an important part of the processing infrastructure, not only as an environmental sound practice, but also because it is one of the most repeated concerns expressed by the stock analysts about Cadre Resources shares (EMI Digger Report\textsuperscript{24}, Siliconinvestor\textsuperscript{25}). As it was mentioned in Chapter 4, there are in the market proved treatment for methyl-mercury and heavy metals in water.

Sediments of the Lower Caroni have been considered oligotrophic by nature (low organic material content) and low population of benthic fauna has been reported (Bermudez, 1994). Recent flooding due to the construction of the Caruachi Reservoir in the region may change this condition. Samples of the soil taken before the flooding are currently under analysis (D. Bermudez, 2003, personal communication.). No toxic reagents will be used in the processing part of this project, nevertheless possible heavy metal containing slimes or water have to be treated and safely disposed. After verification of mercury removal and sediments settling, water could safely be sent to the Orinoco River. Water management is discussed further in this document.

\textit{Artisanal Miners: Environmental Issues}

Artisanal miners, also known as small miners, are typically disorganized and often illegal miners who employ rudimentary techniques to extract economic minerals from primary or secondary deposits (Hinton et al, 2002). In the Lower Caroni region the artisanal gold and diamond miners extract the minerals using small dredgers. CVG\textsuperscript{26} estimated in 1995 that in Venezuela, particularly in Bolivar State the number of small scale and artisanal miners were between 30,000 to 40,000 in which between 7,000 and 10,000 of them are illegal (Veiga, 1996). In Venezuela, small mining activities were defined until 1991 based on investments up to 5 million Bolivars (US$ 3,128.91\textsuperscript{27}), but until recently there were many small miners who own barges of 80 million Bolivars (US$ 50,062.578) (Veiga, 1996). The Association of Miners of Ikabaru\textsuperscript{28} estimated that each miner supports

\textsuperscript{24} http://www.mine.mn/Digger_Report_C.htm, August 24\textsuperscript{th}, 2002
\textsuperscript{25} http://www.siliconinvestor.com. April 7th, 2003
\textsuperscript{26} Venezuelan Guayana Corporation (Corporación Venezolana de Guayana)
\textsuperscript{27} At April 16 2003
\textsuperscript{28} mining town located close to the upper section of the Caroni River, Bolivar State
a family of four people, on average. About 80\% of the gold in the State of Bolivar came from artisanal mining activities.

At one time, artisanal mining in the Caroni region financially supported hundreds of self-employed entrepreneurial and semi-skilled minimum tax paying workers and their families. Now, the local community has been impacted by the lack of tenure of existing gold and diamond concessions allocated to artisanal miners. As miners have been unable to satisfy increasingly stringent environmental requirements, in part due to their inability to invest in new equipment technology and a lack of reliable geological exploration methods, many artisanal miners are unable to renew their concessions. At this point, there are not granted concessions to operate in the Guri Reservoir.

With a concession tenure (up to 50 years), the Lower Caroni Project have the potential for upgrade the skills of several existing miners who are interested in participating in the project, enabling them to remain in their community and continue involvement in an industry they know and understand.

Despite this, the potential exists for conflict between the Lower Caroni Project and currently active artisanal miners. A contingent of artisanal miners continues to operate illegally in the area and their response to a large, formal dredging operation cannot be predicted. An assessment of conflict risks and identification of measures to mitigate any risks is strongly advised.

**Hydrological characteristics**

Another issue raised during the EnTA exercise was the possible impact of a massive sediment extraction in the hydrologic stability within the dredging zone. Large-scale sediment dredging projects have been shown to impact channel characteristics, potentially resulting in channel instability and suspension of sediments. This is mainly due to the change in width-to-depth ratio of the channel and impacts on the armouring capability of coarser materials. As armour materials (e.g. gravel) are removed, underlying sediments may be more susceptible to erosion and transport though the river. Areas
where dredging has occurred can also create steeper temporary gradients and may result in upstream and/or downstream scouring of the riverbed after or during mining activities. To a lesser extent, in-channel dredging can result in changes to local groundwater levels. Sand and gravel extraction on flood plain tend to lower the alluvial water table disrupting fluvial flow paths (Hancock, 2002).

Riverbank instability with the modification of channel dimensions is a potential impact that can be easily prevented with consideration of the location and depth of dredging activities in proximity to riverbanks. Reinforcement of the riverbanks can effectively inhibit riverbank erosion.

Flooded rivers generally alter the balance between surface and groundwater, in particular when the characteristics are considerably different. It can be possible for heavy metals to be mobilized during the rupture of the equilibrium on hyporheic zones (zones of equilibrium between surface and underground water). The massive extraction of sand and gravel in these regions may exacerbate these problems (Hancock, 2002). The generation of pits will change the flow regime around riverbed it may generate turbulence that may be significant depending on the water velocity. At this point there is no available impact assessment of the Caruachi reservoir flooding.

As concluding remarks for this environmental impacts session, it can be said that previous work has primarily focused on uptake of mercury in aquatic organisms. Subsequent studies should evaluate the potential for increased uptake of mercury, as well as other metals (e.g. lead), with the implementation of the proposed dredging project on the Lower Caroni. A representative size distribution of the sediments, characterization of the biological community should also be conducted for baseline purposes.
Perhaps the more studied and perceived environmental consideration associated with the Lower Caroni Project relates to the widespread mercury contamination derived from the activities of artisanal miners. More than 5 tons of metallic mercury has been discharged by artisanal miners into the Caroni River throughout the last 30 years (Veiga, 1996). As elevated mercury levels have been detected in biota, such as certain species of fish, this pollution represents a health risk to local inhabitants who rely on fish as a major protein source. The Caroni Project intends to recover mercury from extracted sediments, thereby remediating large sections of the river. Some mercury related issues to be considered in the Lower Caroni Project include:

- The potential for mobilization of mercury through dredging;
- The influence of mercury in processing the material, particularly in relation to gold recovery;
- Techniques to recover and immobilize mercury from dredged materials; and
- Health and safety issues in the processing plant.

Mercury is naturally present in waters at very low levels. Uncontaminated freshwater generally contains from <5ng/L (25pM of total Hg) (Bloom, and Craig, cited by Ullrich et al, 2001). Levels up to 10 - 20 ng/l can be found in humic lakes or rivers rich on particulate mercury (Meili, cited by Ullrich et al, 2001). Metallic mercury in deep waters with little oxygen would take long to oxidize. However, based on the water properties, metallic mercury can dissolve and form Hg(OH)_2 and HgOHCl without precipitating. In solution, Hg has a strong affinity to particulates which tend to remove it from the water column to the sediment. Once in the sediments, metallic mercury can be oxidized to inorganic divalent [Hg(II)] mercury or/and transform by bacterial intervention to methyl mercury (CH_3Hg: MeHg).(Twidwell, 2000).

How mercury associated with organics transforms into methyl mercury is unclear. What is clear is that positive correlations between MeHg and dissolved organic carbon (DOC)
have been identified in many aquatic systems (Lee et al, 1985, Watrus et al, 1998). In studies conducted by Guimarães et al. (1995, 1998) in the Amazon, higher methylation rates (10^2 %.g^-1.h^-1) were found in organic rich sediments of dark water forest streams than in rivers with cloudy or clear waters.

The Caroni River is a "dark water" system, i.e., it has low suspended solids and conductivity (1.6 to 10 mg/l; 7.5 to 11 μS/cm), is slightly acidic (with a pH fluctuating from 5.3 in the rainy season to 6.8 in the dry season - Sanchez and Vasquez, 1989), and is rich in humic substances (humic and fulvic acids), which are degradation products of organic matter. Organic acids, such as humic and fulvic acid, are believed to be important parameters in the solubilization of metallic mercury, which is the form of mercury predominantly discharged into the river by artisanal miners. In cases where organic matter is present in concentrations above 1 mg/l (1 ppm), organic acids form soluble complexes with mercury that can be transported great distances. These complexes are much more stable than other inorganic forms of mercury (Duinker, 1980; Xu and Allard, 1991). The average concentration of dissolved organic carbon in the Caroni River ranges between 0.67 and 5.87 mg/l (Paolini, 1986).

High mercury methylation rates have commonly been associated with the low pH characteristic of organic sediments and dark waters (Lacerda, 1995). It is also suggested that MeHg generated in darkwater (organic-rich) systems tends to persist longer than in cloudy or clear waters due to inhibited photo-destruction (Waturu et al, 1998). Since fulvic acids are known to be methyl-group donors, methylation of these complexes seems to be feasible through either biotic or abiotic processes (Mannio et al., 1986; Verta et al., 1986).

Organic acids may also contribute to mercury-organic complex adsorption to colloidal matter, which serves as a substrate for methylating bacteria. Other evidence suggests that direct bioaccumulation of ingested mercury-organic complexes by some organisms (e.g. fish, invertebrates) may be possible (Hinton and Veiga, 2002, Veiga et al, 1997, Rowland et al, 1977). An important characteristic of methylmercury in the environment relates to
its tendency to magnify as it moves up trophic levels of the food chain (bioaccumulation). For example, mercury concentrations are more than a million times greater in predatory fish compared to the water they inhabit (US EPA, 1999). Not surprisingly, inhabitants of communities dependent upon mercury laden fish as a primary food source are likely to have elevated levels of mercury in hair, blood and urine (Wheatley et al., 1995, Malm et al., 1997).

The potential for bioaccumulation of methyl-mercury has been a matter of intense research since late 1960s when a strong correlation between increase in Hg levels in biota and man made reservoirs was found (D'Itri and D'Itri, 1977; Bodaly et al., 1984; Smith et al. 1974; Stoke and Wren 1987). Since early 70's, extensive research has been done that link man-made reservoirs with the increase of mercury levels in locals fish population. By 1987 almost 30 cases were reported by Stoke and Wren, even in places where evident mercury sources were not identified. Stoke and Wren (1987) recognized the influence of the submerged vegetation, type of organic matter and bacteria in flooded sediments in mercury bioaccumulation. Nowadays deforesting before flooding is a common practice in the northern hemisphere to avoid the production of CO$_2$ (greenhouse gases) and the increase of levels and mobilization of methyl-mercury.

Evidence of mercury bioaccumulation in the Guri Reservoir was presented by Leal (1995). These studies determined that mercury accumulation was above acceptable levels in many organisms, particularly those occupying the upper trophic levels (gastropods, several fish species). The initial study of bioaccumulation performed on the Guri Reservoir reported that around 40% of fish samples were showing Hg levels above 0.5 ppm $^{29}$

In the Guayana Region, an official resolution$^{30}$ suggested that fish from Guri should be exploited commercially. For this purpose, a Committee coordinated by the CVG-Vice-presidency of Agricultural Development was created. This committee involved

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$^{29}$ guideline recommended by World Health Organization for human consumption.

$^{30}$Resolution # DM/09 of Ministry of Agriculture and Farm and # DM/18 Ministery of Environment and Natural Renewable Resources of Feb 16, 1995.
limnologists, biologists and toxicologists from CVG, Min. Environment, Min. Agriculture, National Guard, Universities, Non-Governmental Organizations, etc. A monitoring fish program was determined to check Hg levels before starting commercial activities. This program was conducted by a group of professionals led by the biologist Luis Perez from "Fundación La Salle" (Veiga, 1996). As shown in Table 5.2 fish tissue from Guri reservoir evaluated by the previously mentioned committee, carnivorous species presented medium to high mercury levels.

Table 5.2: Mercury levels on fish tissue from the Guri Reservoirs

(Guri Committee, 1995 - unpublished) (Average Hg - mg/kg in muscles of fish)

<table>
<thead>
<tr>
<th>Fish Name</th>
<th>Fish (scientific name)</th>
<th>Hg (ppm)</th>
<th>Hg range</th>
<th>n</th>
<th>Remarks on Hg level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aimara (c)</td>
<td>Hoplias malabaricus</td>
<td>1.32</td>
<td>0.5 - 4.55</td>
<td>5</td>
<td>high</td>
</tr>
<tr>
<td>Caribe (c)</td>
<td>Serrasalmus sp.</td>
<td>0.51</td>
<td>-</td>
<td>1</td>
<td>high</td>
</tr>
<tr>
<td>Coporo (d)</td>
<td>Prochilodus nigricans</td>
<td>0.17</td>
<td>0.04 - 0.84(?)</td>
<td>61</td>
<td>low</td>
</tr>
<tr>
<td>Curvinata (c)</td>
<td>Plagioscion squamosissimus</td>
<td>0.80</td>
<td>0.16 - 2.96</td>
<td>39</td>
<td>high</td>
</tr>
<tr>
<td>Guitarrilla (c)</td>
<td>Oxydoras niger</td>
<td>0.28</td>
<td>0.09 - 0.46</td>
<td>14</td>
<td>medium</td>
</tr>
<tr>
<td>Pavon (c)</td>
<td>Cichla ocellaris</td>
<td>0.32</td>
<td>0.14 - 0.54</td>
<td>6</td>
<td>medium</td>
</tr>
<tr>
<td>Payara (c)</td>
<td>Raphiodon vulpinus</td>
<td>2.70</td>
<td>0.17 - 8.25</td>
<td>31</td>
<td>very high</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td></td>
<td></td>
<td>157</td>
<td></td>
</tr>
</tbody>
</table>

n = number of samples  
(Average Hg - mg/kg in muscles of fish)

In previous studies, samples taken from the lower section of the Caroni River, carnivorous fish showed low-medium degree of bioaccumulation. It was estimated that mining operations in the region had discharged about 5 tonnes of mercury in the bottom sediments before 1991 (Veiga, 1996). Table 5.3 shows the results of the mercury content evaluated in fish tissue from the Lower Caroni River evaluated by Minproc (1991)

Veiga’s (1996) assessment of the Guri case concluded that the methylation rate of mercury formerly deposited in sediments mostly by atmospheric sources, increases with decomposition of submerged vegetation, amount of organic matter transported into the reservoir, and type of methylating and demethylating bacteria in sediments. “The large
area of submerged sediments (4000 km$^2$) by the Guri reservoir is the main variable for methylmercury production.” The main atmospheric mercury sources are those emitted by natural sources, industrial sources (including mining) and combustion processes, such as forest fires (Veiga, 1996).
Table 5.3 - Mercury levels in fish from Lower Caroni River (Minproc, 1991)

<table>
<thead>
<tr>
<th>Fish (popular name)</th>
<th>Fish (scientific name)</th>
<th>Hg(ppm) in muscle or whole fish</th>
<th>Number of samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bagre (o)</td>
<td><em>Pimelodus ornatus</em></td>
<td>0.047</td>
<td>1</td>
</tr>
<tr>
<td>Bagre (o)</td>
<td><em>Pimelodus ornatus</em></td>
<td>0.33</td>
<td>1</td>
</tr>
<tr>
<td>Bocachico (d)</td>
<td><em>Curimata sp.</em></td>
<td>0.069</td>
<td>1</td>
</tr>
<tr>
<td>Cabeza de Manteco (h)</td>
<td><em>Leporinus friderichi</em></td>
<td>0.05</td>
<td>1</td>
</tr>
<tr>
<td>Caré (o/c)</td>
<td><em>Serrasalmus sp.</em></td>
<td>0.217</td>
<td>6</td>
</tr>
<tr>
<td>Caribe (c)</td>
<td><em>Serrasalmus sp.</em></td>
<td>0.754</td>
<td>1</td>
</tr>
<tr>
<td>Caribe (c)</td>
<td><em>Serrasalmus sp.</em></td>
<td>0.318</td>
<td>1</td>
</tr>
<tr>
<td>Caribe (c)</td>
<td><em>Serrasalmus sp.</em></td>
<td>0.446</td>
<td>2</td>
</tr>
<tr>
<td>Caribe (c)</td>
<td><em>Serrasalmus sp.</em></td>
<td>0.203</td>
<td>2</td>
</tr>
<tr>
<td>Caribe (c)</td>
<td><em>Serrasalmus sp.</em></td>
<td>1.210</td>
<td>1</td>
</tr>
<tr>
<td>Caribe (c)</td>
<td><em>Serrasalmus sp.</em></td>
<td>0.013</td>
<td>1</td>
</tr>
<tr>
<td>Curvinata (c)</td>
<td><em>Plagioscion squamosissimus</em></td>
<td>2.52</td>
<td>1</td>
</tr>
<tr>
<td>Coporo (d)</td>
<td><em>Prochilodus mariae</em></td>
<td>0.189</td>
<td>5</td>
</tr>
<tr>
<td>Mataguaro (c)</td>
<td><em>Crenicichlamacrophthalmus</em></td>
<td>0.106</td>
<td>1</td>
</tr>
<tr>
<td>Mataguaro (c)</td>
<td><em>Crenicichla lugubris</em></td>
<td>0.138</td>
<td>5</td>
</tr>
<tr>
<td>Mochoroca (o)</td>
<td><em>Aequidens geayi</em></td>
<td>0.395</td>
<td>6</td>
</tr>
<tr>
<td>Mochoroca (o)</td>
<td><em>Aequidens portaroensis</em></td>
<td>1.360</td>
<td>3</td>
</tr>
<tr>
<td>Morocoto (o/h)</td>
<td><em>Piaractus brachipomus</em></td>
<td>0.014</td>
<td>1</td>
</tr>
<tr>
<td>Morocoto (o/h)</td>
<td><em>Piaractus brachipomus</em></td>
<td>0.03</td>
<td>1</td>
</tr>
<tr>
<td>Palambra (o)</td>
<td><em>Brycon cf. coquenani</em></td>
<td>0.037</td>
<td>1</td>
</tr>
<tr>
<td>Palambra (o)</td>
<td><em>Brycon cf. coquenani</em></td>
<td>0.055</td>
<td>1</td>
</tr>
<tr>
<td>Puyón (c)</td>
<td><em>Pimelodella sp.</em></td>
<td>0.391</td>
<td>2</td>
</tr>
<tr>
<td>Sardina (d)</td>
<td><em>Curimatopsis sp.</em></td>
<td>0.065</td>
<td>9</td>
</tr>
<tr>
<td>Sardina (d)</td>
<td><em>Curimata spilura</em></td>
<td>0.24</td>
<td>21</td>
</tr>
<tr>
<td>Sardina (d)</td>
<td><em>Curimata spilura</em></td>
<td>0.088</td>
<td>3</td>
</tr>
<tr>
<td>Sardina (d)</td>
<td><em>Curimata spilura</em></td>
<td>0.068</td>
<td>4</td>
</tr>
<tr>
<td>Sardina (d)</td>
<td><em>Steindachnerina argentea</em></td>
<td>0.029</td>
<td>1</td>
</tr>
<tr>
<td>Sierra (o)</td>
<td><em>Opsodoras sp.</em></td>
<td>0.233</td>
<td>1</td>
</tr>
<tr>
<td>Sierra (o)</td>
<td><em>Opsodoras sp.</em></td>
<td>0.099</td>
<td>2</td>
</tr>
<tr>
<td>Sierra (o)</td>
<td><em>Opsodoras sp.</em></td>
<td>0.205</td>
<td>1</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td></td>
<td>87</td>
</tr>
</tbody>
</table>
The rate of metallic mercury complexation with organic acids increases with oxygen levels, as oxygen is likely the main electron donor in the complex formation reaction. The dissolved oxygen level in the Lower Caroni River ranges from 4.2 to 8.8 mg/l (Sanchez and Vasquez, 1989), although diffusion of oxygen through the water column may be increased by dredging. As the dredging technology intends to – and very nearly does - recover all sediments within the active dredging zone, any potential influence on mercury transformations would likely be inconsequential. The worst scenario exists in sediments at channel margins, where considerable dissolved oxygen is available.

In conjunction with the extraction of economically valuable minerals from the Lower Caroni River, the Caroni Project intends to recover mercury in dredged sediments, thereby remediating large areas of the river. Mercury recovery is a simple, well understood process that involves volatilization and subsequent recovery in special fume hoods followed by condensation and immobilization or use of filters impregnated with activated carbon or iodine. Mercury can also be recovered from gold concentrates by electrolytic methods.

A method involving electrolytic leaching of sands concentrated for removal of mercury (Sobral et al, 1996), which involves the addition of small amounts of NaCl, is highly effective for the solubilisation of mercury. Typically, some gold may precipitate simultaneously with the mercury. Recovery of mercury may also be achievable through some gravity concentration, followed by retorting and recovery in a carbon- or iodine-impregnated filter. It also will require development of management and health and safety protocols. Thus, recovered mercury would be immobilized, likely through an encapsulation process, and hopefully isolated in perpetuity.

A number of permanent immobilization or encapsulation technologies for mercury containing sludge are currently being employed in reclamation programs around the world, although any method selected for this project will require subsequent testing to ensure leaching does not occur. At this point the characteristics of the processing waste
sludge and its possible mercury content is not clear. The immobilization of metallic mercury in the other hand is an important issue to address at early stage. Most immobilization techniques generally intend to improve the physical characteristics of sediments or sludge, so that they are more amenable for transport. Many methods are specifically suited to encapsulate metallic mercury.

Many suppliers propose various concoctions of stabilizing agents (e.g. organic polymers), although cement, calcium carbonate spiked with binders (furnace slag silicates or fly ash), asphalt or bitumen are most commonly used. Other patented compounds (e.g. Omni/Ajax, Polysiloxan, Duratek (GTSD), NFS DeHgSM, and ADA) have also been demonstrated. Standard techniques for solidification and stabilization of hazardous wastes are well described by the US EPA and the US Federal Remediation Technologies Roundtable (2001). Any immobilizing agents proposed for use in the Lower Caroni Project should be evaluated using well-established procedures for leachability, specifically, the Land Disposal Restriction (LDR) standards [0.025 mg Hg/L], Toxicity Characteristic Leaching Procedures (TCLP) [0.2 mg Hg/L], and the Universal Treatment Standards (UTS) [0.025 mg Hg/L].

Based on the processing system, a major tailings impoundment would not be required. The size of the facility needed for slimes/sludge storage will primarily depend on the volume and composition of ‘capa’ material recovered. Previous studies have indicated that the capa is cemented with limonite, hematite, magnetite and manganese oxide. Slimes will be generated from breakdown of capa material through transport in the pipeline and potentially through processing. In accordance with this, a pond will be needed for long-term storage of the material. As the volume and composition of slimes cannot be determined based on presently available information, the requirements of this containment facility (i.e. dimensions, location etc) must be determined in subsequent studies. There is a possibility that gold concentrate have remaining mercury.
Other than an aquaculture project initiated by the LaSalle Foundation31 (Fundación La Salle), a commercial fishery has not been documented in the Lower Caroni River, although consumption of several fish species by local fishermen and miners has been observed. The potential for trophic (i.e. food chain) transfer of metals, particularly mercury, and fish consumption levels in humans inhabiting the area should be further evaluated. Even though it was not part of the initial hypothesis of this thesis, an important environmental issue affecting the Caroni Project is the local practice of artisanal dredging/mining.

31 The LaSalle Foundation aquaculture project is producing fish for nutritional, commercial and decorative purposes. As fish are fed an external, artificial diet, the risk of mercury bioaccumulation is low.
INTEGRATION OF SUSTAINABILITY PRACTICES INTO THE PROJECT

7.1 The Seven Questions Initiative

In 1999 the World Business Council for Sustainable Development commissioned the International Institute for Sustainable Development to undertake the project that evaluated the sustainable development in the Mining and Mineral Industry, “The Mining Minerals and Sustainable Development (MMSD)” initiative. One of the outcomes of eight months of multidisciplinary research was the development of guidelines applicable to different stages of the mine life cycle. These guidelines, “The seven Questions of Sustainability: How to Assess the Contribution of Mining and Mineral Activities” (MMSD, 2002) provide a way to assess the contribution that the mining or mineral initiatives towards sustainable practices. The seven questions proposed by the guidelines are:

1. **Engagement**: Are engagement process in place and working effectively?
2. **People**: Will people’s well being be maintained or improved?
3. **Environment**: Is the integrity of the environment assured over a long term?
4. **Economy**: Is the economic viability of the project or operation assured, and will the economy of the community and beyond be better of as a result?
5. **Traditional and Non-Market Activities**: Are traditional and no-market activities in the community and surrounding area accounted for in a way that is acceptable to the local people?
6. **Institutional Arrangements and Governance**: Are rules incentives, programs and capacities in place to address project or operational consequences?
7. **Synthesis and Continuous Learning**: Does a full synthesis show that the net result will be positive or negative in the long term, and will there be periodic reassessment? (MMSD, 2002).

The application of this framework to the Caroni Project could provide the proponent with a more tangible way to evaluate the sustainability of the project in a practical
way and would project a positive image to regulators, financial institutions, shareholders and community in general.

7.2 Business Success and Sustainability Factors

Perhaps motivated by the pressure of environmental and social organizations, preceding cases of conflicts with communities and the flexibility that small companies have to redirect their practices, exploration and junior mining companies are starting to see the importance of implementing sustainable practices since an early stage of their projects, not only as a way to reduce potential conflicts with local communities but as a business strategy that will add value to their projects and facilitate the transformation of possible challenges into opportunities. The World Bank has been promoting the implementation of sustainability as part of the business plan of new projects. They highlighted the business case for sustainability in emerging markets by analysing benefits and risk from social and environmental improvements based on more than 240 real-life examples in over 60 countries around the world (IFC et al, 2002). The opportunities more often found after evaluating the case studies were:

- Save cost by making reduction to environmental impacts
- Save cost by ensuring well being of employees
- Increase revenues by improving the environment
- Increase revenues by benefiting the local economy
- Reduce risk through engagement with stakeholders
- Build reputation by increasing environmental efficiency
- Develop human capital though better human resource management
- Improve access to capital through better governance

The same concept of find agreement between business success factors and sustainability factors is being applied to the Caroni Project, in order to evaluate their particular business case. Possible advantages of integrating sustainable practices to their business strategy are:

- **Save costs by reducing environmental impacts**: Selecting a high density dredging and pumping system would reduce the cost of waste water storage and
management. Also the use of cheap clean hydro-electrical energy would reduce risk of oil spills

- *Save cost by ensuring well being of employees:* Fair wages and benefits for employees would result in low desertion and a decrease cost of hiring and training

- *Increase revenue by improving environmental conditions:* For this particular project the potential for good revenues due to ensuring the better possible environmental conditions from the beginning, lies in minimizing the cost of remedial measures. Diamond and gold markets have a growing ethical/environmental component in the sense that ethical or environmentally friendly label gold and diamonds have and accepted higher prices in some markets.

- *Increase revenue by benefiting local economy:* There is an opportunity for development importation markets and for exportation of local products talking advantage of the shipment increase that the project would bring.

- *Reduce risk by engaging stakeholders:* An early engagement of local interest groups like former artisanal dredgers, local settlements, and local social and environmental organizations, the understanding of their concerns and expectations, and initial agreements related to the project would facilitate the development of initial feasibility studies, reducing the risk of confrontation and delays.

- *Build reputation by increasing environmental efficiency:* The implementation of environmental sound practices like low impact dredging, proper treatment of waste and preventive and safety measures would add value to the operation and the company brand and stocks perception. Adopting well respected standards as ISO 14001 would also open new ethical and environmental driven diamond and gold markets

- *Develop human capital through better human resource management:* In a project with too many environmental and perhaps social variables that can impact and jeopardise the operation, it is vital to build a stimulating and positive environment that promote creative thinking to face all possible challenges.

- *Improve access to capital through better governance:* Perhaps because the cost of capital is driven by perceived risks, a well define structure and management where
policies and practices work together would more easily access resources from financial institutions and create a sense of security on shareholders (IFC, 2002)

In summary, the primary social impacts of the Lower Caroni Project relate to employment and the economic contribution to the local tax base. As the labour force in Puerto Ordaz is moderately-to-highly skilled, the local labour pool can be used, although some training for specific functions may be required. The Lower Caroni Project would generate at least 145 long-term positions (+50 years), and would indirectly benefit at least another 1000 persons and their families. An estimated $40-50 million per annum would be generated from the project for taxes, mineral royalties, and river tolls. Ideally, these funds would be used to strengthen social services and infrastructure (e.g. be directed towards construction and maintenance of schools, hospitals, and roads.). The use of local machine, shops, goods and services would also provide economic benefits to the community. The Lower Caroni Project would upgrade the skills of many existing miners who are interested in participating in the Project, enabling them to remain in their community and continue involvement in an industry they know and understand.

The removal of large volumes of sediments from the reservoirs would improve their performance by increase of storage capacity and reduce the maintenance cost of EDELCA’s hydro-electrical operations.

As the Lower Caroni region is already highly industrialized, both project land use and injection of funds into the community would not significantly change their way of life or social and cultural values as might happen in a remote rural area. Therefore, it is not likely to expect a negative socio-cultural impact. However, one urbanization project is currently underway in a region in close proximity to the proposed processing plant site. Other significant issues are related to land use, health and safety; and potential conflict risks with the artisanal mining community.

At one time, artisanal mining in the Caroni region financially supported hundreds of self-employed entrepreneurial and semi-skilled minimum tax paying workers and their families.
A potential exists for conflict with the currently active artisanal miners. A contingent of artisanal miners continues to operate illegally in the surrounding area of interest and their response to a large, formal dredging operation cannot be predicted. An assessment of conflict risks and identification of measures to mitigate any risks should be included in the socio–environmental component of the feasibility study. Artisanal dredging in the zone also generated erosion and mobilization of sediments that reached the turbines of some of the hydro-electrical facilities along the river, forcing them to lower the electricity production capabilities up to the point that electrical generation had to be rationed (Santorio, 2000), creating a general displease towards dredgers among the regional population. The lower Caroni region faces a series of challenges in order to reclaim the riverbed without jeopardizing the performance of the hydro-electrical complex located along the river, which provides 75% of the electricity consumption in the country and without compromising the water quality of the river. Table 7.1 attempts to compare the advantages and disadvantages of concession of this project to current artisanal miners within the region, and the alternative of granting the same concession to the proponent of the Caroni project.
Table 7.1: Comparative evaluation of Artisanal dredging Vs. Proposed Project

<table>
<thead>
<tr>
<th>Artisanal Dredging Operations</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
</table>
|                             | • Massive employment generation for unskilled workers  
|                             | • Direct access to resources for locals  
|                             | • 100% of revenue would be spent on Venezuela  |
| Large Scale Dredging Operations | • Increase of technical skills of local workforce  
|                             | • Pay out tax and royalty to local government  
|                             | • Economic and technical capacity for reinvestment of revenue in employment generation industry  
|                             | • Create an opportunity for some Venezuelan companies to take advantage of the infrastructure created by the project  
|                             | • Contribute to the diversification of local economy  |
|                             | • Low control of tax evasion  
|                             | • Low control of environmental sound practices  
|                             | • Limited access to funding due to lack of business credibility  |
|                             | • Less direct employment generation than artisanal dredging operations  
|                             | • Little control over government or distribution of royalties and taxes  
|                             | • Most of the capital generated will be move out of the country  |
7.3 Proposed Action Plan

There are several scenarios where the Caroni Project could implement practices that would contribute to the long term economical environmental and social well being of the community and the company itself.

- Implementation of polices and practices committed to develop successful business in a way that ensure the long term economical environmental and social well being of the communities where operates.
- Implementation of a communication strategy that is agreed, clear and understood by all participants of the project.
- Implementation of a Feasibility Study that contains a social environmental and economical impact-benefit assessment.
- Evaluation of the feasibility study using the Seven Questions Initiative

The results of feasibility study will determine if the project will proceed. Nevertheless there are some opportunities that should be explored:

- Development of training and research programs in conjunction with La Salle institute and UNEG for increase workers skills and socio-environmental awareness in relation to operation, monitoring, closure and reclamation.
- Re-investing part of the revenue from the projected into local employ generation projects. Non-dependent of mineral dredged. A preliminary search of possible markets shows a potential for:
  - Programs on fisheries development within the region. The treated dredged water may be used in irrigation projects or aquaculture farms using local species (i.e. cachamoto hybrid)
  - Tourism development around the lakes area,
  - Construction finishing products (high quality facades aggregates).
• Export of such local commodities such as alumina and iron products (taking advantage of the frequent shipment boosted by the project) as well as importation of commodities from North America and the Caribbean.

This parallel investment could be considered an economical endorsement in case of early closure or socio-environmental unforeseen expenses and also will contribute to lowering the revenue figures, therefore the taxes.

• *Generation of secondary industry related to the main project:* The proposed project shows a significant limitation for production expansion due to the limited shipping capacity of the Orinoco River. One possible alternative is the generation of a secondary industry that uses products from the Caroni Project as raw material. The possibility of producing titanium oxide (TiO₂ 85%) and pig Iron (97% Fe) in a refining plant from dark sands (ilmenite concentrates). This plant can generate more employment opportunities. It also could become a mayor customer for local hydroelectric energy producers, and boost local providers of services and equipment. As a new project it should be feasible to adopt state of the art clean technologies. Other secondary industries like diamond finishing, and jewelry manufacturing could also be evaluated.

• Development of an interactive program for community liaisons, and transparency agreement including a Government/Community/Company negotiated community control capital for social investment.

The possibility of conflict should be reduced if the proponents adopt the following practices:

• Community mapping and profiling.

• One to one communication with stakeholder leaders within the region to identify their concerns.

• Develop with the local stakeholder’s group a participatory monitoring projects for environmental and community liaison performance of the feasibility stage of the project, in order to generate a transparency environment for the project.
• Implementation of a risk communication strategy that clarifies and clearly explains the nature and goals of the feasibility study.

• Equity practices for hiring local personnel for the feasibility study in order to avoid perceived early association with a particular political or organizational group.

• Education of proponent staff about the company policies, goals and communication strategies.
8 CONCLUSION

There is a diversity of factors that influence the viability of the Caroni mining project. The principal factors are sediments disturbance and mobilization, quality and use of the water, land use conflict, social and political conflicts. These are the main issues to consider in any proposed reclamation program design. This thesis considers the first step towards the implementation of sustainable practices by a junior mining company. It creates the potential for subsequent monitoring successes in a detailed form. If the proposed outlined considerations are taken into account, then the Caroni Project has a good potential to be sustainable.

A key contribution of this thesis is that it demonstrates how available tools and methodologies of forecasting social and environmental impacts in the mining and reclamation dredging industries are easily adapted and applied to the aggregates and mineral dredging sector from the early stages of an exploitation project.

Forecasting methods helped to identify key impacts, a central one of which is river water turbidity during dredging operations. Turbidity can be prevented by using a combination of the pneumatic high density suction dredging method and an underwater crusher or cutter where needed. Regardless of the low fines content in sampled sediments, these procedures must be accompanied by turbidity preventive measures like turbidity curtains and a low impact cutterhead due to the extreme sensitivity of the dredging area. Turbidity is a significant environmental and social concern because it may create contaminants mobilization, lower the quality of local tap water and impact local costly hydro-electrical infrastructure.

Another key impact is mobilization of mercury, however removal of metallic mercury contained in the sediments can be achieved throughout the processing stage and by gravity concentration, retorting. Residual mercury is expected to be associated to fine concentrates that could be treated by mechanical or electrochemical methods if required.
Encapsulation of metallic mercury and organic mercury containing sludge is possible by commercially available methods. Nevertheless mercury removal processes for the Caroni sediments have to be evaluated. Economical feasibility will be determined by the efficiency of these processing operations. The possibility of low mercury containing Caroni aggregates and its implications on marketability has also to be evaluated.

Another concern identified in this work is the lack of a well designed contingency plan. A plan must be incorporated into the development of the project, in order to avoid or at least mitigate the impacts of possible accidents in pipelines, temporary storage facilities or the processing plant.

One forecasting approach, known as the Environmental Technology Assessment Approach was useful in the identification of key concerns of turbidity generation during dredging and processing waste water quality. These impacts can be mitigated by using appropriated technology. However, turbidity generation and mercury mobilisation are perceived to be of greater impact. Furthermore, there is a general perception that heavy metal cannot be recovered from waste water. However, it is feasible to treat these using well known organic agents. Water treatment may be costly, so it is recommended the evaluation of after treatment uses for the water, to compensate the cost.

The project proponent has a role to educate and provide information about the new dredging techniques it is planning to implement. Performance tests of the adequate technologies have to be conducted and properly disseminated within the lower Caroni Region.

A development of a Sustainable Business Case would contribute to better foreseen opportunities to negotiate mutually beneficial agreements and reduce land use conflict with EDELCA, former artisanal miners and other potential actors not yet identified.

In summary, there is a wide diversity of factors influencing the viability of the Caroni mining project that require an integrated approach. Land use conflict, social conflicts,
quality and use of the water, sediments disturbance and mobilization, and political conflict are some of the main issues to consider in proposed reclamation program options. This thesis represents a first step towards implementation of sustainable practices by a junior mining company and creates the potential for further monitoring successes and challenges in a detailed form. If the considerations outlined are carefully addressed the Caroni Project should have a good potential to achieve sustainable practices.
REFERENCES


Bateman Engineering Ltd. (2000), Preliminary feasibility report incorporating proposal for supply of bulk sampling plant for Caroni River, Venezuela, April, 2000


Hancock, Peter (2002): Human Impact on the Stream-Groundwater Exchange Zone


MEM and MARNR (1992-1993) Project CVG/EDELCA – 15-page document prepared by a combination of Government agencies whereby they proposed mining the lower Caroni on a JV basis with private contractors. (Original in Spanish, translated into English)


APPENDIX I     ESTIMATED CASH FLOW FOR THE CARONI PROJECT
<table>
<thead>
<tr>
<th>Estimated Cash flow/year</th>
<th>year 0</th>
<th>year 1</th>
<th>year 2</th>
<th>year 3</th>
<th>year 4</th>
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### Estimated Cash flow/year

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