An Examination of Environmental Performance and Eco-Efficiency in the North American Gold Mining Industry

By

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Abstract

This paper provides a historical account – since the advent of major environmental legislation circa-1970 – of the changes in environmental performance in the North American gold mining industry and provides an overview of eco-efficiency at North American gold mines. The paper begins with an examination and critique of various pieces of literature in an attempt to clarify how corporate environmental “best practice” has evolved in North America over the past three decades, and to illustrate the basic types of corporate environmental management strategies that exist today. From this review, a model of different corporate environmental management approaches – here called the “Corporate Environmental and Social Performance Spectrum (CESPS)” – is developed for use in the sections to follow. The remainder of the paper is devoted to illustrating trends of environmental performance in the North American gold mining industry, namely the changes that have occurred over the past three decades, and what environmental direction the industry is moving in today. Specific environmental data and complementary qualitative analysis contained in various sources are used for the historical assessment of environmental performance, and results from a questionnaire that had been distributed to the industry are used to show what types of management strategies and technologies are being employed to deal with sector-specific environmental problems today.

To summarize, over the past 25-30 years, the industry has improved its environmental performance and outlook, and at present, is practicing eco-efficiency in a number of areas. However, at certain gold mines, in particular those of the smaller, resource-strapped Junior Mining Companies, it was discovered that major economic and legislative barriers are preventing further improvement of environmental management practices. These obstacles, in effect, have and continue to prevent these mines from progressing upward along the CESPS. The paper concludes with a discussion about why and how these barriers have prevented implementation of improved environmental management practices and have slowed progress toward eco-efficiency at North American gold mines, proposes a brief strategy to overcome these difficulties, and identifies areas needing further research.
Acknowledgements

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<th>Description</th>
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<tbody>
<tr>
<td>AMD</td>
<td>Acid Mine Drainage</td>
</tr>
<tr>
<td>CEPA</td>
<td>Canadian Environmental Protection Act</td>
</tr>
<tr>
<td>CERC</td>
<td>Canadian Environmental Research Council</td>
</tr>
<tr>
<td>CESPS</td>
<td>Corporate Environmental and Social Performance Spectrum</td>
</tr>
<tr>
<td>CWA</td>
<td>US Clean Water Act</td>
</tr>
<tr>
<td>EA</td>
<td>Environmental Assessment</td>
</tr>
<tr>
<td>EARP</td>
<td>Environmental Assessment Review Process</td>
</tr>
<tr>
<td>EC</td>
<td>Environment Canada</td>
</tr>
<tr>
<td>EIS</td>
<td>Environmental Impact Statement</td>
</tr>
<tr>
<td>EPA</td>
<td>US Environmental Protection Agency</td>
</tr>
<tr>
<td>HSWA</td>
<td>Hazardous and Solid Waste Treatment</td>
</tr>
<tr>
<td>LDR</td>
<td>Land Disposal Regulations</td>
</tr>
<tr>
<td>MAC</td>
<td>Mining Association of Canada</td>
</tr>
<tr>
<td>MISA</td>
<td>Municipal and Industrial Strategy for Abatement</td>
</tr>
<tr>
<td>MOE</td>
<td>Ministry of the Environment (Ontario)</td>
</tr>
<tr>
<td>NRTEE</td>
<td>National Round Table on Environment and Economy</td>
</tr>
<tr>
<td>NPDES</td>
<td>National Pollution Discharge Elimination System</td>
</tr>
<tr>
<td>P2</td>
<td>Pollution Prevention</td>
</tr>
<tr>
<td>RCRA</td>
<td>Resource Conservation and Recovery Act</td>
</tr>
<tr>
<td>SME</td>
<td>Small and Medium Sized Enterprises</td>
</tr>
<tr>
<td>TSDFs</td>
<td>Treatment, Storage and Disposal Facilities</td>
</tr>
<tr>
<td>WQA</td>
<td>Water Quality Act</td>
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<tr>
<td>WBCSD</td>
<td>World Business Council for Sustainable Development</td>
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Chapter 1:
The Research Proposal

Introduction

In the twentieth century, the emergence of global environmental concerns has created new challenges for business. Since the advent of major environmental legislation circa-1970, there have been increased expectations for companies to minimize their pollution, improve their management of waste streams, and redesign industrial processes to operate in a more environmentally benign fashion. Although industry overall has responded positively to the introduced regulations by improving environmental performance on numerous fronts, there still remains room for improvement in many areas of operations.

Arguably, one of the most effective methods of improving environmental performance in any industry is eco-efficiency. This strategy, the premise of which involves doing “more with less”, categorizes activities that create economic value for a firm, and at the same time, minimize ecological impacts and the misuse of resources. At the corporate level, eco-efficiency embraces strategies in the areas of “pollution prevention”, “waste management”, “source reduction”, and “cleaner production”, all of which capture the idea of pollution and waste reduction through process change, as opposed to the traditional pollution control approaches to tackling environmental problems. To date, several businesses have benefited from integrating eco-efficient practices into business operations, and in the process, have dramatically improved the quality of surrounding environments.

Most of these firms, however, occupy the manufacturing and service sectors, and the numerous eco-efficiency case studies presented in the literature (e.g. Cramer 1996; Montgomery 1997; Reneud 1997) reveal this. As far as the primary sector of industry is concerned, few studies on eco-efficiency have been conducted, and few studies comprehensively assess which technological strategies are the most environmentally and economically effective for primary operations. Baseline assessments are needed to determine: (1) how far individual primary industries have “progressed” environmentally, (2) what technologies protect the environment the most effectively and provide the biggest return on investment, and (3) what is preventing improved eco-efficiency, and what must be changed to overcome these barriers. There are a plethora of environmental problems in the primary sector of industry but with expanded
research in these areas, ecological impacts will be minimized, substantial cost savings will be achieved, and overall, eco-efficiency will increase in operations.

To help bridge these gaps in the literature, an eco-efficiency case study on the North American gold mining industry is presented. By successfully integrating eco-efficiency into operations, the industry, which has a long been a significant polluter, would reduce environmental contamination from sources such as Acid Mine Drainage (AMD), heavy metals, and cyanide (from refining), and in the process, would receive enormous economic benefits such as reduced environmental expenditures and improved investor relations. Becoming practitioners of eco-efficiency, however, will require the industry to rid itself of the obvious "barriers" that work to impede its ability to improve its environmental management strategy and environmental performance. The North American gold mining sector is only one of hundreds that need to be examined but the goal of the study is not only to provide valuable information on eco-efficiency and environmental management practices at North American gold mines, but also to lay groundwork for further studies on eco-efficiency in the primary sector of industry.

**Problem Statement**

No individual piece of literature provides historical documentation of the changes in environmental management and environmental performance in the North American gold mining industry since the advent of major legislation circa-1970. Further, the literature is lacking sufficient assessment, measurement, and discussion about eco-efficiency in the primary sector of industry, let alone gold mining. Fully conceptualizing the economic merits of eco-efficiency at North American gold mines and in related industries would lead to enormous improvements to the environment, as well as a series of economic benefits for individual firms. The industry, however, currently operates under a stringent web of environmental legislation that is constantly changing, and has, to a degree, been impacted by the recent economic crash in gold stocks. Collectively, these could be impeding the integration of eco-efficient practices into operations.
Statement of Purpose and Research Approach

The aim is to gain an overall understanding of the corporate environmental management practices of both the past and the present in the North American gold mining industry. This involves analyzing historical environmental data and literature, and determining through the use of a questionnaire, what environmental management strategies and practices exist at sites today. The purpose of this paper is to interpret this information to provide a historical account – since the advent of major environmental legislation – of environmental performance in the North American gold mining industry, to determine the degree to which it has engaged in eco-efficiency, and assess whether economic and legislative pressures have impacted environmental management at mines.

The paper is structured as follows. The following chapter reviews and critiques the literature to illustrate how environmental “best practice” has evolved in North America, and clarifies what types of corporate environmental management strategies exist today. These environmental strategies comprise the corporate environmental management model – the “Corporate Environmental and Social Performance Spectrum (CESPS)” – that is used for the purposes of this study. Chapter 3 provides an overview of the study, including methodologies, central research questions and hypotheses. Chapter 4 serves as a review chapter that provides an overview of the economic and environmental conditions in the North American gold mining industry. Chapter 5 examines the environmental legislation regulating North American gold mining operations, and explains how adhering to these standards, which are frequently being amended, can be challenging for mines. Chapter 6 provides a historical account of environmental performance in the industry since the advent of major legislation circa-1970. Chapter 7 determines what the most eco-efficient technological setups are for abating and preventing contamination from AMD and cyanide – recognized as the two most serious environmental concerns at gold mines. Chapter 8 uses these results to interpret findings obtained from a questionnaire distributed to the industry, principally to determine where the industry lies on the CESPS, and the degree to which it is practicing eco-efficiency. Finally, Chapter 9 serves as the discussion component of the paper. Here, a brief assessment of the study is given, conclusions are drawn, and opportunities for further research are identified.
Chapter 2: Literature Review

Introduction

This chapter seeks to illustrate the evolution and types of corporate environmental management strategies in North America. In this assessment, the existing works – notably the indicator (measures) and management models – that have been developed in the literature to categorize performance are critiqued in order to clarify what types of environmental management strategies exist today. The past 25-30 year period has seen select firms progress from taking an ad hoc approach to environmental issues to adopting a more proactive eco-efficient vision. However, others continue to view environmental concerns as threats to operations, and change only when legislation changes. It is concluded from reviewing the literature that five types of corporate environmental management strategies exist: (1) Reactive Management, (2) Compliant Management, (3) Transitional Environmental Management, (4) Accommodative Management, and (5) (Leading-Edge) Proactive Environmental Management. These stages comprise the Corporate Environmental and Social Performance Spectrum (CESPS) developed for use in the paper.

Following this broad review, the concept of eco-efficiency is reviewed, followed by a discussion on its applicability to the mining industry. The chapter concludes with a brief discussion about environmental “drivers” – internal or external pressures – that influence a mine’s selection of its environmental management strategy.

Theoretical Approaches

Environmental Indicators

Many organizations, businesspeople, and academics (Cheatle 1995; Gilbert 1996; De Kruijff and Van Vuuren 1998), have, over the past 10-15 years, written and worked to develop comprehensive indicator sets (measures) that can be used to evaluate and monitor environmental performance. These simply attempt to address environmental issues in a quantitative manner, enabling the firm to manipulate data to determine levels of environmental performance. However, as Jorjani and Dyer (1996) explain, despite the widespread need for performance measures in business, very few practical systems have been
developed to date. The major challenges are what to measure and what numerical systems to use. Unlike several quantitative expressions (GDP, GNP, etc.), most environmental performance measures are designed to provide a qualitative scale of effects and a value judgement. Further, all companies and industries are different and therefore face different environmental challenges. Recognizing this, many (see e.g. Jung 1997; Rennings and Wiggering 1997; Azar et al. 1996) have tried to develop sets of more generalized environmental indicators designed to evaluate environmental issues universally but in the process, have produced tools too diluted to provide accurate assessments of corporate environmental performance.

Most of the articles that have been written on performance measurement and environmental indicators focus more on attributes of effective systems rather than on defining and measuring corporate environmental performance (Ilinitch et al., 1998). In a comprehensive review of the literature, Metcalf et al. (1995) found few articles that detailed corporate environmental performance systems that use indicator sets. Further, as Lober (1996) notes, in the literature, there is ambiguity associated with the term green. Judgements are frequently made about which companies are most green but no clear definition of greenness exists. These complications have made it difficult to develop universal sets of environmental indicators that can be used to monitor, evaluate and measure corporate environmental performance.

**Corporate Environmental Models**

A simplified approach to evaluating corporate environmental performance is categorization using environmental models. To date, many models of environmental management have been developed in the literature, each of which is largely prescriptive, and based on consultancy experience. The majority describe a series of “stages” by which firms become progressively more environmentally conscious (Schaefer and Harvey, 1998). Although the models vary in the number and definition of stages, they all have a similar scale that generally ranges from a mode of “noncompliant” environmental management to a mode of “proactive” environmental management.

The pioneer framework of corporate environmental management was developed by Topfer (1985 in Bostrum et al., 1992), who divides companies into four categories based upon their environmental performance: resistant, passive, reactive, and innovative. Firms in the first category – resistant – view environmental issues as a hindrance to their growth, and do their best to prevent the passing of
environmental laws. Passive companies ignore the environment altogether because they impose little environmental threat, and therefore have few environmentally based market opportunities. Reactive companies are those that only take environmental action to comply with legislation and keep up with competitors. The final category, innovative companies, are those that have moved beyond compliance, and have incorporated environmental strategy into their overall business plan.

A simplified model developed later by Simpson (1991) groups corporate responses to environmental pressures into three groups: the “Why Mes”, the “Smart Movers” and the “Enthusiasts”. Involvement in well-publicized environmental accidents (e.g. chemical spills, oil spills, etc.) serves as the catalyst in initiating the “Why Mes” to take any environmental action. “Smart movers” are more receptive to environmental issues, and have begun exploiting opportunities created by green consumerism. Finally, “Enthusiasts” are the companies that have moved beyond compliance, and have developed a strategic environmental policy.

More detailed frameworks have since been developed. Fiesinger (1992) argues that although environmental issues vary in their scope, sources, effects, risks, and socioeconomic consequences, each passes through a lifecycle that consists of four phases: recognition, policy formulation, implementation, and control. He maintains that the contours of long-term corporate development can be discerned using a parallel four-stage process: ad hoc, technocratic, top-management driven, and vision driven policy.

Newman’s (1993) work introduced the idea of the environmental management continuum: progressive environmental management. At one end, an organization takes a reactive posture to environmental issues. As it moves toward the middle ground, it progressively becomes more proactive but still lacks a full understanding of environmental risk beyond minimizing penalties for noncompliance. Organizations at the far “innovative” end of the spectrum have developed a comprehensive understanding of potential environmental issues, and have assessed the costs and benefits as well as the methods to control these risks.

James (1992) framework builds further on the idea of the environmental management continuum, grouping corporate environmental strategy into four categories: noncompliance, compliance, transitional, and environmental excellence. Companies that fall into the “noncompliance” stage simply ignore all environmental issues, and companies that fall into the “environmental excellence” stage, are innovative on most environmental fronts, often using the environment as a tool for gaining competitive advantage.
Roome’s (1992) model (Figure 1) of corporate strategic response to environmental issues, and Dodge and Welford’s ROAST Environmental Performance Scale (Figure 2) are among the most comprehensively defined. Roome’s model is similar to James’ but it identifies more effectively a continuum of strategic options open to a company, based chiefly upon notions of the degree of proactivity a company exhibits in relation to the requirements of environmental law and social pressures (Ghobadian et al., 1998). Roome suggests that most companies are reactive to various shades of environmental threat, and proposes five strategic responses to environmental pressures: non-compliance, compliance, compliance-plus, commercial and environmental excellence, and leading edge. The first response (non-compliance) characterizes companies that do not react to environmental pressures, and which lack a long-term vision. As the firm becomes more environmentally proactive, it progresses toward the last phase (leading edge), which characterizes companies that use state-of-the-art environmental management techniques, and are the leading environmental practitioners in their respective sector of industry. In Dodge and Welford’s ROAST scale, the traditional environmental categorizations are extended to include social responsibility (Figure 2). The least sensitive measure on the ROAST scale (Stage I) is represented by the “resistant firm”, which totally disregards ecological issues in decision-making processes. By Stage V, “transcendent”, a company has adopted strategies consistent with proactive, innovative ecological and environmental management, and has environmental values, attitudes, beliefs and culture that exhibit a total support for the environment (Welford, 1996).

Figure 1: Roome’s Strategic Options Model.

Non-compliant ➔ Compliance ➔ Compliance-Plus ➔ Environmental Excellence ➔ Leading-edge

(Source: Roome, 1992)
Figure 2: Dodge and Welford's ROAST environmental performance scale.

R  Resistant  (Stage I)  - Total resistance to environmental values and rules.  
- Unresponsive to environmental initiatives
O  Observe & Comply  (Stage II)  - Observes environmental laws but still unwilling to comply  
- Actions are enforced through legislation or court decisions
A  Accommodate  (Stage III)  - Organization begins to adapt to change  
- Early indications of proactive and responsive behaviours  
- Actions no longer entirely based upon compliance 
- Beginning of voluntary movement
S  Seize & Preempt  (Stage IV)  - The organization voluntarily seizes and preempts its actions with environmental concerns  
- Progressively engages in setting the agenda  
- Responsive to many external stakeholders
T  Transcend  (Stage V)  - Organization's environmental values, attitudes, beliefs and culture exhibit a total support for the environment

(Source: Welford, 1996)

The following discussion builds on these models. As Schaefer and Harvey (1998) have demonstrated, although many corporate environmental frameworks have been developed in the literature, even when using the most comprehensive examples, it is difficult to classify companies unequivocally according to individual information as most lack sufficient measurable, comparative criteria. Therefore, for the purpose of this study, rather than attempting to integrate the works of authors, the focus will be on outlining the various corporate environmental management strategies that have evolved in North America over the past 25-30 years. The emergence of each is owed to specific sets of environmental "drivers" that surfaced during different time periods. When using this simplified approach, a continuum of corporate environmental behaviour can be formulated and divided into five distinct stages (Figure 3): Resistant Environmental Management, Compliant Environmental Management, Transitional Environmental Management, Accommodative Environmental Management and Proactive Environmental Management. Although such a continuum represents a historical progression of corporate environmental management strategy, at the same time, it also represents a static categorization of corporate environmental management strategy as firms, for a variety of reasons, view environmental issues differently. The literature (di Norcia,
1996; Pezzey 1992; George and Weimerskirch 1994; Fuchs and Mazmanian 1998; Fiksel 1997) supports the development of such a model.

What necessitated development of the Continuum – entitled the Corporate Environmental and Social Performance Spectrum (CESPS) – was the discovery of three major misconceptions in the literature. First, many authors (e.g. Garrod and Chadwick 1996; Fiksel 1997) imply a corporate shift to proactive modes of environmental management has occurred universally throughout industry. Only select firms, however, in particular industries exposed to specific environmental and socioeconomic conditions have adopted Proactive Environmental Management strategies. Second, in many historical reviews of environmental best practice (e.g. Colby 1991; Gladwin et. al 1995) that summarize the environmental management paradigms of the past 25-30 years, authors neglect to mention that the overall corporate strategy that emerged in each of these paradigms still exists today. Third, the authors of environmental management frameworks design these with the intention of universal application but each ends up lacking sufficient comparable criteria. Each stage of the CESPS is examined in the section to follow.

Figure 3: Corporate Environmental and Social Performance Spectrum (CESPS), its stages and the decade in which each emerged.

<table>
<thead>
<tr>
<th>Left: Reactive/ Unresponsive</th>
<th>Right: Intermediary</th>
<th>Right: Responsive/ Proactive</th>
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<tbody>
<tr>
<td>Resistant 1960s</td>
<td>Compliant 1970s</td>
<td>Transitional Early 1980s</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Accommodative Mid-1980s</td>
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<td></td>
<td></td>
<td>Proactive 1990s</td>
</tr>
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</table>

Stages of Corporate Environmental Management
Stage I: Resistant Environmental Management

There was virtually no corporate environmental management prior to the 1960s. Early industrializing societies were so occupied with increased production that the environmental damage associated with economic growth was virtually ignored. The absence of environmental legislation enabled firms to operate without any environmental safeguards, and the ensuing pollution created a wide range of ecological problems throughout North America (see e.g. Gunn et. al 1995; Cappon 1987).
The publication of Rachel Carson’s *Silent Spring* (1962), however, heralded the arrival of the environmental era, helping to initiate a major shift in societal perception about the environment. Shortly after its release, both the Canadian and American government responded by passing cornerstone pieces of legislation such as the *US Air Quality Act* (1967), the *US National Environmental Policy Act* (1969), the *Canada Water Act* (1972), and the *Canadian Clean Air Act* (1971). Industry initially opposed the introduction of the new environmental legislation, maintaining that meeting the newly introduced regulations required heavy investment in costly technologies, which would cut into profits. In response, firms continued producing mass outputs of pollution, taking full advantage of the “looseness” of the newly introduced legislation, which failed to effectively penalize those that violated environmental law.

Today, few industries occupy the “Resistant Environmental Management” stage. Environmental regulations have since become stricter and the penalties resulting from their violation make it economically unproductive for a firm to be noncompliant. As Nadeau (1997) explains, although regulatory costs – the expenses a firm pays for generating pollution – rises as enforcement and monitoring actions intensify, so do the expected fines for noncompliance. As a result, few firms in North America choose to violate environmental regulations. Only in the Third World, where, in many instances, environmental legislation is still in its infancy, is there a proliferation of companies occupying the “Resistant Environmental Management” stage. Here, firms choose to resist regulations because few fines are imposed if violated, and even when enforced, the penalties are insufficient to facilitate an improvement in corporate environmental behaviour.

**Stage II: Compliant Environmental Management with Emphasis on Pollution Control**

The 1970s marked a makeshift movement in environmental legislation in North America. Regulations became stricter, fines heftier, and as a result, corporate environmental practices began improving. A combination of changed societal demands, and the emergence of green politics led to the passing of this new legislation, and for the first time in history, North American companies were forced to abandon the polluting industrial systems responsible for the environmental crisis in the first place. Also characteristic of this time period was the establishment of federal, state and provincial environmental
protection agencies and ministries, which were assigned the responsibility of setting environmental limits (Colby, 1991). Business responded to environmental issues in a reactive and ad hoc manner, setting to meet only the minimum standards required in achieving legislative compliance. This general pattern of performance continued well into the 1980s.

Today, in spite of the legislation becoming more stringent, many firms remain content with just meeting the minimum environmental standards required to meet legislative compliance, changing only when laws change. The typical pollution abatement strategy employed is pollution control, which emphasizes using conventional, typically ineffective end-of-pipe solutions (Yamaji 1997; Preul 1995; Luken and Freij 1995) that tackle environmental problems after they have occurred, rather than at the source. As Irwin and Hooper (1992) note, conventional end-of-pipe technology is an attractive option to many firms because it requires less capital investment, less development, and less disruption to production processes than more eco-efficient technologies. However, as far as effectively minimizing wastes is concerned, pollution control strategies lag far behind the leading-edge pollution prevention and waste minimization approaches.

Although compliant firms have a grasp on environmental issues, their modes are fundamentally reactive to legislation, and only pursue environmental policies at a minimum level in order to avoid legal penalties (Ghobadian et al., 1998). As Roome (1992) details, a major problem with companies operating in this stage is that legislation itself tends to be driven reactively and often lags significantly behind current environmental thinking and concerns. Consequently, a firm with a compliant strategy employing conventional pollution abatement strategies, unless undergoing a major management change, is not likely to ever anticipate future changes in the environmental agenda, take control of its environmental priorities, or plan to use its environmental stance to put itself in a position to gain competitive advantage.

Stage III: Transitional Management

The "Transitional" Phase was inserted into the CESPS because it safe to assume that shifting from a corporate mode of noncompliance and environmental resistance into a more environmentally responsive state cannot be instantaneous. Before shifting into Phase IV ("Accommodative Environmental
Management”), a firm must have a keen understanding of environmental issues, and must recognize the importance of having effective environmental management infrastructure in place. Further, any operation, before implementing cleaner technology or more effective environmental management practices, must have a grasp of their purposes and fully realize the potential benefits to both it and the surrounding environment. A firm in this “Transitional Management” stage is defined as one that has begun laying important groundwork for responsible environmental management. It does not necessarily mean that the more effective technologies and plans are in place, or that environmental performance is significantly different from that of firms residing in the previous stage of the CESPS (“Compliant Environmental Management”). It simply means that a company has begun actively “studying” to become more environmentally responsible. Transitional firms typically have an environmental officer or have begun developing an environmental department, have begun strategizing to implement environmental policies, and have begun examining options for cleaner industrial production.

Stage IV: Accommodative Environmental Management

By the mid-1980s, many firms had made the transition, fully shifting from resisting and complying with environmental legislation (Margerum and Born, 1995) to adopting a more positive approach to the environment. A number of widely publicized environmental accidents, particularly the methyl isocyanide leak (1984) in India, a chemical spill in the Rhine River (1986), and the Chernobyl disaster in Russia (1986) helped initiate a change in philosophy (Howes et al, 1997). New concepts like cradle to grave responsibility, sustainable development and retroactive liability began surfacing in corporate agendas. The companies taking a more anticipatory stance to environmental issues – categorized here as having an “Accommodative Environmental Management” strategy – have made two significant changes: (1) each has extended social and environmental responsibility, and (2) each has adopted a series of unique environmental management tools and strategies.
Extended Corporate Environmental and Social Responsibility

As DeJardins (1998) notes, initially, the concept of corporate responsibility never incorporated the needs of the environment. Since the publication of the highly influential Brundtland Commission’s report, *Our Common Future* (1987), however, global environmental awareness has dramatically increased and with it, corporate environmental responsibility (Roome, 1994, Morelli 1999). Firms that have credible environmental care and responsibility have specified how they will react to its environmental problems, a major “add on” to “business as usual” Compliant Environmental Management (Freeman, 1983).

These firms have extended Ansoff’s (1965) “stakeholder” principle to several business fronts. Stakeholders are organized groups of people who stand to be affected by the implications of business decisions and who can directly or indirectly influence industrial actions (Earl and Clift, 1999). Some of the major stakeholder groups affected by corporate environmental decisions include:

- Local communities
- Municipalities
- Insurers/bankers
- Shareholders
- Customers
- Employees

“Accommodative” firms, unlike “Compliant” firms, account for some of the needs of these groups when devising environmental plans and strategies.

*Environmental Tools and Strategies*

Many “Accommodative” companies, in an attempt to more effectively anticipate environmental challenges, have implemented a number of comprehensive environmental management tools, including:

1) Comprehensive environmental policies: blueprints that outline clearly the environmental goals of a firm, along with environmental strategies, plans and initiatives.

2) A well-defined environmental management system (EMS): a set of organizational procedures, responsibilities, processes, and necessary means to implement environmental policies (Begley, 1996).
Beginning with a thorough review of operations that extends to every level of business, an EMS accounts for corporate organization and the actions taken with respect to environmental issues. It allows a company to control and reduce its environmental impacts and enables it to react more effectively to changing environmental conditions (Jorjani and Dyer 1996).

3) An environmental review: a baseline study that assesses present environmental performance, and is very much the starting point for any environmental management strategy (Garrod and Chadwick, 1996).

4) Performance audits: follow-up examinations that assess environmental behaviour and compare them to targets and goals. Each is a systematic, documented, and objective evaluation undertaken at regular time intervals that seek to (Welford, 1996):

- Verify compliance
- Identify potential problems
- Measure environmental impacts
- Measure performance
- Confirm the effectiveness of existing environmental management strategies

5) The environmental report: demonstrates a company’s commitment to the environment and details performance and associated trends (Azzone et. al 1997). Although voluntary and publicly available, corporate environmental reports serve as communication mediums to potentially impacted stakeholder groups. Selecting the audience for the environmental report is the most difficult hurdle, because it determines what information is to be included (Lober, 1997). Although many have argued that the report, because it is written with a specific set of stakeholders in mind, has limited application, its design shows initiative on behalf of the firm, which has taken the time to address the environmental concerns of potentially impacted parties.

6) Product life-cycle management: an integrated approach to minimizing the environmental burdens, risks and costs associated with a product or service over its life cycle (Brady et. al, 1999).

Adopting these tools puts a firm in a better position to manage environmental issues.
Stage V: Proactive Environmental Management

The final stage of the CESPS, "Proactive Environmental Management", categorizes firms that, like "Accommodative" firms, have extended social responsibility but more importantly, have fully conceptualized the potential environmental impacts of their industrial processes, and have implemented highly effective programs for mitigation and environmental improvement. These firms have in place the most effective systems of environmental management, which, as Plaut (1998) has indicated, are those that extend far beyond compliance with laws and regulations, and which produce the "cleanest" environmental results. Each shares a number of key characteristics:

- Improves the efficiency and quality of products, processes, and workers
- Important players – directors, researchers and employees – in each have made a commitment to go beyond mere regulatory compliance, and have, in fact, made a commitment to continuous improvement.
- Environmental decisions made within each are largely voluntary-based
- Has highly-developed environmental management "tools" and strategies

Few firms have reached this stage, which, of course, is constantly being redefined since new practices are continually being introduced.

Naturally, it is the environmental leaders that occupy this stage and the few labeled as being "Environmentally Proactive", is highly anticipatory, and even highly distinguished from the well-respected "Accommodative" performers. The companies Monsanto, 3M, S.C. Johnson and Sons, Weyerhaeuser, and Xerox, which are clearly leading environmental stewards, and which are the companies others within their respective sectors benchmark themselves against, could be safely placed within this stage. In sum, for a firm to be placed in Stage V ("Proactive Environmental Management") of the CESPS, it must have a track record of consistent and significant environmental improvement, emit minimal waste product, have leading-edge environmental management practices in place, and must also have extended social responsibility similar to or beyond that of "Accommodative" companies.

Table 1 provides a concise list of expectations at each stage of the CESPS
Table 1: CESPS stages and the characteristics of each.

<table>
<thead>
<tr>
<th></th>
<th>Resistant</th>
<th>Compliant</th>
<th>Transitional</th>
<th>Accommodative</th>
<th>Proactive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unresponsive to environmental legislation</td>
<td>Perform in line with legislation</td>
<td>Have begun implementing more practical environmental management tools</td>
<td>Have implemented a number of effective environmental management tools</td>
<td>Anticipatory</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Only improve environmentally when regulations change</td>
<td>Have begun “studying” environmental management and its importance</td>
<td>Have extended social responsibility to a number of fronts</td>
<td>Leading edge environmental practitioners</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Use conventional end-of-pipe technology</td>
<td>Do not have improved environmental technologies in place but are in the process of upgrading existing systems</td>
<td>Have upgraded a number of environmental technologies</td>
<td>Use the cleanest of environmental technologies in industrial production</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Never anticipate changing regulations and technology</td>
<td></td>
<td></td>
<td>Exhibit the strongest socioeconomic performance of all firms</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Are continuously improving both environmentally, socially and economically</td>
<td></td>
</tr>
</tbody>
</table>

Eco-Efficiency

Brief Overview

A major purpose of this study is to determine the degree to which the North American gold mining industry is embracing eco-efficiency, defined as “the delivery of competitively priced goods that satisfy human needs and bring quality of life, while progressively reducing ecological impacts and resource intensity throughout the lifecycle, to a level at least in line with Earth’s carrying capacity” (WBCSD 1997; WBCSD 1998a). The first word of the concept encompasses both ecological and economic resources, and the second means making optimal use of both. In other words eco-efficiency is doing more with less, and is a practical strategy for achieving maximum environmental improvement in industry.

As DeSimone and Popoff (1997) note, eco-efficiency has five core themes: (1) an emphasis on service, (2) a focus on needs and environmental quality of life, (3) consideration of the entire life cycle, (4) a recognition of limits to eco-capacity, and (5) a process view. It involves the constant searching for strategies that achieve higher levels of economic and environmental performance through continuous improvement. In an attempt to operationalize eco-efficiency, the World Business Council for Sustainable Development (WBCSD), an organization that aims to “provide leadership as a catalyst for change” in the achievement of environmental excellence, and promotes “the attainment” of eco-efficiency “through high
standards of environmental management in business” (Wyburn, 1996), developed seven industrial guidelines:

1) Reduce the material intensity of products and services.
2) Reduce the energy intensity of products and services.
3) Reduce the dispersion of toxic materials in industrial processes.
4) Increase material recyclability.
5) Maximize sustainable use of renewable resources.
6) Extend the durability of products.
7) Increase the service intensity of goods and products.

Each is broad in scope and collectively, can serve as blueprints for firms to follow in order to extend and maximize stewardship practices in all levels of industrial operation. Several companies worldwide have already integrated eco-efficiency into operations in a number of ways, including (WBCSD, 1998):

- Building environmental stewardship and excellence into corporate philosophy and fabric
- Setting targets for improved performance, and introducing systems to track, measure and enforce those targets
- Taking responsibility for products throughout their life-cycles
- Integrating cleaner technologies into operations
- Being innovative in developing new processes and products
- Putting a priority on preventing pollution, rather than paying for clean-up

In each instance, there is an emphasis on value creation, which profits the firm, and yields maximum benefit to the environment.

Further Clarifying Eco-Efficiency in the Mining Context

In the chapters to follow, a case study of environmental management practices and eco-efficiency is presented for the North American gold mining industry. Before the investigation commences, however, eco-efficiency must be further defined in the mining context. Although much of the literature (e.g. Insead et al., 1997; Cramer, 1996; van Nes and Cramer, 1997; Choucri, 1995) examines the value of eco-
efficiency in the manufacturing and services industries, it fails to clarify its specific role in the primary industries. Compounding the problem is that the WBCSD, in their definition of eco-efficiency, appeared more focused upon developing environmental plans for firms engaged in manufacturing and services operations, rather than those involved in natural resource extraction and processing.

Of the five core themes of the WBCSD's definition of eco-efficiency, three ("Emphasis on Service", "Focus on Needs and Environmental Quality of Life", and "A Process View") relate to processes in service and manufacturing industries. For example, the "Emphasis on Service", according to the WBCSD, requires "satisfying customers needs", and the "Focus on Needs and Environmental Quality of Life" requires "understanding customers' real needs". Since mines are not engaged directly in customer service, these would not be important management foci. On another note, some of the eco-efficiency guidelines developed by the WBCSD have little, if any, applicability to mining operations. Specifically strategies #6 ("Extended durability of products") and #7 ("Increased service intensity of goods and products") are suited most for operations engaged in services and manufacturing processes because again, there is minimal customer influence. DeSimone and Popoff (1997) also contend that the definition of eco-efficiency, when applied to a specific industrial sector, must be further defined to clarify meaning and purpose.

The premise of eco-efficiency, which is "doing more with less", can be an effective approach for mines if properly defined and applied. In view of the slight shortcomings in the WBCSD's framework and the literature, the following definition of eco-efficiency was developed for use in this study:

State-of-the art, economically viable environmental management techniques, including strategic approaches, "tools", improved treatment practices, and waste reduction measures.

**Integrating Eco-Efficiency into the CESPS**

Since eco-efficiency is a continuous drive toward combined economic and environmental improvement, it would be incorrect to assume that all of the indicators of eco-efficiency should be placed within the final stage of the CESPS ("Proactive Environmental Management"), and to argue that only the firms within this stage are eco-efficient. Becoming eco-efficient is incremental, and requires that a number
of key steps are made in chronological order. The WBCSD has proposed valuable guidelines for eco-efficiency but every theoretical proposition for industrial environmental improvement is a procedural task that requires that firms follow a precise methodology in order to achieve results. Therefore, eco-efficiency, like stages of corporate environmental management, can be expressed in a continuum, and since firms occupying different stages of a corporate environmental management model – in this case, the CESPS – can be eco-efficient, although to varying degrees, indicators of eco-efficiency are found throughout different stages.

One key difference is that each indicator of eco-efficiency is never static, and can easily "descend" to a lower stage in a corporate environmental management model. For example, if, at one point in time, the establishment of a corporate environmental policy was viewed as being one of the most eco-efficient strategies, it could legitimately be placed in Stage V of the CESPS, and used as an indicator of "Proactive Environmental Management". If, however, a number of firms begin implementing environmental policies, the strategy is no longer unique, and could hypothetically descend to Stage III of the CESPS and used as an indicator of "Transitional Firms". The strategy would be no less important, just that, from the perspective of eco-efficiency, it would be no longer leading edge on the continuum.

Each of the indicators selected for this study conform to the guidelines for a "good robust indicator" of eco-efficiency identified by Lehni (1998):

- Simplistic but reflects the relevant environmental impact factors
- Based on characteristics, which are common to all processes, goods or services
- Easily measurable and accessible by calculations
- Leads to cost efficient application
- Transparent and allows reproducible results for all steps of the product life cycle
- Leads always to results in the right direction
- Forms a link to aspects of the market
- Is useful locally, regionally, or globally

Further, to avoid making the same mistakes evident in existing of indicator sets – which, as identified earlier, was that most have too broad of a focus – each indicator of eco-efficiency selected were only those most relevant to mines. The following is a list of six important eco-efficiency indicators chosen to assess
the gold mines that are examined in this study, along with an explanation describing the stage of the CESPS in which each is found and why. The indicators are presented in ascending order, from least eco-efficient to most eco-efficient.

1) Wider implementation of environmental management tools, including policies, reporting systems and training programs: Organizational restructuring is a necessary first step in becoming more eco-efficient. Wider implementation of environmental management tools serve as indication that the mine is changing its corporate focus, and has begun working toward achieving higher environmental standards through economic improvement. Most mines have already begun making this change, and for this reason, this first indicator of eco-efficiency is placed in Stage III of the CESPS.

2) Implementation of an EMS: Another important management step in becoming more eco-efficient is to become better organized and more prepared for problems in environmental management. Beyond standard environmental policymaking, and increased environmental awareness, the next step is implementation of an EMS, which enables an organization to more effectively identify potential management problems, and opportunities for possible improvements. In recent years, the growing popularity of the EMS in most industries, including mining, no longer makes it a unique environmental management strategy. A strong global industrial environmental movement has today made the EMS, which remains another fundamental first step toward improved eco-efficiency, a characteristic of the "Transitional" Companies of Stage III of the CESPS, which recognize that this organizational procedure is key in moving towards a more "Accommodative" state.

3) In-house Recycling: Once management goals have been set, and the proper tools implemented, a mine can focus more on its practices. In-house recycling, which emphasizes the reuse of products such as water, energy, and wastes, is a very common but effective component of eco-efficiency. Although a simple and widely practiced strategy, here, it is placed high in Stage III, and can even be placed in the early part of Stage IV, simply because, in the case of a mine, by largely focusing
upon in-house recycling, environmental impacts can be substantially reduced, and economic savings can be enormous.

4) Highly Effective Waste Treatment and Control Mechanisms: The companies in Stages II and III of the CESPS still employ the conventional pollution control apparatuses to tackle environmental problems. A number of more effective waste treatment remedies have since emerged on the market that produces environmental results far beyond those of conventional technologies. It is suggested here that this indicator lies within the lower portion of Stage IV ("Accommodative Environmental Management") of the CESPS, because regardless of possible minor secondary costs, overall, the use of such technologies produces improved environmental results.

5) Evidence of Environmental Improvement and Existence of More Comprehensive Environmental Management Tools: Is there strong evidence that the mine has seriously improved all of its environmental management tools, and that each is highly comprehensive? Further, has the mine improved its training programs, and does it exhibit a steady pattern for environmental improvement? Finally, is the environmental management infrastructure it has in place sufficient for the mine to progress to a position of waste minimization? If so, the mine has performed all of the necessary steps in order to progress further through Stage IV and perhaps into Stage V of the CESPS.

6) Development and integration of cleaner technologies: Has the mine progressed beyond treatment and control, and adopted a vision of waste minimization? Has it begun installing cleaner technologies that foster both waste minimization and pollution prevention (P2). It is important, however, to first clarify the definitions of both waste minimization and P2 in the mining context, in view of their ambiguity in the literature. Baas (1998) has identified this, arguing that while the concept of prevention of waste and emissions has become increasingly known within companies, many have vastly different interpretations of P2. The Office of Pollution Prevention and Toxics of the US Environmental Protection Agency (EPA), for example, defines pollution prevention with
source reduction: preventing pollution before it is created, so there is less or no need to control, treat, or dispose of it (see Bridges, 1994; Burton 1998). The Pollution Prevention Office of the Ontario Ministry of Environment (MOE) has adopted a similar definition of pollution prevention to that of the EPA, defining pollution prevention as activities that “reduce or eliminate pollutants or wastes at the source” (MOE, 1997). The US Pollution Prevention Act of 1990 defines P2 as source reduction, which itself is defined as any practice “that (i) reduces the amount of any hazardous substance, pollutant, or contaminant entering any waste stream or otherwise released into the environment; and (ii) reduces the hazards to public health and the environment associated with the release of such substances, pollutants or contaminants”. To clarify the definition of waste minimization and P2 in the mining context, for the purposes of this paper, they are defined as adopted technologies and practices that: (a) result in significant elimination or reduction of pollutants; (b) create benefits to the environment through reduced energy use or more efficient use of materials and resources; (c) demonstrate technical innovation and; (d) save money through avoidance or deferral of pollution control equipment costs, reducing operating and material expenses, or increasing sales of an existing or new product. Each of these four characteristics were developed from the criteria an environmental project must meet to receive formal recognition under 3M's Pollution Prevention Pays (3P) Program, one of the world’s largest and most successful pollution prevention projects. This indicator of eco-efficiency is characterizes highly “Accommodative” firms, on the verge of being leading edge.

Table 2 incorporates these indicators into the CESPS to better illustrate progress toward improved eco-efficiency.

The study presented in this paper seeks to evaluate a number of environmental management aspects in order to determine levels of eco-efficiency at North American gold mines, but for environmental technologies, only evaluates those being used to deal with problems of pollution from Acid Mine Drainage (AMD), and cyanidation processes – recognized as being the gold mining industry’s two biggest environmental challenges. Progress toward eco-efficiency, however, is treated separately to overall corporate performance because eco-efficiency does not account for social responsibility, which is now regarded as being another important component of corporate management strategy, and each stage of the
CESPS is a cumulative representation of different "levels" of environmental and socioeconomic performance.

Table 2: Illustrating Progress Towards Improved Eco-Efficiency.

<table>
<thead>
<tr>
<th>CESPS Stage</th>
<th>Environmental Strategy</th>
<th>Level of Eco-efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage V: Proactive Environmental Management</td>
<td>• Cleaner Technologies and Waste Minimization Measures</td>
<td></td>
</tr>
<tr>
<td>Stage IV: Accommodative Environmental Management</td>
<td>• Implementation of Comprehensive Environmental Management Practices</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Highly Effective Control Systems and Improved Treatment Measures</td>
<td></td>
</tr>
<tr>
<td>Stage III: Transitional Environmental Management</td>
<td>• In-House Recycling</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Implementation of an EMS</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Expanded Implementation of Environmental Management Tools</td>
<td></td>
</tr>
<tr>
<td>Stage II: Compliant Environmental Management</td>
<td>• Conventional Technologies and Strategies</td>
<td></td>
</tr>
<tr>
<td>Stage I: Resistant Environmental Management</td>
<td>• Minimal, Ineffective Environmental Cleanup Equipment</td>
<td></td>
</tr>
</tbody>
</table>

High Eco-Efficiency

Moderate Eco-Efficiency

No Eco-Efficiency

The Role of Environmental Drivers in the Mining Industry

Environmental "drivers" are largely responsible for influencing a firm's selection of its corporate environmental strategy. These play an equally important role in initiating forward movement of a firm into another "stage" of corporate environmental management (e.g. "Compliant" to "Transitional"). As Epstein and Roy (1998) explain, environmental drivers can either be internal or external. Internal factors include:
(1) corporate culture, (2) environmental performance, and (3) internal stakeholder groups (e.g. employees and executives) that recognize that installing industrial systems geared toward achieving continuous environmental improvement creates bottom-line benefits for a wealth of parties, including themselves. External pressures include (1) regulations, (2) market influences, and (3) geographic factors. In short, regulations are governmental pressures, market influences are consumer pressures, and geographic factors refer to regional influences, such as climatic, ecology and topography. While Epstein and Roy (1998) provide a broad overview of environmental drivers in industry, however, it is important to note that each industrial sector has its own set of environmental drivers.

Which environmental drivers are most responsible for influencing a mine's selection of its corporate environmental strategy? There are two major drivers. The first is pressure from legislation (Warhurst and Bridge, 1996), which, in the North American regulatory environment, is stringent and is strictly enforced. As Sawatsky (1998) notes, the lack of sound mine management can lead to a violation of legislation, an impediment to mine operation and an expensive irritation to mine operators. Such problems can be avoided, however, with advanced planning, proactive intervention, compatibility between environmental protection and mine profitability, and integrated management planning. Further, since most mines are under intense governmental scrutiny in strict regulatory environments, an incentive to perform at high environmental levels is to simply avoid frequent government inspections, conflicts with environmental ministries, costly corporate auditing, and simply the chance of incurring costly penalties. Several North American mines are targeting to comply beyond legislation and have already developed partnerships with governments in broad-based environmental research programs to demonstrate corporate environmental commitment (Sanchez, 1998). In Canada, for example, the Mine Environment Neutral Drainage (MEND) program is a Can$18 million government-industry initiative, the purpose of which is to achieve a better understanding of the mechanisms behind Acid Mine Drainage (AMD), and devising ways of preventing it (MEND, 1993).

From a regulatory standpoint, another practical reason for mines to strive to continuously improve environmentally is that legislation is amended after its implementation, which can turn a set of proactive environmental management practices into mere compliance tools. As Chapter 5 will show, the North
American regulatory environment is changing, and in order for mines to avoid costly fines and penalties, changes need to be made.

The second environmental driver for mines relates to external stakeholder pressure, specifically that coming from insurance companies, banks and shareholders involved with the operation (Atkinson 1996; Plant et al. 1998; Kra11998). Crichton and Clarry (1997) have examined these issues in more detail, explaining that lenders are concerned with the financial risk related to environmental degradation of property since they are potentially liable for cleanup costs should the company go bankrupt, and for unforeseen environmental costs the borrower cannot service. Due to these areas of risk, many lenders are requiring an environmental site assessment that outlines (1) historical contamination, (2) close-out costs, (3) major compliance issues with existing or foreseeable upcoming environmental legislation, (4) causes of ongoing contamination, (5) third party liabilities, and (6) an assessment of existing environmental management practices. Thus, in order to easily secure loans from banks, and support from insurance companies, mines must demonstrate that they are performing at a high environmental level. These positive relations in turn attract shareholder investment. Community demands further affect a mine’s selection of its corporate environmental management strategy. Community relations can be initially sour but demonstrating a serious commitment to environmental management, accounting for the needs of residents, and financing important community service such as education and healthcare, can significantly ease the functioning of mine operations.

**Economic Challenges for Junior Mining Companies?**

Various drivers naturally motivate a company – in this case a mine – to improve environmentally. However, environmental upgrading requires a mine to have economic flexibility, and if funds are unavailable, improvement is completely impossible. Particularly challenged are smaller companies, which lack both money and resources to anticipate environmental change, and to implement leading edge practices. There is a rich literature that examines problems with implementing waste minimization measures in small and medium sized enterprises (SMEs) – defined as firms with a capital investment of less than US$1.5 million, total assets less than US$4.5, or employees less than 200 (Chiu et. al. 1999). The
SME label typically describes companies residing within the manufacturing and service sectors of industry. From the perspective of environmental management, the argument presented in the literature is that the SME lacks the funds to be proactive, and lack the requisite resources, information technology and personnel to identify opportunities for waste minimization and improved environmental management practices.

In the case of the mining industry, analogous to the SME-environmental management issue is the Junior Mining Company-eco-efficiency issue. The premise here is that Junior Mining Companies, which are defined as the smaller exploration and mineral processing corporations, like SMEs, have a shortage of resources that could prevent them from being environmentally proactive. The “Junior Mining Company” was formerly a label used for individual or independent companies, mostly involved in mineral exploration, spending on average less than CAN$1 million per year (Miller, 1980). It has since become more broadly used as a classification for all small mining companies that are most affected by mineral price fluctuations, and that represent the financially volatile and high-risk portion of the industry. In Canada alone, Junior Mining Companies outnumber the more vertically integrated, diversified Senior Mining Companies by a ratio of 8:1, and their numbers are increasing throughout all of North America. A major focus of the study presented in the chapters to follow is to determine if mineral price fluctuations – in this case gold – affected the selection of environmental management strategies at mine sites. Specifically, an attempt is made to determine if market instability impacted the environmental strategy at the gold mines of both Senior Mining Companies and Junior Mining Companies. Have fallen gold prices, which has been a major stimulus in the rapid decline in gold mining on federal lands (NRC, 1999), had any impact on environmental management practices at North American gold mines, particularly those owned and operated by Junior Mining Companies?

Summary

Apparent weaknesses with existing environmental management models and indicator frameworks necessitated the development of an environmental management scale – the Corporate Environmental and Social Performance Spectrum (CESPS) – for use in this paper. The chapter first detailed the weaknesses of
other management frameworks, and then outlined the CESPS and its importance in this study. Next, the concept of eco-efficiency – strategies that are cost effective and highly environmentally sound – was introduced, and primary indicators were developed for use in the study presented in the chapters to follow. After each indicator of eco-efficiency was placed in the “appropriate” stage of the CESPS, a discussion on environmental drivers – primary reasons behind a firm’s selection of its corporate environmental management strategy – was presented, along with a detailed description about the two major environmental drivers in the mining industry: legislative pressure and stakeholder concerns. The chapter concluded with a discussion about how economics limits what a firm can do to improve its environmental management practices, and that the strategies of smaller businesses, which, in the case of the mining industry are the Junior Mining Companies, can be seriously impacted in the event of serious financial disturbance.
Chapter 3: Research Questions and Methodology

Core Research Questions

Using the Corporate Environmental and Social Performance Spectrum (CESPS) as guidance, the primary objectives of this study are to provide a historical account of environmental management practices and environmental performance in the North American gold mining sector, to determine the degree to which the sector has engaged in eco-efficiency, and to assess whether there is room for improvement. These specific research questions are examined:

1) How has environmental management and performance in the industry changed since the passing of major environmental legislation?
2) From an environmental management perspective, where is the industry today?
3) Is eco-efficiency being practiced in the industry, and if so, what is the evidence?
4) Is there opportunity for improvement, and if not, what is preventing the improvement?

The “Corporate Environmental and Social Performance Spectrum” (CESPS) developed in Chapter 2 is used to help answer each research question. To help answer research questions 3 and 4, the mitigation measures used to combat pollution from cyanide and AMD are examined, since these environmental problems are regarded as being the most serious in the industry. It was concluded earlier that gaining an overall picture of the environmental management practices being used in these two problem areas would aid in determining how eco-efficient the industry has become.

Research Hypothesis

The literature review reveals that over the past 25-30 years, environmental management in North America has changed dramatically. Further, it suggests that today, although strict legislation prohibits the industrial environmentally damaging activities of the past, companies still approach environmental issues differently. This study posits that environmental management in the North American gold mining industry has, collectively, over the past 25-30 year, improved. It is also hypothesized that several mines owned by
Senior Mining companies have shifted to a more “Accommodative” modes of environmental management but in the case of the more resource-deficient operations of Junior Mining Companies, current economic and legislative constraints have, and will continue to prevent a significant integration of more eco-efficient practices.

**Methodology**

**Overview**

In order to present as much information as possible on the changing environmental performance of the North American gold mining industry, a number of environmental statistics were used, as well as particular qualitative information contained in reports and articles. The first section of the study amalgamates historical environmental data and information presented in published studies to illustrate how environmental management practices in the industry have changed in the past 25-30 years. The second section assesses the types and effectiveness of a number of environmental technologies being used in AMD management and cyanidation processes at North American gold mines. The final section interprets feedback from a questionnaire distributed to North American gold mines to illustrate patterns of environmental management practices and eco-efficiency, and to determine where the industry, as a unit, is falls on the CESPS.

**Data Sources**

The first part of the research used a number of data sources, principally to help illustrate how environmental performance and environmental management has changed in the industry in the past 25-30 years. The topics of the statistics used include:

- Annual pollution abatement and control expenditures
- Allocated cost allowances
- Environmental expenditures
- Environmental protection expenditures
Environment Canada, MAC, Statistics Canada, the EPA, and the US Department of Commerce collected the data used.

Complementary Information

Additional information on stewardship practices in the North American gold mining industry presented in the first section of the research was obtained from corporate environmental reports, industrial reports, and journal articles. These sources provide historical accounts of changing environmental management practices in the industry, case studies on environmental management practices at specific mines, and evidence of how particular environmental management tools have contributed to improving environmental performance.

Questionnaire

In the final section of the research, feedback from a questionnaire (see Appendix II) is used to (1) gain a better understanding about what types of environmental management strategies and technologies exist in the North American gold mining industry today, and (2) to determine the degree to which the industry is currently practicing eco-efficient management. The questionnaire had three parts. The first section sought to determine general characteristics about the mine, including mine type and operating conditions. The second section, the purpose of which was to find out whether the industry has at least progressed to Stage III of the CESPS ("Accommodative Environmental Management"), sought to obtain information about the environmental management strategies and tools being used at sites. The final section, under each theme of eco-efficiency relevant to gold mining, sought to determine to what degree the industry is doing "more from less". A number of practices were examined, but in the assessment of environmental technologies, emphasis was placed upon AMD management and cyanidation practices.

Surveyed was every gold mine listed in Environment Canada's database of mines and on the US Geological Survey's web site of all U.S. gold mines, which totaled 148 operations (The mines surveyed are listed in Appendix I). While the majority of questionnaires were sent via email, others were faxed or mailed. The preferred method by the companies was to send the survey to the corporate environmental
manager or officer, who, following a preliminary inspection, then forwarded copies to each company gold mining site. Where email contact could not be established, the survey was simply faxed or mailed to the attention of the environmental manager or supervisor of the mine.

Structure of this Study

The study begins in Chapter 4 with a brief review of the gold mining process, an economic overview of the industry, and the potential environmental problems that can result from operations. In the chapter to follow, the pertinent environmental legislation regulating North American gold mines is outlines. In Chapter 6, the CESPS developed in Chapter 2 is used to illustrate the changes in environmental performance and environmental management experienced within the industry over the past 25-30 years. Chapter 7 assesses levels of eco-efficiency for major environmental strategies and technologies used at gold mines. Chapter 8 reports the findings from the questionnaire, and uses the information in Chapter 7 to interpret results and trends. Finally, Chapter 9 provides some brief conclusions about the study, and identifies opportunities for further research.
Chapter 4:  
The Gold Mining Industry Today

Introduction

To what degree has environmental performance and environmental strategy – with reference to the CESPS – changed in the North American gold mining industry since the introduction of major environmental legislation? The next sections of this paper seek to determine this. Before the investigation commences, however, an overview of present conditions in the North American gold mining industry is provided. First, the methods used to extract and refine gold are outlined. Second, the current economic situation in the industry is examined, specifically how the current gold market economic crisis has impacted gold mining operations. Finally, the potential environmental problems associated with mining gold is reviewed.

A Review of the Gold Mining Process

Gold occurs mostly as spot-like particles in veins of bedrock containing numerous minerals. Each mine follows a similar production process to that illustrated in Figure 4. Ore is first crushed using jaw or gyratory cutters for the larger rocks, followed by cone, roll, or reduction-gyratory crushers that reduce ore to a 5-25 mm size (Ripley et al., 1996). The grain is further reduced when added to a cylindrical barrel with a grinding machine. Following gravitation and thickening, which reduces the crushed rock even further, particles are treated with a cyanide solution to remove gold particles (Hiatt et al., 1982). For over one hundred years, cyanide has been the leach reagent of choice for the extraction of gold, replacing primitive panning and mercury amalgamation techniques (Pironne et al., 1998), which are still used in many developing countries, however. In a process called heap leaching, a dilute cyanide solution is sprinkled on the crushed, gold-aggregated ore stacked on a permeable pad (see cyanidation process in Figure 5). The percolating cyanide forms an amalgam with the gold as it leaches through the ore, after
which the gold is removed from the pregnant solution in the refining process (Mosher and Figueroa 1996; White and Schnabel 1998). The waste pile is then treated and disposed of.

Figure 4: An outline of the gold production process.

Ore ➞ Crushing ➞ Gravity Concentration and Thickening ➞ Cyanidation ➞ Refining

Figure 5: The cyanidation process.

(Reagent Preparation
NaCN solution is mixed with lime and water)

(Cyanidation
Dissolution of gold to give gold pregnant solution)

(Isolation of gold from pregnant solution
Cementation with zinc
Carbon-in-pulp/carbon-in-leach (CIP/CIL)
Gold
Elution of gold-cyanide complexes followed by electrowinning of gold
Recycling)

(Source: Duffield and May, 1998)

Traditionally, gold has been mined underground (Figure 6). In short, once economic deposits have been located, a shaft is sunk and "drifts" or passages are cut in the shaft wall at regular intervals to gain access to the ore. The ore is then removed and transported to the shaft, where it is crushed before being hoisted to the surface, and then treated chemically (with cyanide) outside the mine surface (Peters, 1978; Lewis and Clark 1964). This method has changed relatively little over the years but in select instances, gold's obscurity in nature has necessitated the development of surface open pit *placer* mines (Salomons, 1995), a technique more suitable for deposits located at shallower depths (Ripley et al., 1996). This requires extensive blasting, as well as soil, rock, and vegetation removal to reach deposits. Benches
are then cut into mine walls, and ore is removed and transported for refining (EPA, 1995). Figure 7 illustrates the design of a typical open pit mine.

Figure 6: Design of a typical underground mine.

(Source: Marshall, 1982)

Figure 7: Design of a typical open pit mine.

(Source: Marshall, 1982)
Economic Overview of the North American Gold Mining Industry

Late 1997, all of 1998, and early 1999 were troubled times for the world gold industry, which impacted the economic performance of North American mining operations overall. Events in Europe, specifically the creation of the new European Central Bank and the float of its new currency, the Euro, as well as the monetary disruptions in Asia – notably the Bre-X scandal – have caused gold prices to plummet in recent years. Today, gold prices are approximately US$270, down from a record high of US$370 in early 1997 (Simao, 1999).

How has the decline in gold prices impacted gold mining operations in North America? First, since the crash, companies have become more active in restructuring and acquisitions. As Dobra (1999) summarizes, these activities have included the mergers of medium-sized companies such as Kinross and Amax Gold to create larger, million-ounce producers, as well as proposed mergers of Juniors such as Rayrock and Glamis to create more viable corporate structures in the current environment. In the case of many of the stronger companies such as Barrick Gold, Homestake Mining Company, Newmont Gold Company, and Placer Dome Inc., significant outright acquisitions of property have been made (e.g. Homestake’s acquisition of Prime Resources in Canada, and Placer Dome’s acquisition of Getchell Gold in the US). These operations appear less affected by economic conditions.

Second, many North American gold mining companies have had to suspend operations at selected sites because of low gold prices. For example, the Turquoise Ridge Project on the Getchell Property in Nevada, in an effort to conserve money, suspended operations in its higher-grade Northwest ore zones. A similar situation occurred at Pegasus Gold Inc.’s Zortman Mine in Montana in 1996, when operations were ceased. Residual leaching continued into 1997 but in March of 1998, the company decided not to construct the Zortman Extension Project because at then current gold prices, the project was not considered economically viable (Randol Mining Directory, 1999). Others, such as Vista Gold’s Hycroft Mine have announced impending closures unless gold prices improve and still others, such as Homestake’s Pinson Mine, have announced shutdowns of part of their facilities as cost-saving moves.

Third, exploration has declined as companies have announced postponement of activities pending gold price increases. In a survey undertaken by Dobra (1999), the sampled companies, after experiencing
an increase in exploration production from US$443.9 million in 1996 to US$500.6 million in 1997, fell to US$347.7 million in 1998, and will further decrease in 1999 with reductions of 44.2 percent in exploration budgets. In a similar survey conducted by Driesner (1998) that included both Junior companies and pure explorations companies with operations in Nevada, a 32 percent decline in Nevada exploration expenditures was discovered from 1997 to 1998. The same companies had projected a similar decline in worldwide exploration expenditures, which dropped from US$1083 million in 1997 to US$767 million in 1998.

In sum, economic constraints in the gold market have forced most North American gold operations to restructure and adopt stricter budgets. In extreme instances, companies have even gone bankrupt (e.g. Pegasus Gold).

**Common Environmental Problems in the Gold Mining Industry**

**Overview**

The geological setting of gold, coupled with the techniques used in its production, are responsible for pollution and environmental problems in the industry. Since gold deposits have fixed locations, the extraction and processing activities used for their removal are not subject to rational selection or advanced planning, which in turn can lead to extensive environmental damage (Figure 8). Impacts can be wide ranging, affecting everything from soils to biota. The major environmental challenges facing gold mining operations are summarized below.

**Managing Effluent Discharges of Acid Mine Drainage (AMD)**

Acid mine drainage (AMD) is one of the most prevalent environmental pollution problems in the mining industry (Singh and Sinha, 1990). When a large quantity of rock containing pyrite and sulphide minerals are excavated from an open pit or underground mine, it reacts with water and oxygen. Gold, like most nonferrous metals, occurs as sulphides that are usually accompanied by iron sulphides. These easily oxidize to become sulphuric acid, which in turn solubilize residual metals and anions when flushed with
rainwater or melted snow (Sanchez, 1998; Paktunc, 1999). The ensuing AMD creates conditions that are uninhabitable for plants, terrestrial species and benthic invertebrate.

Two main pollution problems result from AMD. First, AMD renders heavy metals soluble and hence greatly increases toxicity problems (Gray, 1996; Down and Stocks, 1977). Acid-generating processes in rocks, which produces the AMD, dissolve heavy metals contained within sediments when flushed with water, which then migrates from the generation site and enters the natural environment. Through absorption and ingestion, these metals quickly bioaccumulate in the tissues of fish, birds, and mammals, causing neural, immune, and endocrine system dysfunctioning (Sengupta, 1993; Gray 1998).

Second, AMD destroys the acid buffering capacity of receiving waterbodies. The alkaline bicarbonate systems in lakes, streams, and rivers work to neutralize "natural" inputs of acid but are ill-equipped for dealing with AMD, and if bombarded, pH lowers, aquatic life diminishes, and riverbeds become coated with rust-like particles (Gazea et. al, 1996). Many organisms are killed directly as a result of the acidic shock (Kelly et. al, 1988).

**Management of Cyanide**

Although heap-leaching techniques yield high gold recoveries, mismanaged cyanide can cause toxicity problems. After gold is removed with the cyanide solution and collected, toxic transition metal cyanides and free cyanides remain in the pile (Clayton et. al, 1997), which, if leached, is lethal to a wide range of species. The cyanide is capable of complexing at low concentrations with virtually every heavy metal, and because the health and survival of plants and animals are dependent on the transport of these heavy metals through their tissues, even in small amounts, the chemical can be lethal (Young and Jordan 1996; Clayton et. al, 1997). In additional, following heap leaching, spent ore is left as is or is deposited in disposal areas. These wastes contain wastewater from rinsing the ore, residual cyanide, metal cyanide complexes, and small quantities of trace metals (EPA, 1995).

According to theoretical stoichiometry, to dissolve gold contained in a typical ore body, between 3 and 4 grams of cyanide should be used per ton of rock (Soto et. al, 1995). The lethal dose of cyanide for humans is 1-3 mg/kg body weight. Long-term exposure can cause irritation to eyes, appetite loss,
headaches, dizziness, and damage to the nervous system and thyroid glands. Equally affected when exposed are fish, mammals and plants. Cyanide from heap leaching can enter the natural environment through tears in pad liners, or from spills in solution ponds. Following accidental release, it accumulates in soils and waterbodies, where plants and animals ingest, inhale, and absorb the chemical. Further, birds are drawn to cyanide solution ponds for drink. In the past decade, accidental spills of cyanide solutions in rivers and streams have produced massive kills of fish, amphibians, aquatic insects, and vegetation near a number of gold mining operations around the world. (see e.g. Young, 1992; Herman, 1996). For those gold mines not using cyanide, ore is typically shipped off-site to process.

Minimizing Heavy Metals Loading and Related Soil and Water Contamination

Release of metals from gold mining sites occurs primarily through acid mine drainage and erosion of waste dumps and tailings deposits (Salomon, 1995), both of which have diverse physical, chemical and ecological properties (Dudka and Adriano, 1997). In the sulphur orebodies in which it is found, gold occurs with other metallic elements including copper, nickel, arsenic, cadmium, lead and zinc. When disposed of, these tailings combine physically with soils and are then leached by water, which removes the metals and contaminates the soils and groundwater of the natural ecosystem (Champigny and Abott 1992; Gray 1997; Kesler 1994; Luis et al., 1986). For gold, contamination from waste tailings is a serious problem because its volume of waste rock is higher than any other ore: the tonnage of waste rock is almost equal to the amount of ore extracted, and tailings amount to nearly sixty percent of the ore (Ripley et al., 1996). These tailings are loaded with contaminating heavy metals.

Trace quantities of heavy metals are essential for plant and animal life but in abnormal quantities, when ingested or absorbed, can cause serious health problems. For example, Thornton (1996) reports that several agricultural crops and wild plants found in soils containing high concentrations of nonferrous cadmium, exhibit symptoms of leaf chlorosis. Further, people consuming water from wells containing elevated levels of arsenic have been documented as having an increased chance of contracting skin and internal cancers. In the past, environmental exposures to mined waste tailings have also increased loadings of heavy metals in surface waters like creeks and rivers. The obvious perturbable effects include depletion
of benthic aquatic organisms, dissipation of spawning gravel for fish, and restriction on the use of water for irrigation and livestock watering (Chukwuma Sr., 1998).

Minimizing Erosion and Sedimentation

All mining operations initiate an inevitable chain of soil erosion and sedimentation. Extraction operations naturally break up the terrain and hence increase the surface area of material exposed to rainfall and wind (Barbour, 1994). The subsequent erosion degrades soil quality by transporting and leaching organics and nutrients, which inhibits the natural recovery of the ecosystem. Water and wind-blown sediments accumulate in waterbodies where they cause numerous ecological impacts, including clogging reservoirs, destroying fish habitat, filling navigation channels, and reducing productivity of floodplain soils (Sengupta, 1993). In many instances, gold mining occurs in areas characterized by highly erodible soils that often go undetected below a mask of vegetation cover. Compounding the erosion problem at gold mining operations is the quantity of earth that must be overturned and removed to obtain the mineral ore. The vast quantities of uncovered soils and waste tailings that remain are often left exposed to natural elements.

Reduced Sulphur Dioxide Emissions from Ore Roasting

The air pollution impacts of sulphide ore smelting have been well documented (Luisis et al. 1986; Mallory et al. 1998; Rutherford and Bray 1979). Gold, however, is not smelted on a large industrial scale like nickel, copper and tin. The most significant air pollution problem from gold mining is caused by small-scale smelting called roasting, where ores are heated to remove sulphur compounds that would otherwise interfere with the cyanide leaching process (Horn, 1966). In particular rockbodies, gold occurs as minute particles locked in the crystal lattice of pyrite and arsenopyrite minerals. Such ores require roasting to oxidize the sulphides and thus liberate the gold so that it can be solubilized. Sulphide roasting releases enormous quantities of gaseous sulphur dioxide (SO₂), and arsenic into the atmosphere. In
sufficient quantities, SO₂, a principal component of acid rain, can be deleterious to ecosystems and man-made structures.

According to Habashi (1996), gold roasting is now not widely acceptable because the AS₂O₃ and SO₂ byproducts are recognized as environmental contaminants. At most North American gold mines, roasting has been replaced with autoclave technology, where ores are treated in aqueous solution with oxygen at high temperatures to oxidize sulphide minerals, liberate the gold, and to render arsenic as a harmless ferrous arsenate. While the practice has been largely discontinued, by 1992, at least three Canadian gold mining operations, located in Ontario, British Columbia, and the Northwest Territories, were still roasting gold ores (EMR, 1993).

Contamination from Arsenic

Contamination from arsenic has long been a troublesome problem in select gold mining regions in North America. Within the orebodies located at these sites, gold grains occur with not only sulphur and pyrite but with compounds of arsenic (Burckle et al., 1981). In high concentrations, arsenic is toxic to aquatic organisms and plants, and as Gebel (1998) notes, overexposure can lead to the development of various cancers in humans. Initially, when nonferrous ore was roasted, electrostatic precipitators were used to collect airborne particulates (see e.g. Burckle et al., 1981). However, since gold roasting has been largely prohibited by law, arsenic contamination has been mainly a water pollution concern.

In a personal communication with Mr. Paul Rochon, Senior Program Engineer of the Minerals and Metals Division of Environment Canada, it was indicated that water pollution from arsenic much relates to the geological composition of gold ore. In Canada, arsenic is prevalent within the orebodies of the Ontario Hemlo region (Paehlke et al., 1982; Azcue and Nriagu, 1993), Alaska (LaPerriere et al., 1985) and Northwest Territory region (Bright et al., 1996; Bright et al., 1994), and to a lesser degree, British Columbia (Azcue et al., 1995) and the Dakotas (Hale, 1977). In short, the problem with arsenic is site-specific.
Summary

The major environmental problems facing gold mining operations have been examined. While problems with erosion, heavy metals and waste rock pose concern, the most serious environmental challenges relate to contamination from cyanide and AMD. The second section of the study (presented in Chapters 7 and 8) seeks to determine what environmental management practices are in place at North American gold mines for dealing with and preventing these two problems. It was concluded that examining these two issues would provide the best indication of whether the any of the industry has engaged in Eco-efficient Management.
Chapter 5: 
Environmental Legislation and North American Gold Mines

Introduction

An important first step in assessing any industry's environmental performance is identifying relevant environmental legislation, since it sets the standard from which any proactive environmental management can be measured. Governments play a leading role in environmental protection (Andrews, 1998), and are instrumental in initiating shifts in corporate environmental behaviour. Such has been the case in the North American gold mining industry, where sites are subject to a broad range of environmental laws and regulations that cover virtually every aspect of mine operations. In both Canada and the US, most of the environmental legislation relevant to gold mining was passed during the 1970s, and in many instances, individual laws have been amended several times since their inception. At the federal level, environmental standards are issued by Environment Canada and by the US Environmental Protection Agency. Additional regulations exist at regional levels, which are administered in Canada by provincial governments, and in the US by state governments.

The purpose of this chapter is two-fold. First, it provides an overview of the important environmental legislation regulating North American gold mines. Second, it discusses the challenge of complying with this legislation, along with newly introduced legislation.

A Review of Environmental Legislation Affecting Gold Mining Operations
Canada

Although the cornerstone piece of national environmental legislation in Canada is the Canadian Environmental Protection Act (CEPA), it plays absolutely no role in regulating mining operation. National environmental standards for mines – the Metal Mining Liquid Effluent Regulations (MMLER) – have been put in place by Environment Canada but most gold mines are not subject to the regulations. The MMLER, which were promulgated under the federal Fisheries Act and embodied in the “Consolidated Regulations of
Canada", 1978, Chapter S 19 (Environment Canada, 1992), were based upon Best Practicable Technology (BPT) at the time of their development, and since no effective cyanide detoxification and spill prevention measures existed in the late 1970s, it was decided that all cyanide-using mines would be exempt from the standards (Environment Canada, 1994). Thus, it has long been the responsibility of provincial governments to ensure that industry-wide, there is acceptable environmental performance at gold mines.

In Ontario, the principal piece of environmental legislation regulating gold mines is the Municipal/Industrial Strategy for Abatement (MISA), a requirement based upon the Ontario Environmental Protection Act that has industry monitor its' wastewater discharges for acute lethality to rainbow trout and Daphnia magna. In 1986, the Ontario Ministry of the Environment (MOE) developed the MISA program in attempt to reduce the pollutants discharged from industrial and municipal sources into Ontario’s lakes and rivers. Under MISA, nine different industrial sectors are identified: petroleum refining, organic chemical manufacturing, iron and steel, mining, pulp and paper, inorganic chemicals, metal casting, electric power generation, and industrial minerals. Each sector has its own regulations, which were developed individually with input from representatives from the industry, environmental groups, academia, the MOE and Environment Canada. Requirements for toxicity testing are identified in the General Effluent Monitoring Regulation (Ontario Regulation 695/88) and in the Effluent Monitoring Regulation for the Ontario Mineral Industry Sector (Ontario Regulation 491/89), which the replaced the former, less stringent Regulation 358/88. Regulatory toxicity tests involved exposing both trout and Daphnia magna to different effluent dilutions over different time periods, and are based upon chemical concentrations that resulted in mortality to 50 percent of the organisms. The MISA mining regulations are divided into six groups for mines, each of which has a separate monitoring schedule that reflects the individual mineral(s) characteristics. Gold mines alone represent one of the six groups, and of particular significance is the regulation for total cyanide, which is a limit of 1.0 mg/L.

The environmental legislation regulating gold mines in British Columbia and Quebec, while effective, is not nearly as strict as Ontario’s. Rather than having set regulations, these provinces elect to issue individual permits that set effluent limits for each gold mine. In October 1989, the Quebec Ministry of the Environment issued Directive 019, under the Environmental Quality Act, which addresses the environmental and permitting aspects of all provincial mines (Government du Quebec, 1989). Principally,
the directive requires that final effluent discharges from all mines meet the same concentration limits as the MMLER for heavy metals, as well as the following limits: 3.0 mg/L total iron, 1.5 mg/L total cyanide, 0.1 mg/L free cyanide, and a pH between 6.5 and 9.5.

In 1979, British Columbia issued “Pollution Control Objectives for the Mining, Smelting and Related Industries” under the provincial Pollution Control Act, which addresses both effluents and air emissions from mines. However, discharge limits at British Columbia gold mines, like at Quebec sites, are set by the provincial government on a site-specific basis. Permits are based upon (1) the sensitivity of recipient waterbodies, (2) seasonal water flows, and (3) efficiencies of treatment technologies. As indicated under Section 10 of the Mines Act, a mine must apply for, and obtain, a permit from the Chief Inspector of Mines prior to mining or significant ground disturbance. The regulatory philosophy appreciates that every mine has a unique set of geological and environmental conditions and therefore will be evaluated on a site-specific basis. The permit approves the mine plan, the program for the protection of land and watercourses, and the reclamation program. Metal leaching and AMD prediction and prevention plans must be submitted as part of this application. The Mines Branch of the Provincial Ministry of Energy and Mines (MEM) and the Pollution Prevention Program of the Ministry of Environment, Lands and Parks (MELP) share the Province's responsibility for regulating releases of AMD and metal contaminated effluent from the new and existing mines (MEM and MELP, 1998). Similar setups to Quebec and BC exist in both the Northwest and Yukon Territories, where effluent limits for gold mines are set in water licenses issued under Territorial Water Boards.

Each of Ontario, Quebec and British Columbia’s effluent regulations relevant to gold mines are presented in Table 3.
Table 3: Canadian effluent limitations.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Ontario Monthly Mean</th>
<th>Quebec Monthly Mean</th>
<th>British Columbia Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mg/L</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cadmium</td>
<td>0.001</td>
<td></td>
<td>0.01-0.1</td>
</tr>
<tr>
<td>Mercury</td>
<td>15</td>
<td>15</td>
<td>25</td>
</tr>
<tr>
<td>PH</td>
<td>6.0-9.5</td>
<td>6.5-9.5</td>
<td>6.5-8.5 (new industries)</td>
</tr>
<tr>
<td>Arsenic</td>
<td>0.5</td>
<td>0.5</td>
<td>0.1-1.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.05-0.25 (new industries)</td>
</tr>
<tr>
<td>Copper</td>
<td>0.3</td>
<td>0.3</td>
<td>0.05-0.03</td>
</tr>
<tr>
<td>Nickel</td>
<td>0.5</td>
<td>0.5</td>
<td>0.2-1.0</td>
</tr>
<tr>
<td>Lead</td>
<td>0.2</td>
<td>0.2</td>
<td>0.05-0.2</td>
</tr>
<tr>
<td>Zinc</td>
<td>0.5</td>
<td>0.5</td>
<td>0.2-1.0</td>
</tr>
<tr>
<td>Iron</td>
<td>3</td>
<td></td>
<td>0.3-1.0</td>
</tr>
<tr>
<td>Chromium</td>
<td></td>
<td></td>
<td>0.05-0.3</td>
</tr>
<tr>
<td>Cyanide</td>
<td>1.0</td>
<td>1.5</td>
<td>1.5</td>
</tr>
</tbody>
</table>

(Source: Kilborn, 1991)

United States

Unlike in Canada, most of the legislation responsible for regulating US gold mines exists at the federal level. Although state regulations play a small role, principally, it is the Clean Water Act (CWA) and Resource Conservation and Recovery Act (RCRA) that set environmental standards for US gold mining operations. The CWA – commonly referred to as the US Federal Water Pollution Control Act – is the main body of federal legislation affecting American gold mining operations. Implemented in 1972, it works to restore and maintain the chemical, physical, and biological integrity of national surface waters. The CWA was amended by the Water Quality Act (WQA) in 1979, which established requirements, policy measures, and standards, to be regulated and enforced by the EPA (German and Aranda, 1996). The EPA uses the National Pollutant Discharge Elimination System (NPDES) program to regulate direct industrial discharges – in this case, from gold mines – into navigable waters. NPDES permits, which contain industry-specific, technology-based and or water-quality based limits, and which establish pollutant monitoring and reporting requirements, are issued by either the EPA or an authorized state government. The premise here is that any facility intending to discharge into national waters must obtain a permit and provide quantitative information up-front detailing what is being released. The EPA established (under 40
CFR Part 440) national technology-based daily and monthly effluent discharge limitation guidelines for all mining and milling (refining) operations. Amendments were made to the CWA in 1987 (Tables 4 and 5).

The Resource Conservation and Recovery Act (RCRA), 42 U.S.C. 6901, was enacted in 1976 to address the problems associated with the disposal of hazardous and solid wastes (Stoloff, 1991). As Bryant (1998) summarizes, the EPA’s Land Disposal Restrictions (LDR) program under the RCRA is the centerpiece of the federal government’s efforts to control the risks associated with hazardous and toxic wastes. It promotes the protection of health and the environment, and conserves valuable material and energy resources. Regulated under the Act are generators and transporters of hazardous waste, and owners and operators of hazardous waste treatment, storage and disposal facilities (TSDFs). Owners and operators of TSDFs require permits for their operations. Presently, the EPA has identified more than 700 hazardous wastes, and even if the wastes that have not been listed as hazardous under RCRA, each must be reported if it possesses any of the following characteristics: ignitability, corrosivity, reactivity or toxicity (Stoloff, 1991). For gold mines, the RCRA applies to tailings, which are potentially loaded with contaminants.

### Table 4: US Mine discharge limitations.

<table>
<thead>
<tr>
<th>Effluent</th>
<th>Maximum Daily Discharge (mg/L)</th>
<th>Maximum Monthly Discharge (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSS</td>
<td>30</td>
<td>20</td>
</tr>
<tr>
<td>Cu</td>
<td>30</td>
<td>15</td>
</tr>
<tr>
<td>Zn</td>
<td>15</td>
<td>7.5</td>
</tr>
<tr>
<td>Pb</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>Hg</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>PH*</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* within the range 6.0-9.0
(Source: EPA, 1995)

### Table 5: US Mill discharge limitations.

<table>
<thead>
<tr>
<th>Effluent</th>
<th>Maximum Daily Discharge (mg/L)</th>
<th>Maximum Monthly Discharge (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSS</td>
<td>30</td>
<td>20</td>
</tr>
<tr>
<td>Cu</td>
<td>30</td>
<td>15</td>
</tr>
<tr>
<td>Zn</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>Pb</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>Hg</td>
<td>0.002</td>
<td>0.001</td>
</tr>
<tr>
<td>PH*</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* within the range 6.0 to 9.0
(Source: EPA, 1995)
Legislative Pressures for North American Gold Mines

Overview

It is premised in this paper that legislative pressures, namely changing regulations along with the advent of environmental assessment legislation, have impacted selection of environmental management practices at North American gold mines. When implementation of strict environmental legislation first began in the early 1970s, mining companies were resistant, lobbying that achieving compliance would require a mass restructuring of operations, and in turn would cut into profits and affect global competitiveness. While it took years for North American mines to accept and adjust to the newly introduced legislation, what has compounded the difficulty of a mine to achieve legislative compliance, and more recently, proactive modes of environmental management, is the fact that regulations are frequently being amended. This section highlights some of the significant legislative changes that have affected North American gold mining operations.

Environmental Assessment (EA)

Environmental Assessment (EA) imposes serious challenges for all mines. EA is a systematic means of planning for the environment in projects and policies, and involves identifying, predicting, evaluating, and mitigating the broad environmental effects of the proposed undertakings before irrevocable decisions are made (CEAA, 1997). A mining company must provide sufficient documentation of proposed operations throughout the lifecycle of the mine, from exploration, through excavation, to reclamation. The government must evaluate mine plans, and operations only commence when given approval. In Canada, both levels of government have been active in the area of EA. Popular concern about environmental quality prompted the passing of the Environmental Assessment and Review Process (EARP) in 1973, and since then, nearly every province has followed suit (Government of Newfoundland and Labrador, 1999). Fifteen years later, the Canadian Environmental Research Council (CEARC) included legislative proposals in its revised definition of EA, and by 1990, the Minister of the Environment announced as part of an EARP reform package, that major federal government policies would be subject to EA (Marsden, 1998). In
1995, the comprehensive *Canadian Environmental Assessment Act* was proclaimed, and today, is the legal basis for the federal environmental assessment process (Delicat, 1995).

In the US, the *National Environmental Policy Act* (NEPA), passed in 1969, requires that all federal agencies prepare detailed statements assessing the environmental impact of, alternatives to major federal actions that may significantly impact the environment (EPA, 1995). In the case of mines, federal action may require issuance of an *Environmental Impact Statement* (EIS) – a report that provides a fair and full discussion of significant environmental impacts, and informs decision makers and the public of reasonable alternatives that would avoid or minimize impacts to the environment (Jessee, 1998) – to federal land management agencies for approval of plans of operating mines on federally-managed lands.

A major challenge for many mines is that many communities are keen on the idea of EA, demanding that companies commit to sound environmental management during operation, and that they develop practical reclamation programs after mine abandonment. The biggest challenge for mines, however, is that EA processes have, and should continue to become more comprehensive, making operating extra difficult. In Canada, for example, the pattern of change began in 1977 when the 1973 EARp was modified by a second cabinet decision (CCREM, 1982). Recently, in April of 1997, the federal government established the Federal Coordination Regulation (FCR) as means to ensure that EAs are efficiently coordinated, and to facilitate harmonization of the federal and provincial EA process. More pertinent to mining operations, however, is the *Guide to Information Requirement for Federal Environmental Assessment of Mining Projects in Canada*, a work developed by the Canadian Environmental Assessment Agency (the Agency), in collaboration with EC and Natural Resources Canada that helps proponents with the federal EA process for mining projects. The work symbolizes the substantial effort of the government to increasingly pressure mining companies to account for the environment in operations.

As the EA process continues to evolve, and becomes more widely recognized in communities, mines will have to increasingly demonstrate high levels of environmental excellence. Expanding EA processes will only mean more well-articulated environmental management plans, and the development of more comprehensive pollution abatement strategies, which can pose serious difficulties for mines with limited resources.
Changing Environmental Regulations

As noted by the NRC (1999), substantial changes have taken place in the regulatory environment over the past two decades that have had a significant impact on the characteristics of the mining industry. Changing environmental regulations impose large problems for mines since selection of environmental management strategies and technologies depends largely upon what regulatory pressures exist. A changing legislative standard can turn the existing "proactive" systems into mere compliance machines. For a mine with limited resources, since staying ahead of the frequently changing legislation requires substantial investment and research, simply complying with legislation, and changing operations only when necessary, could, in fact, be more practical.

To what degree have North American environmental regulations changed? A historical pattern of revised legislation relevant to gold mining is clearly evident. In the US, significant amendments have been made over the past 20-25 years to the environmental legislation relevant to gold mining activity. In 1977, the Federal Water Pollution Control Act (or CWA) was amended to address toxic water pollutants, and at the same time, the NPDES Program was established under Section 402, which requires that permits be obtained for all point sources from which pollutants are discharged into national waters. Only two years later, in an attempt to minimize the introduction of toxic and hazardous substances into surface waters the permit program was revised to include a new feature, Best Management Practices (BMPs), on a case-by-case basis. Further amendments followed in 1987, when it was decided that compliance deadlines be modified for the following (EPA, 1987):

- Best Practicable Technologies (BATs)
- Best Available Technology Economically Achievable (BAT) for priority toxic pollutants
- BAT for other toxic pollutants
- BAT for nonconventional pollutants
- Best Conventional Technology (BCT) for conventional pollutants

It was felt, however, even after these significant amendments, that storm water discharges from point sources were receiving little attention under the NPDES program. Thus, on November 16, 1990, regulation 55 FR 47990 was implemented by the EPA, which specifically addresses point source discharges of storm
water from industrial facilities, including active and inactive/abandoned mine sites. Further, the WQA added 402(p)(2)(B), requiring that point source discharges of storm water associated with industrial activity (including active and inactive mining operations) be permitted, effective October, 1992 (EPA, 1995).

The other cornerstone piece of US legislation, the RCRA, was first amended in 1980, and again in 1984, which brought about drastic changes in the coverage required by the Act. It restricted, for the first time, land disposal of hazardous wastes, and also provided for corrective actions against contamination resulting from releases of hazardous wastes. On November 8, 1985, under Section 3004(b)(3), it became illegal to dispose of any nonhazardous liquid waste operating under interim status or permit, and on July 8, 1987, the Act was amended again to prohibit land disposal of the wastes listed in section 3004(d)(2). As Indelicato and Tipton (1998) note, in recent years, emphasis has been placed on the hazardous and solid waste amendments (HSWA) to the RCRA, which govern the manner in which hazardous materials are managed, restrict disposal of the hazardous wastes identified by the EPA, and require each to be treated according to specified standards – each of which define technology and concentration limits – before they are disposed (Regulation 40 CFR 268.40). Hazardous wastes that do not meet the standards are prohibited from being disposed of in landfills, surface impoundments, land treatment units, injection wells, and abandoned mines. From an environmental compliance and risk management point of view, adherence to the environmental and safety plan outlined in the RCRA can be as important as adhering to a facility operations plan, since noncompliance can cause health risks and regulatory penalties. These provisions, as well as new soil treatment standards and modifications to existing treatment standards for metallic constituents in hazardous wastes, present significant new environmental management considerations for affected waste streams (Weisemen and Grossclose, 1998) from gold mining.

A number of important amendments have been made to Canadian regulations as well but the most significant changes (relevant to gold mining activity) have been made in the past 15 years. First, in Ontario, 1988, Regulation 358/88 was revoked, and replaced with the more stringent Regulation 695/88 MISA statute. In 1989, Regulation 491/89 was enacted for the purpose of establishing a "data base on effluent quality in the metal and salt mining sector, that would be used along with other pertinent information to develop effluent limits for that sector". In 1990, 491/89 was amended to detail sampling requirements and methods for mines, and in 1994, MISA Regulation 560/94 was promulgated, which set
new regulations for Ontario’s metal mining sector (Ontario Gazettes, 1988-1994). All MISA regulations, including 695/94 are currently undergoing further review, and it is expected that they will be amended further by 2001.

Mine legislation in British Columbia has undergone similar transformation. Thirty-eight amendments were made to the Mines Act in 1989, one of which made the permitting process stricter, one of which was the Placer Mine Waste Control Regulation (BC Reg. 107/89), which legislates small placer mining operations (BC Gazette, 1991). One amendment followed in 1992 (Amendment 1992-82-165), two in 1994 (Amendments 1994-43-38 and 1994-43-40), and one other in 1995 (Amendment 1995-53-26). Section 38(2) of the Act was further amended in 1998 for the purpose of placing time limits on permits and approval times. In Quebec, amendments were made to its Environmental Quality Act in 1988 (Brunnee, 1992). One important regulation included was the mean level of 1.5 mg/L for cyanide discharge from gold mines. Although this, and other regulations have not since changed in Quebec, the modified MMLER, which are in the process of being amended to include all cyanide-using facilities, will soon be regulating Quebec’s and all other Canadian gold mines, and will require each to further reduce toxic releases of cyanide. The amended regulations are expected to be stricter than the existing mandates in place at the provincial level. Complying with the newly introduced standards could cost millions, and operating beyond the regulatory scope could be a huge financial burden, enormous challenges for a resource-strapped mine.

Table 6 illustrates some of the major amendments made over the past 20-25 years to North American environmental legislation significant to gold mining activity.
Table 6: Important amendments made to North American gold mining legislation.

<table>
<thead>
<tr>
<th>Year</th>
<th>Amendment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1977</td>
<td>US CWA is amended to address toxic pollutants; NPDES Program established under Section 402</td>
</tr>
<tr>
<td>1979</td>
<td>NPDES is revised to include BMPs</td>
</tr>
<tr>
<td>1980</td>
<td>US RCRA is revised for the first time</td>
</tr>
<tr>
<td>1984</td>
<td>RCRA is modified to account more heavily for hazardous wastes</td>
</tr>
<tr>
<td>1985</td>
<td>RCRA is modified again: under Section 3004(b)(3), it becomes illegal to dispose of any hazardous liquid waste in temporary disposal areas</td>
</tr>
<tr>
<td>1987</td>
<td>Compliance deadlines are modified in the NPDES; RCRA is modified under 3004(d)(2)</td>
</tr>
<tr>
<td>1988</td>
<td>Ontario water effluent Regulation 358/88 is replaced with more stringent Regulation 695/88; Quebec's Environmental Quality Act is changed significantly to more heavily regulate gold mines</td>
</tr>
<tr>
<td>1989</td>
<td>Ontario MISA Regulation 491/89 enacted; Thirty-eight amendments made to BC's Mines Act</td>
</tr>
<tr>
<td>1990</td>
<td>NPDES is modified (under Regulation 55 FR 47990) to address point source discharges of storm water; MISA Regulation 591/89 is amended</td>
</tr>
<tr>
<td>1992</td>
<td>One amendment (1992-82-165) made to BC's Mines Act; NPDES adds 402(p)(2)(B), which requires point source discharges of storm water from industrial facilities to be permitted</td>
</tr>
<tr>
<td>1998</td>
<td>Section 38(2) of the Mines Act is modified, making the permitting system more strict</td>
</tr>
<tr>
<td>Future</td>
<td>MISA regulations and MMLER in process of being modified</td>
</tr>
</tbody>
</table>

Summary

While there is numerous legislation in place regulating North American mining operations, the challenge for gold mines is not only adhering to these requirements but also anticipating and adapting to major legislative changes. This is increasingly difficult for those gold mines with limited financial, information and personnel resources. The legislation has already, over the past three decades, been amended on numerous occasions, and the pattern of change should continue into the next century.
Chapter 6:
A Historical Assessment of Environmental Performance in the North American Gold Mining Industry

This chapter traces the pattern of environmental performance in the North American gold mining industry over the past 25-30 years, since the passing of the major legislation reviewed in Chapter 5. Select environmental data, accompanying qualitative analysis, and case studies are used to illustrate the changes in environmental management and environmental behaviour that occurred during this time period. The chapter begins by providing a general overview of environmental performance in the industry over the past 25-30 years, and gives a more detailed assessment of its progression along the CESPS. The chapter concludes with a presentation of case studies that more clearly detail some of the environmental progress that has occurred at select North American gold mines.

Analysis of Environmental Performance in North American Gold Mines since the Passing of Environmental Legislation

Environmentally, how have North American gold mines performed since the advent of major environmental legislation circa-1970? It was hypothesized in Chapter 3 that overall environmental performance in the North American gold mining industry has improved since the introduction of this major environmental legislation. Analysis of a number of sources validates the hypothesis. Environmental data compiled by Statistics Canada and Environment Canada reveals that the Canadian mining industry as a whole, has reduced its discharges of wastes, and has increased investment in environmental control and pollution abatement equipment. For example, in 1992, industry-wide, there was CAN$6 million invested in waste treatment facilities, which increased to CAN$116.6 million by 1996 (Statistics Canada, 1999). Many surveys and studies have further proven that Canadian mines are committed to improving its environmental performance. In a study conducted by Statistics Canada, Environmental Protection Expenditures in the Business Sector, 1995, it was discovered that of all the Canadian industries, the mining sector spends the largest amount on environmental protection projects (16 percent of total costs), a sum of
approximately CANS$390 million each year (Statistics Canada, 1998; Statistics Canada 1999a). Improved environmental practices have led to decreased releases of pollutants. Tables 7 and 8 illustrate the progress some Canadian gold mining companies have made in reducing the amount of wastes released from their sites (a limited availability of data prevented restricted the number of companies that were included in the tables). Collectively, these companies had, between 1993 and 1997, reduced discharges of heavy metals, from 277.484 t to 213 t, and cyanide from 6.539 t to 1.845 t. Similar environmental improvements have occurred in the US mining industry. These are directly attributed to an increased investment in pollution abatement measures, which, since 1973, has more than tripled (see Table 9). These in turn have been in large part responsible for the improvement in environmental performance at US gold mines (Statistical Abstracts, 1985-1998).

Table 7: Releases of heavy metals \(^1\) (tons) from gold mines in Canada, by company.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Barrick Gold</td>
<td>.407</td>
<td>.440</td>
<td>.292</td>
<td>.770</td>
<td>.352</td>
</tr>
<tr>
<td>Battle Mountain</td>
<td>.0359</td>
<td>.212</td>
<td>.050</td>
<td>.040</td>
<td>.0238</td>
</tr>
<tr>
<td>Cambior</td>
<td>.606</td>
<td>.315</td>
<td>.1</td>
<td>.05</td>
<td>.4</td>
</tr>
<tr>
<td>Cominico</td>
<td>276</td>
<td>234.5</td>
<td>291.3</td>
<td>454.6</td>
<td>210.5</td>
</tr>
<tr>
<td>Echo Bay Mines</td>
<td>.2293</td>
<td>.2519</td>
<td>.25655</td>
<td>.315</td>
<td>.564</td>
</tr>
<tr>
<td>Homestake</td>
<td>.2055</td>
<td>.32</td>
<td>.2064</td>
<td>.2066</td>
<td>.3376</td>
</tr>
<tr>
<td>Placer Dome</td>
<td>1.336</td>
<td>.462</td>
<td>1.045</td>
<td>.743</td>
<td>.78</td>
</tr>
<tr>
<td>Total</td>
<td>277.484</td>
<td>236.5</td>
<td>293.3</td>
<td>457.6</td>
<td>213</td>
</tr>
</tbody>
</table>

(Source: MAC, 1998)

\(^1\) Includes arsenic, cadmium, lead and zinc.
Table 8: Releases of cyanide (tons) from gold mines in Canada, by company.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Barrick Gold</td>
<td>.308</td>
<td>.239</td>
<td>.158</td>
<td>.272</td>
<td>.097</td>
</tr>
<tr>
<td>Battle Mountain</td>
<td>.928</td>
<td>1.347</td>
<td>.311</td>
<td>.805</td>
<td>.605</td>
</tr>
<tr>
<td>Cambior</td>
<td>.04</td>
<td>.03</td>
<td>.02</td>
<td>.02</td>
<td>.09</td>
</tr>
<tr>
<td>Cominico</td>
<td>N/A</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Echo Bay Mines</td>
<td>.16</td>
<td>.0095</td>
<td>.0234</td>
<td>.077</td>
<td>.053</td>
</tr>
<tr>
<td>Homestake</td>
<td>.103</td>
<td>.135</td>
<td>.068</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Placer Dome</td>
<td>5</td>
<td>2</td>
<td>3</td>
<td>5.2</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>6.539</td>
<td>3.76</td>
<td>3.58</td>
<td>6.374</td>
<td>1.845</td>
</tr>
</tbody>
</table>

(Source: MAC, 1998)

Table 9: Investment in pollution abatement measures by the US mining industry, in US millions, 1992 dollars

<table>
<thead>
<tr>
<th>Year</th>
<th>Investment</th>
<th>Operating Costs</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1973</td>
<td>498.6</td>
<td>466.8</td>
<td>965.4</td>
</tr>
<tr>
<td>1974</td>
<td>646.8</td>
<td>590.2</td>
<td>1237</td>
</tr>
<tr>
<td>1975</td>
<td>833.5</td>
<td>715.2</td>
<td>1548.7</td>
</tr>
<tr>
<td>1976</td>
<td>833.7</td>
<td>895.8</td>
<td>1729.5</td>
</tr>
<tr>
<td>1977</td>
<td>874.6</td>
<td>1122.3</td>
<td>1996.9</td>
</tr>
<tr>
<td>1978</td>
<td>791.8</td>
<td>1321.4</td>
<td>2113.2</td>
</tr>
<tr>
<td>1979</td>
<td>823.1</td>
<td>1587.2</td>
<td>2410.3</td>
</tr>
<tr>
<td>1980</td>
<td>740</td>
<td>1677.3</td>
<td>2417.3</td>
</tr>
<tr>
<td>1981</td>
<td>728.2</td>
<td>1911.8</td>
<td>2640</td>
</tr>
<tr>
<td>1982</td>
<td>569.8</td>
<td>1513.6</td>
<td>2083.4</td>
</tr>
<tr>
<td>1983</td>
<td>225.3</td>
<td>1615.6</td>
<td>1840.9</td>
</tr>
<tr>
<td>1984</td>
<td>274.6</td>
<td>1769.7</td>
<td>2044.3</td>
</tr>
<tr>
<td>1985</td>
<td>252.9</td>
<td>1863.0</td>
<td>2115.9</td>
</tr>
<tr>
<td>1986</td>
<td>225.9</td>
<td>1721.9</td>
<td>1947.8</td>
</tr>
<tr>
<td>1987</td>
<td>309.8</td>
<td>1809</td>
<td>2118.8</td>
</tr>
<tr>
<td>1988</td>
<td>407</td>
<td>1931.1</td>
<td>2338.1</td>
</tr>
<tr>
<td>1989</td>
<td>499</td>
<td>2054</td>
<td>2553</td>
</tr>
<tr>
<td>1990</td>
<td>673.4</td>
<td>2002</td>
<td>2675.4</td>
</tr>
<tr>
<td>1991</td>
<td>575.7</td>
<td>1993.4</td>
<td>2569</td>
</tr>
</tbody>
</table>

(Source: Department of Commerce, 1992; Department of Commerce 1993).

Resistant Environmental Management and Compliant Environmental Management

Today, most North American gold mines lie within or operate beyond the "Compliant Environmental Management" stage (Stage II of the CESPS). The hefty fines associated with noncompliance (e.g. CAN$5000 for violating MISA regulations, and CAN$10 000 for each day the offense...
continues) are incentives to perform in accordance with regulations. Examination of earlier literature (Scott, 1974; Oko and Taylor, 1974; Gilles, 1974; Sirois and MacDonald, 1983) shows that the North American gold mining industry, following the passing of major environmental legislation, although initially struggling to comply, introduced several pollution control methods to combat environmental problems. Thus, the industry, by the beginning of the 1980s, entered Stage II (Compliant Environmental Management) of the CESPS.

Although exact figures are unavailable, early estimates on spending for pollution control in North American gold mines were, by today's standards, very low. Rabbits et al (1971) projected that, between 1971 and 1976, Canadian gold mines collectively, would only spend only CAN$2 million (1971 dollars) on environmental control and improvement, most of which would be spent on tailings pond facilities. At Canadian placer gold mines, annual waste generation per site declined slightly from 1971 to 1976, from 59,159 t to 48,862 t. As a unit, the Canadian gold mining industry, between 1964 and 1976 reduced its consumption of power and light, from 838,876,394 kWh to 443,024,000 kWh. Efforts like these were reactions to the newly introduced legislation.

Transitional and Accommodative Environmental Management Overview

Has most the North American gold mining industry at least entered Stage III ("Transitional Environmental Management") of the CESPS, and if so, are they progressing toward Stage IV ("Accommodative Environmental Management")? The literature (e.g. Uihol et al, 1996; Nash and Ehrenfeld, 1996; Karliner, 1994) indicates that in the early 1980s, many companies from a wide range of industry began improving environmentally, and that much of the mining sector became a part of the movement in North America. As one of the most heavily environmentally regulated industries, many mining companies began to recognize that by committing to continuous environmental performance, legislative pressures are avoided, and relations with stakeholders are improved. As Miller (1997) notes, mining industry policies and practices have evolved rapidly in the environmental arena, and more recently, in the social arena as well. Most of the well-documented changes, however, have occurred in the
operations of Senior Mining Companies, which, as indicated in Chapter 2, are those firms that have abundant resources, and are least susceptible to market change.

**Major Changes**

In a survey of North American mining practices conducted by Todd and Struhsacker (1997), improved environmental practices were evident at each site sampled. Each has an environmental staff, displays quantitative and qualitative understanding of the environment in which it operates, and has established positive relations with surrounding communities. In the early 1980s, a select group of North American gold mining operations began assuming greater environmental responsibility, and as a result, entered Stage III of the CESPS – “Transitional Environmental Management”. These firms, all of which were Senior Mining Companies, made specific changes to their operations that resulted in improved environmental performance. First, each has adopted a fully-fledged EMS that includes (EPA, 1995a):

- an organizational commitment
- a corporate environmental policy
- an environmental impact assessment (EIA) blueprint
- plans for community consultation
- objectives and targets (indicators)
- an environmental management program
- documentation and records

Some sites have accepted or are considering accepting the ISO 14001 international standard for corporate EMS. Second, each provides resources, staff and requisite training so that employees at all levels are able to fulfill their environmental responsibilities. Previously, much of the technology and environmental training courses were not structured to deliver real problem-solving skills, relying on a bottom-up approach to learning with an emphasis on theory (Hale, 1995). The training programs provided by these gold mining companies are more extensive, often requiring a hiring of outside expertise (consultants, engineers, etc.). Finally, these mines have begun conducting regular reviews and audits of performance and act on the results. Often, a baseline review is conducted annually, with follow-up audits occurring throughout the
year at regular intervals. Targets are amended as environmental legislation changes to ensure the site is operating beyond the regulatory requirements.

In addition to increasingly accounting for environmental problems, many of these gold mines have even begun accounting for social needs. First, a community perceptions regarding development have begun being accounted for when environmental plans and policies are developed or amended. The managers of these mines (e.g. those of Barrick Gold, Placer Dome Inc., Homestake Mining Company, Newmont Gold Company, Echo Bay Mines and Teck Inc.) have started holding public meetings, and have begun encouraging participation from the surrounding community in the mine project. Second, each has begun researching the potential impacts the mine would have on surrounding historic and cultural sites, and has even sketched out mitigation measures. Examples include Native lands, ecological reserves and burial grounds. Finally, many have begun providing project benefits to the community, specifically in the form of monetary aid (Epps, 1997). Examples include issuing a mandate to hire locally, contributing to community pension funds, and building recreational, educational and health facilities for the community. This evidence of improved social responsibility is clear indication that at least part of the industry is progressing toward Stage IV of the CESPS.

The formation of major North American mining industry associations such as the US Gold Institute and the Mining Association of Canada (MAC) have assisted many North American gold mining operations improve their environmental and social performance. Each has helped provide opportunities for companies to use collaborative approaches in developing and applying improved technology, systems and practices. Over 90 percent of MAC's member companies, for example, of which eight are North American gold mining corporations, have voluntarily subscribed to the ARET (Accelerated Reduction of Emissions and Toxics) programme (Miller, 1997). Similarly, member companies of the US Gold Institute have committed to improving site planning, protecting wildlife, and continually improving environmental performance.

MAC, which is the national organization of the Canadian mining industry, has, for nearly three decades, been active in the environmental management arena. Its member must adhere to its strict environmental policy, which, as Miller (1997) describes, was the first environmental policy developed by any national mining association. The policy was updated and strengthened in 1995, and in 1996, the MAC
produced an accompanying Environmental Management Framework. Its members include eight North American-based gold mining companies, each of which have demonstrated high levels of environmental and socioeconomic performance. Presented are case studies of three companies that collectively, is evidence of how at least some of the industry has progressed through Stage III of the CESPS, and has made important strides toward Stage IV.

**Case Study I: Homestake Mining Company**

Homestake Mining Company, headquartered in San Francisco, California, has mines in both Canada and the US. It also owns or partly owns operations in Chile and Australia. Of its North American properties, the largest is the Homestake Mine in Black Hills, South Dakota, which, as of December 31, 1996, contained proven gold reserves of 4.7 million ounces (Homestake, 1998). Here and at its other sites, the company performs at a high environmental and social level.

The company has begun recycling and conserving resources. In 1997 alone, Homestake’s mines recycled a total of 9.73 billion gallons of wastewater, and conserved a total of 1.01 billion kWh of electricity and 2.7 billion gallons of freshwater (Homestake, 1998a). In addition to these conservation practices, the company has also adopted leading-edge environmental technologies at its sites. For example, at its Whitewood Creek Mine in South Dakota, the company has not deposited waste tailings in the ecologically sensitive creek since 1977. Rather, it has constructed a US$70 million facility to contain waste tailings. Efforts like these have earned Homestake numerous awards from private and public groups, including the B.C. Ministry of Energy and Mines, US Department of the Interior, and the Sierra Club.

As Thompson (1997) describes, Homestake has also shown high levels of corporate social responsibility at its mines. First, mine managers regularly discuss goals, objectives and decisions with stakeholders, and solicit their input. At its McLaughlin Mine, for example, Homestake moved pipeline corridors while still in the design stage to avoid sensitive and endangered plants. Second, Homestake arranges for dialogue with its stakeholders. As indicated in its annual report (Homestake, 1998a), in 1997 alone, a total of 57 community meetings were hosted at locations all over the world. Finally, the company
issues timely communications to the community that cite information regarding incidents, safety records and achievements. The best example is its annual Environmental, Health and Safety Report.

Case Study II: Barrick Gold Corporation

Toronto-based Barrick Gold Corporation is Canada’s largest gold producer. It operates six mines in North America, each of which has invested in a number of advanced environmental technologies, procedures and strategies. Each property has a group of senior, full-time environmental professionals who are involved in every step of mining and processing. These people are responsible for regulatory compliance and undertaking research projects involving air, soil and water (White and Kral, 1994). Further, each site is designed in a fashion that accounts more for environmental needs. For example, at its Mercur Mine in Utah, a tailings impoundment area has been created 1.5 miles north of the site, in a less ecologically sensitive area, and is formed by a dam across the mouth of the canyon. It is embedded with impermeable clay that helps prevent chemical leakage (Wicks, 1987). The most notable environmental efforts occurring at Barrick properties, however, have been land management applications. For example, at its Goldstrike Mine, Barrick posted a US$20 million bond to fund reclamation and monitoring after the mine is closed (White and Kral, 1994). On the social front, Barrick’s policy is to donate one percent of pre-tax income to charitable endeavors. In 1998 alone, a total of US$4.3 million was donated for education, health and other causes in the communities in which the company operates around the world (Barrick Gold, 1999).

Case Study III: Placer Dome Inc.

Placer Dome Inc. is the second largest gold mining company in Canada. It has a total of eight North American operations (nine including Mexico), each of which has advanced environmental safeguards in place, and has established positive relations with communities. On the environmental front, Placer Dome Inc. commits to protecting human health and minimizing impacts to the ecosystem. This is accomplished by regularly assessing environmental conditions, identifying all issues of environmental
concern, and establishing objectives and strategies for their management (Placer Dome, 1998). Each of Placer Dome's mines have well articulated designs, make use of highly efficient equipment, generate minimum amounts of waste, and puts forth numerous effort to protect nature. For example, at its Bald Mountain Mine in Nevada, an estimated US$700,000 will be spent to cover its tailings pond with floating balls to ensure that birds do not come into contact with processed solutions. An additional US$15,000 is given annually to the Nevada Division of Wildlife to sponsor field projects. Additional donations are given to Hawkwatch. For its efforts at Bald Mountain, Placer Dome Inc. received the Bureau of Land Management Health of the Land Reward in 1997 (Placer Dome, 1998a).

On the social front, Placer Dome contributes to the quality of life of its employees and local communities. Often, it has worked in a collaborative manner with governments, the populous and non-governmental organizations. For example, at its newest site, Musselwhite, located in southwestern Ontario, 25 percent of its employees have been drawn from the surrounding community. Further, the mine makes use of local services such as catering, laundry, air, engineering and consultation. Community opinions are voiced at the monthly Musselwhite meetings, which has representatives from the mine, the MOE and the Geological Survey.

Summary and Assessment

It is clear, based upon the information and case studies presented in this chapter, that the North American gold mining industry has, over the past 25-30 years, improved its environmental performance, and that today, many gold mines are operating at higher environmental and social levels than in previous decades. Is the pattern of performance, however, uniform throughout the industry? In the survey conducted by Todd and Shruhsacker (1997), it was discovered that each of the North American mines sampled make extensive use of pollution prevention and environmental protection technology, showed evidence of socially and environmentally responsible operations, and had some positive environmental story to tell. This chapter has only identified the progress documented in the literature but has there been further improvement made? More specifically, where do North American gold mines fall on the CESPS
and to what degree have they engaged in eco-efficiency? Further, is there opportunity for further improvement, and if so, what is preventing the industry from doing so?

In the chapters to follow, these questions are addressed. The next chapter (Chapter 7) determines what environmental management measures used in AMD management and cyanidation practices are most eco-efficient. It was concluded earlier that gaining an understanding of which environmental management measures are most effective for mitigating and preventing pollution problems in these two areas, which are widely recognized as being the most serious environmental challenges in the gold mining industry, provides an effective indication of eco-efficiency. Chapter 8 reports findings from a distributed questionnaire, and, in order to help answer Research Question #3 (Is eco-efficiency being practiced in the industry, and if so, what is the evidence?), compares the results of Chapter 7 to these findings. Chapter 9 serves as the discussion component of this paper. The performance of the industry is briefly assessed, conclusions are drawn, and opportunities for further research are identified.
Chapter 7: 
An Assessment of Eco-efficiency in Acid Mine Drainage (AMD) 
Management and Cyanidation Practices

Introduction

In Chapter 2, eco-efficiency was defined and further clarified in the mining context, and it was indicated that in the case of environmental technologies, the most eco-efficient result produce the fewest waste materials. The most eco-efficient mines make use of the most highly effective (eco-efficient) equipment – here called cleaner technologies – and are very keen on the ideas of waste minimization and P2. The premise of eco-efficiency is doing more with less, and cleaner technologies are those that achieve the most positive environmental results.

Eco-efficiency can occur in a number of industrial situations. For example, a company combusting fewer fossil fuels in an industrial process as a result of using improved environmental treatment measures and cleaner technologies, generates less pollution, and reduces costs, specifically those associated cleanup. This is a clear indication of eco-efficiency: environmental impacts have lessened and savings have increased simply because fossil fuel inputs have decreased. As Figure 9 shows, every industrial process uses resource inputs, and generates products and by-products, and it is the types of technologies (installations) being used determine the overall eco-efficiency of the process. This requires an assessment of technologies and practices to be conducted.

In the case of gold mining, what are the most eco-efficient technologies available? As noted earlier, in this assessment, only the technologies used in AMD and cyanidation processes were examined. Since these problems are two of the most pressing at gold mines, it was concluded that an assessment of technological utilization in these two areas would serve as an excellent indicator of progress toward eco-efficiency industry-wide. The focus of this chapter is on the many environmental technologies available for AMD management and cyanidation processes. Each major setup available for use in AMD management and cyanidation processes is assessed (examined further in Appendix III), and those that are
the most practical (eco-efficient), both from an economic and environmental performance are identified, and further classified as being either improved treatment/control measures or cleaner technologies.

Figure 9: Basic scheme of an industrial process.

![Basic scheme of an industrial process](image)

(Source: Naradoslawsky and Krotscheck, 1995)

**Rationale Used for Assessing Environmental Technologies**

In a book by Schaltegger et al (1997), the level of eco-efficiency is defined as a combination of economic and ecological efficiency, and is expressed by the ratio:

\[
\text{Economic Value Added} / \text{Environmental Impact Added} \quad (1)
\]

The higher the value, the more eco-efficient the product, process, service or technology. A practical method to calculate eco-efficiency has yet to be devised. Thus, determining which were the cleaner of the technologies available required an efficient assessment of which combinations of equipment represented the most cost-effective and most environmentally sound strategies. It was decided that to determine the economic contribution of each technology — “Economic Value Added” — three things should be considered. The first was production efficiency, which, simply, is a measure of the improvement (over a period of time) that would result from implementing the technology or strategy. For instance, would this technology use less electricity than the preexisting one, or does it replace a job and reduce corporate expenses in the process? The second relates to initial value, or, more specifically the difference in costs between the two practices. Is the strategy or technology being replaced cheaper/more expensive than the preexisting technology/strategy? Finally, would there be a return on investment (ROI) if the technology is implemented?

Three criteria were also used to determine “Environmental Value Added”. The first was energy efficiency, the idea being that a cleaner technology would have a higher energy efficiency since it uses and
wastes fewer resources. The second related to the level of environmental risk associated with the technology. How toxic are the wastes the technology produces? How much pollution is generated? How environmentally benign is the technology or strategy itself. The final criterion used in the assessment was resource efficiency. Does the technology make use of additional resources and is it wasteful? Cleaner technologies impact the fewest resources.

Technologies Used in AMD and Cyanidation Treatment/Prevention
Heap Leaching/ Cyanidation Technologies

In the cyanidation process, environmental technologies and safeguards are required for three purposes. First, for the heap leaching process, pads are needed for storage ponds to prevent the seepage of chemical. The pad includes a liner that is responsible for containing the leach solution in the facility, ensuring that no valuable gold solution is lost or that no accidental leakage occurs. Although each design varies in thickness, strength and material composition, an eco-efficient setup will be cost effective and will account for maximum protection to the environment (See Figure 10 for the types of Heap Leach Liner Systems). Second, treatment is needed for the cyanide contained in effluent discharge. A number of systems are available for this purpose. Third, using similar technologies, “contaminated” cyanide must be treated. Once gold has been precipitated from the pregnant solution, gold-free cyanide can be recycled. Even the most efficient of operations, however, are unable to recycle 100 percent of cyanide used. Firms indicating that they recycle 100 percent of cyanide are referring to “usable cyanide”. A portion of the solution must be treated and discarded to prevent a buildup of toxic contaminants (e.g. metallo-cyanide complexes containing complexes of iron, copper, nickel or zinc) that can interfere with further gold dissolution and/or precipitation (AQUAMIN, 1996).

As Young and Jordan (1997) summarize, a number of technologies exist for remediating cyanide-contained effluent and sediment, each providing a different level of environmental protection. As far as leach pad liners are concerned, to ensure maximum environmental protection, each must be durable enough to endure general stresses imposed by a heap, as well as local stresses imposed by equipment used in constructing the heap (Strachan and van Zyl, 1988). Further, designs must be adequate to contain both cyanide solution and rainwater, for economic purposes and for the preservation of soils and groundwater.
An assessment will now be provided.

Pad Liners

Liners can be constructed from soil (clay) or geomembrane (plastic). Clay liners have, in the past, been the most common method used to contain chemicals (Anderson and Jones, 1983), the idea being that clay particles are not aggregated and their rock formations have tiny pores. Economically, clay layers are very attractive since it involves either making use of natural rock formations or compacting a layer of clay particles. Although cost-effective, recent studies (e.g. Brown and Anderson, 1982) have shown that solutions of hydrocarbons can seriously affect the impermeability of clays. Acidic and caustic leachates have been also found to disrupt clay barriers with permeability increases (Anderson and Johnson, 1983). Finally, clay liners can crack if dried out, leading to leakage.

Geomembrane liners are plastic and highly effective because of their negligible permeability and excellent chemical resistance (Webb and Finn, 1988). They are constructed from various materials but most commonly, high-density polyethylene (HDPE) and polyvinyl chloride (PVC). Although effective from an environmental protection standpoint, these liners have high maintenance costs. Each must be monitored regularly for tears and punctures, tested to determine if deteriorated from sunlight exposure, and, if reusable, must be recoated with expensive spray-ons such as CIM and HAC (Hutchinson and Ellison, 1992).

Heap leaching setups are either a single layered or a double layered. Single layers are still used extensively. Their overall design has improved dramatically over the years but setups using single layers lack a "second line of defense" should a leak occur (Strachan and van Zyl, 1988). Composite liners, which consist of a geomembrane in combination with a low permeable soil, costs considerably more than single liner systems but has the advantage of superior seepage control. As Hutchinson and Ellison (1992) summarize, the potential for leakage from composite liners is much less than with single liners because, for failure to occur, leakage must occur at the same location in both areas. With double liners, a constructed drainage area separates two low-permeability membranes. These setups provide a "second line of defense" in the event of excessive leakage but again, are extremely costly to construct and maintain.
Here, the most eco-efficient design is the composite liner, because even though expensive to implement initially, requires the least maintenance per unit of space, and provides maximum environmental protection. It can be placed in the category of “cleaner technology” because of its effectiveness: little, if any, cyanide-contaminated effluent escapes. The geomembrane layer is less eco-efficient because it requires extra maintenance, which can complicate production economically, and must be monitored regularly to ensure longevity and effective environmental protection. Further, it is susceptible to puncture, which can lead to leakage. Clay liners, due to cracking and susceptibility to degradation, questionable production efficiency, and limited longevity, are simply not eco-efficient. Their only advantage is inexpensiveness. A double-layered setup can sometimes be employed to ensure longevity.

Figure 10 illustrates the basic liner types and designs.

Figure 10: Basic liner types and designs.

A) SINGLE LINERS

B) COMPOSITE LINERS

C) DOUBLE LINERS

(Source: Hutchinson and Ellison, 1992)
As indicated before, a number of technologies are available to treat cyanide contaminated effluent and sediment. Unusable water containing cyanide must be treated before discharge but more importantly, spent heaps must be neutralized since after gold is removed from ore, transition cyanides and free cyanide (CN⁻) remain in the highly toxic waste (Clayton et. al, 1997). A variety of technologies are available for treating spent heaps. The advantages and disadvantages of each method are summarized in Table 10. The most well established heap treatment technology is alkaline chlorination but recently, it has fallen out of favor, primarily due to the environmental implications of the process itself. The reagents used – sodium hypochlorite or chlorine gas – have considerable handling considerations, and poor process control could result in the evolution of other toxics. In several instances, this has been replaced with hydrogen peroxide treatment, which, although more environmentally benign, is very expensive (Mosher and Figueroa, 1996).

In 1985, INCO patented the SO₂-INCO Process. Here, cyanide is oxidized using an inexpensive reagent but the waste streams produced results in larger capital costs. Further, licensing/royalty fees to INCO offset some of the savings in reagent cost. More environmentally benign than any of the technologies already identified are biological processes. These have been attracting attention in gold processing recently because of lower operating costs and possibilities for processing low-grade ores that are not easily concentrated using the conventional methods (Somasundaran et al., 1998). Low concentrations of cyanide are produced naturally by living organisms and several microorganisms are known to possess various enzymes able to convert cyanide into naturally occurring compounds (Dictor et al., 1997). Several authors (e.g. Soto et al., 1995; Granato et al., 1996) have explored the biological treatment of cyanide in great detail. The final basic method that can be used to treat spent cyanide heaps is natural degradation, where no technological action is involved. Cyanide, although poisonous in sufficient quantities, is nowhere close to being one of the most environmentally persistent toxins, and there are mechanisms by which time alone can reduce the toxicity of a heap (Mosher and Figueroa, 1996). Natural degradation, however, could take too long to detoxify a heap to meet regulatory limits, during which time operation and maintenance costs are incurred (Marsden and House, 1992).
### Table 10: Advantages and disadvantages of various cyanide detoxification options

<table>
<thead>
<tr>
<th>Detoxification Method</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alkaline Chlorination</td>
<td>• Well established technology</td>
<td>• Adds potentially harmful cations/ anions to water</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Excess hypochlorite is toxic</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Chlorine can react with organics to form chlorinated compounds</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Requires special handling</td>
</tr>
<tr>
<td>Hydrogen Peroxide</td>
<td>• Excess reagent decomposes to water and oxygen</td>
<td>• Costly technology</td>
</tr>
<tr>
<td></td>
<td>• Simple to operate</td>
<td></td>
</tr>
<tr>
<td>S\textsubscript{2}O\textsubscript{3} / Air (INCO) Process</td>
<td>• Inexpensive</td>
<td>• Adds sulphates to treated water</td>
</tr>
<tr>
<td>Biological Processes</td>
<td>• Received well by regulators and the populous (clean technology)</td>
<td>• Not a well established technology</td>
</tr>
<tr>
<td></td>
<td>• Relatively inexpensive</td>
<td>• Tends to be site specific</td>
</tr>
<tr>
<td></td>
<td>• Does not generate secondary waste streams</td>
<td>• High testing costs</td>
</tr>
<tr>
<td>Natural degradation</td>
<td>• No reagent cost</td>
<td>• Slow degradation</td>
</tr>
<tr>
<td></td>
<td>• Very simplistic</td>
<td>• Increased operating and maintenance costs</td>
</tr>
</tbody>
</table>

(Source: Mosher and Figueroa, 1996).

An equally wide range of treatment options exists for effluents containing cyanide, which, before being dispensed into water bodies must be neutralized. The first available option is physical treatment, which can be accomplished using dilution, membranes and electrowinning (Young and Jordan, 1997). As Marsden and House (1992) detail, dilution is the only treatment method that does not separate or destroy cyanide. Simple and cheap, dilution involves mixing the concentrated cyanide solution with a solution devoid of cyanide, thus producing a less toxic mixture. Membranes use electrodes to remove cyanide ions from solution, and electrowinning uses electrodes to reduce weak acids into metals and, since cyanide ions do not respond, other processes can be used to remove the cyanide from the water. The current problem with both of these processes, however, is that they are not economically viable.

The second option is complexation treatment, accomplished primarily through acidification or flotation. In acidification processes, since cyanide begins volatizing below pH 8, solution is acidified until pH lowers to approximately 2. At this point, nearly all of the cyanide is removed but solution must be reacidified before discharge. The major problem here is that the process, overall, is highly energy intensive. In flotation, a surfactant is added to precipitate the cyanide (Young and Jordan, 1997).
However, the process does not remove all cyanide species, and additional contamination can occur from the surfactant itself.

The third option, adsorption methods, involves the use of activated carbons, minerals or resins to adsorb cyanide from solution. Cyanide attenuates to select minerals and in turn purifies ground and surface waters. However, cyanide cannot be recycled, which increases cyanide consumption in leaching operations (Young and Jordan, 1997). The idea with activated carbons, prepared by partially decomposing carbonaceous materials such as wood, peat or coal, is to absorb cyanide ions. Resins, polymeric beads containing a variety of functional groups, can also be added to solution, which adhere to ions. Both of these methods, however, although inexpensive, are situational since, as far as ion type is concerned, adsorption is not very selective (Muir et al., 1988).

The final option is oxidation, which can be conducted using catalytic, electrolytic, chemical or photolytic methods. Catalysis involves the use of activated carbon to treat cyanide but only removes select species of cyanide. In electrolysis, the operating parameters are basically the same to those of electrowinning. Chemical addition involves the addition of oxidants such as oxygen, ozone, or sulphur dioxide (Mosher and Figueroa, 1996). The major problem here is cost and that additional contamination problems can be created. The final option, photolysis, involves using light energy to destroy species of cyanide. Again, only specific species are light sensitive.

The most eco-efficient technologies available to remediate cyanide-contaminated material are biological methods. While many projects are still in pilot stages, those being used are very efficient in terms of production, highly cost-effective in the long run, not energy intensive, not environmental risky to use, and poses no threat to natural resources. Biological approaches show much promise and successful projects have demonstrated environmental excellence, but site-specificity results in them being placed into the “Highly Effective Waste Treatment and Control Mechanisms” category of Stage IV of the CESPS. Eventually, with expanded research, biological methods could be placed higher on the scale of eco-efficiency and considered a “cleaner technology”. One chemical method that can also be placed into the “Highly Effective Waste Treatment and Control Mechanisms” category is the SO₂-INCO process since it produces above-average environmental results, but because of its cost to implement, is a very unrealistic
technology for the more resource-deficient mines. The other methods identified are simply costly pollution control techniques, and most produce environmental results barely satisfactory for legislative compliance.

**AMD Treatment Technologies**

The cleanest technological strategy in an AMD management process is one that best prevents release of the toxic effluent, and most effectively treats what is discharged. In short, the most eco-efficient strategy for minimizing the impacts of AMD is an integrated approach – one that utilizes a number of techniques to ensure waste kept at a minimum. Individual treatment and prevention methods can be grouped into three basic categories. First, passive techniques – here meaning any system that exists naturally and requires minimum maintenance – can be used. The most common approaches involve wetlands, limestone drains, water covers and naturally occurring geochemical/biological processes. In wetlands, dilution occurs, and heavy metals are filtered from water, settle atop the marsh, and gradually break down. Further, a number of anaerobic (mine water oxidation) and aerobic (sulphate reduction) processes are persistent that neutralize the water (Robb and Robinson, 1995). Limestone drains are a series of pipes containing limestone that treat AMD as it flows downward. Such a system, however, is site-specific as it depends upon the level of pH of the AMD. If too acidic, these are inadequate treatment systems (Gazea et al., 1996). Water covers serve as a barrier to atmospheric oxygen that combines with sulphides to produce acid. Although water is a more readily available barrier than soils, which require more transport and handling, as Arnaud (1994) notes, construction costs for containment of the tailings is always high. Naturally occurring geochemical/biological (slag treatment) processes can also be utilized. Here, water is discharged into a water body with a high buffering capacity, the most common instance being a river or lake containing bicarbonate rock, which naturally neutralizes the AMD. Experiments (e.g. Day, 1994) have shown that bicarbonate rock can be an effective AMD neutralizing agent.

Second, active methods can be employed, which can involve costly investment in technologies to treat and control the AMD. Each involves adding an alkali to neutralize, then separating solids and liquids to remove metal hydroxides, and finally, disposing of the metallic sludge (Vachon et al., 1987). Major
examples include chemical precipitation, fluidized bed-ion, alkaline addition, plasmotech, and ion exchange (see e.g. Diz and Novak, 1998; Vachon et al. 1987) for detailed summaries of these processes, and the technologies involved. Most of these processes are costly (Johnson, 1995), and involves using chemicals that can lead to additional cleanup problems. The most effective active method used to treat AMD is internal neutralization using lime, which best ensures that solution, prior to its discharge into the natural environment, is at a nontoxic level for organisms. Again, however, lime additive can be extremely expensive, and is therefore only a realistic AMD treatment technique for a mine with financial flexibility.

Finally, bacterial and algal methods can be used to remediate AMD (Jordan et al., 1996). Algae utilize CO₂, sulphates, nitrates, phosphates, water and sunlight to synthesize their own organic material and give off free oxygen as a waste product (Nemerow, 1971). The oxygen produced is available to bacteria and other microbes. Further, microorganisms can oxidize sulphide minerals and compounds directly, therefore decontaminating the AMD. Several authors (e.g. Johnson 1995; Eccles, 1995; Jordan et al. 1996) discuss the applicability of bacteria and algae in AMD treatment technologies, which, at present, are the most environmentally benign and cost-effective formulas for treating AMD but in select cases, may not work because of technological or locational limitations. For example, some biological reactors require a continuous supply of biomass feed to operate (Umita, 1996), and if unavailable, cannot function.

As indicated before, the most eco-efficient approach in AMD management is one that makes use of the most effective treatment and prevention techniques. From this review, it is apparent that a system that makes good use of natural and bacterial (biological) techniques, internally neutralizes mine water prior its disposal into the natural environment, and that uses natural water covers for tailings to prevent possibility of oxidation, would produce minimal waste. Such a system, because of its effectiveness, can be safely placed in Stage IV of the CESPS (“Accommodative Environmental Management”) under “Highly Effective Waste Treatment and Control Mechanisms” since it produces environmental results that far exceed those of individual passive techniques, and other chemical treatment methods, which, because of their limited environmental effectiveness and high costs, are of equivalent quality to the conventional pollution control devices used by those “Compliant” firms of Stage II. One final note is that such a system, although highly effective, does not quite exhibit the eco-efficiency of a “cleaner technology”, mostly because of the site-specificity of some of the techniques involved (e.g. bacterial utilization).
Summary

The chapter has assessed each of the major environmental technologies that are available for AMD and cyanide treatment. It was determined that the use of composite pad liners in heap leaching processes, and biological methods to treat spent heaps and solution were the most eco-efficient measures in cyanidation processes. In the case of AMD treatment and prevention, it was determined that use of a combination of natural and biological systems represents the most eco-efficient option. The next chapter uses this information to interpret results from a questionnaire distributed to the industry.
Chapter 8: 
Summary of Results

Introduction

The questionnaire sought to determine the degree to which the North American gold mining industry was practicing eco-efficiency, and where mines fall along the CESPS. The questionnaire was sent to a total of 148 operations, which included those of both Junior and Senior Mining Companies. As indicated in Chapter 3, it was hypothesized that both Junior and Senior Mining operations are performing differently in terms of environmental and socioeconomic performance.

The questionnaire was divided into three sections. The first section asked general questions about the mine – project type and conditions. The second section asked questions concerning corporate responsibility, specifically management practices and extended social accommodation. The final section asked questions concerning eco-efficiency in order to determine the degree to which operations are doing “more with less”. Questions regarding in-house environmental management tools and strategies were presented, as well as questions regarding environmental management practices used in cyanidation and AMD management processes.

This chapter presents the results from the questionnaire, and uses information from Chapter 7 and the literature to interpret the findings. First, the general information obtained about the mines is presented. Second, findings related to corporate environmental and social responsibility, and eco-efficiency are presented. These are presented separately for Senior Mining Companies and Junior Mining Companies. Finally, based upon these findings, overall eco-efficiency in the North American gold mining industry is briefly assessed, and the position of the North American gold mining industry along the CESPS is determined.

General Findings

In this study, every gold mine listed in Environment Canada’s database of mines and on the US Geological Survey’s web site of all U.S. gold mines, a total of 148 operations (see Appendix I) were
surveyed. Of these, a total of 45 responded, of which 32 (72 percent) were operations of Senior Mining Companies, and 13 (27 percent) were operations of Junior Mining Companies. A total of 26 of the 32 Senior Mining Company’s mines were of open pit design, while seven were underground mining operations. Of the mines of the Junior Companies, nine of ten were open pit designs, while only one was an underground mine operation. It was discovered, upon analysis of the findings, that the type of mine had no bearing on the types of environmental practices used. Thus, the findings reported in the sections to follow will not be presented according to mine design.

In Chapter 2, the two major environmental drivers identified for the mining industry were corporate desire to comply with legislation, and desire to improve relations with stakeholder groups. It was then posited in Chapter 3 that economic pressures and regulatory changes have played an important role in disrupting these environmental goals, and have been important in dictating what types of environmental management practices are being used at North American gold mines. This assumption was verified. The mine managers of Senior Company mines and Junior Company mines voiced different views on the impacts of economics and legislation in the industry. Of the 32 Senior Mining Company sites, the environmental managers at 31 of these felt that the recent economic crisis in the gold market has not impacted the choice of environmental technologies used in operations. Generally, this group indicated that investment in each technology pays for itself, and equipment is regularly being retrofitted, implying that the mine has sufficient funds to invest in environmental management in spite of the economic crisis. One manager stated that the mine has “remained consistently proactive in environmental technologies even though gold prices have been at a recent historic low”, and a manager of another site indicated that the mine has “the latest technologies in place”, each of which “pays itself off within a short period of time”. From a legislative standpoint, all 32 operations indicated that changing legislation has not interfered with the mine’s ability to stay environmentally proactive. One manager indicated that mine environmental goals “are much higher than government standards”, and another commits “to be the leader in environmental protection and sustainability”. Actually, of the 32, 12 have indicated that they strive to significantly exceed environmental compliance whenever possible, while the remaining 20 strive to operate beyond compliance in selected areas.
At the mines of Junior Mining Companies, the climate appears different. Of the 13 respondents, 10 indicated that recent economic pressures have prevented investment in proactive environmental measures. One mine manager indicated that cashflow problems caused the company to go into receivership, leaving no funds available to invest in high-tech environmental control systems. Another mine manager noted that research, community service and environmental health programs have been deferred because the money is simply not there. In another communication, the same viewpoint was expressed. Citing cyanide management as an example, the environmental manager indicated that "economic pressures forced the company to abandon the development and implementation of bio-detoxification methods on heap leach closure, the most eco-efficient method, and adopt a less expensive chemical detoxification method instead that is more prone to environmental degradation. An equally detailed commentary on legislative difficulties was received, as all 13 indicated that legislative pressures have impacted environmental performance. One manager complained of "overlapping regulations", arguing that it "wasted millions of dollars" because of an "over commitment of funds". All thirteen respondents noted that coping with stringent legislative amendments, increased costs for applications, and stricter water quality standards, has required a major reallocation of funds and resources. In spite of the economic and legislative difficulties, ten of these mines still seek to operate beyond compliance in selected areas, while the remaining three, due to insufficient funds and resource shortages, seek only to comply with environmental legislation.

Based upon the responses from mine managers, it appears that the gold mining operations of Junior Companies are in a constant struggle to "keep up" with Senior Companies, and that economic constraints and legislative pressures have only interfered with selection of environmental technologies and strategies. This can be further verified by analyzing more detailed questionnaire results. Because of the drastic difference in responses from Senior Mine managers and Junior Mine managers to the legislation and economics issues, in the sections to follow, the findings received from both groups will be presented and analyzed separately.
Findings: Corporate Environmental Management and Responsibility
Senior Mining Companies

All but three sites reported having an EMS in place. The earliest implementation was 1991, and most recent, 1998. In addition, every operation has at least two of the five “environmental management tools” in place, and 25 (~78 percent) have all (see Figure 11). Each has indicated on the checklist provided on the questionnaire that the major reason for investing in these tools is either to help ensure regulatory compliance or to improve relations with communities (see Figure 12). A total of 25 respondents (~78 percent) have indicated that stakeholder demands (either from the corporation, the community, or insurance) is the major reason for investing in these proactive environmental measures at sites.

For all respondents, environmental plans are developed at least one year prior to the commencement of a major operation such as decommissioning or reclaimation. Approximately 32 percent of the group (10 mines) indicated that environmental plans are developed between 7 and 10 years in advance. As far as reviews of operations, environmental technologies, and strategies are concerned, 31 of 32 mines indicated that audits are conducted annually.

Perhaps the most interesting result was that all 29 of 32 respondents, in the additional space provided in the questionnaire, made some kind of reference to the importance of community involvement: extended social responsibility. One mine manager, for example, stated that “achieving positive relations with communities is an integral part of environment goal-setting” and that the company has provided a number of resources to inhabitants, including “jobs, local economic spending and finances for education”. One manager indicated that meetings “were held regularly to account for the viewpoints of locals”, and another cited that the mine is contributing to “community pension funds”. Finally, one manager indicated that “best environmental management practice” was in “the interest of shareholders”, and that by "performing at high environmental levels, additional investment is attracted".
Figure 11: Percentage of Sampled mines of Senior Mining Companies with environmental “tools”.

![Chart showing percentage of environmental tools](chart11)

Figure 12: Senior mine reasoning for investment in environmental management “tools”.

![Chart showing reasoning](chart12)

Junior Mining Companies

Of the 13 respondents, only eight (62 percent) have an EMS in place, compared to 91 percent of respondents from the mines of Senior Mining Companies. Further, only 31 percent (four sites) of respondents have all five “environmental management tools” in place, compared to 78 percent of the respondents from mines of Senior Mining Companies. While stakeholder demands are largely driving Senior Mining Companies to adopt proactive “environmental management tools”, 77 percent (10 of 13) of respondents from the properties of Junior Mining Companies indicated that compliance with legislation is the major reason for implementing improved environmental management practices.
As far as environmental planning is concerned, results show that the pattern is similar between the two groups, although four respondents gave no indication of how far in advance environmental management blueprints were devised. Of the remaining nine, six cited that plans were devised a year in advance, while three indicated that plans were developed between 3-5 years prior to the execution of a major operation. Eleven indicated that environmental reviews were conducted annually. The remaining two did not respond.

Findings: Eco-efficiency
In-House Operations

As indicated in Chapter 2, simple adjustments to in-house operations, which can result in reduced ecological stress and increased financial savings, is an important step toward improved eco-efficiency. Some examples of strategies include conservation, recycling, resource reuse, and installation of environmental safeguards. Each not only results in environmental and economic improvements but also can improve relations with governments, communities, and other stakeholder groups.

All 45 respondents have implemented in-house eco-efficient practices. All but 1 site recycles a portion of its wastewater for reuse in other industrial processes. On average, each recycles nearly 89 percent of its water, and the most common method used by these firms to recapture wastewater is settling ponds, where saturated solids “naturally” separate from water by sinking to the bottom of the pond. The water is then skimmed off of the top of the pond for reuse. A total of 32 sites use settling ponds. Other respondents use other methods to recapture wastewater, including pumps (12 mines), filtration (6 mines), storage dams (3 mines), and drains and collectors (3 mines).

Select sites (18) make use of energy-efficient equipment to reduce consumption of fuels and lessen energy costs. The types of energy-efficient equipment being used ranges from operation to operation but each is cheaper and more environmentally benign than the standard technology. Some notable examples include:

- High efficiency motors
- Carbon reactivation kilns
• Electrical starting equipment
• Solar powered pumps
• Solar powered meteorological stations
• Air cooled compressors
• Highly insulated buildings
• Energy efficient pumps
• Energy efficient control equipment
• Automatic shutoff/ control equipment

Further, 23 sites use energy-efficient lighting systems, 19 utilize waste heat for various industrial applications, 17 have reinsulated buildings at their sites, and 15 have begun conducting regularly energy audits of their practices.

From a waste recycling/reprocessing standpoint, several strategies have been adopted. First, 28 sites recycle spent oil to use in other industrial processes, or sell to other businesses. Second, of the 39 operations using cyanide, 35 recycle at least 30 percent of usable solution. Firms are applying minimum amounts to heaps to minimize chance for environmental damage, on average, 0.3 lbs. per ton of ore.

Third, two sites recycle a wide range of chemicals and product, including antifreeze, metals, freon, process solutions, and pyrite. Again, each of these commodities is either reused or is sold to other industries.

Finally, two sites reprocess high-density lime sludge in order to reuse the lime as a neutralizing agent for AMD. In sum, results show that most sites are actively pursuing recycling and material reuse strategies.

Selection of Liners

As indicated in Chapter 7, composite liners – mixtures of geomembrane material and soil – are the most eco-efficient designs. Further, double liners provide a “second line of defense” in the event of a leak but are very expensive to implement. Of the respondents from Junior Mining Operations, 10 indicated that they use cyanide, and of the 32 operations belonging to Senior Mining Companies, 29 use cyanide. Nine of the 10 Junior Mine sites using cyanide have single-layered solution ponds. Of these, 5 are soil layers, the least eco-efficient design due of fragility. All 29 of the Senior Mining Company operations, however, have composite layer designs or doubled layered setups. Further, each has a leak detection system in place.
Cyanide Heap Treatment

To refresh, the most eco-efficient methods available to treat cyanide in heaps are combinations of biological and natural processes, followed by the SO$_2$-INCO technology. As Figure 13 shows, a greater percentage (54 percent) of properties belonging to Junior Mining Companies rely on natural processes for cyanide heap treatment than those of Senior Mining Companies (25 percent). On the contrary, a greater portion (31 percent) of properties belonging to Senior Mining Companies is using the more expensive SO$_2$-INCO treatment than those of Junior Mining Companies (7 percent). In addition, the most eco-efficient biological processes are being used more widely at the operations of Senior Mining Companies (38 percent) than those of Junior Mining Companies (23 percent). Results clearly illustrate that Senior Mining Companies have invested in a wider range of eco-efficient treatment methods.

Figure 13: Strategies used to treat spent cyanide heaps (based on findings).

![Graph showing the percentage of properties using different methods for cyanide heap treatment.]

Treatment of Effluent containing Cyanide

As Chapter 7 indicated, few individual remedies serve as effective method for treating cyanide effluent, which makes it necessary that a combination of strategies be used. All of the operations using cyanide in this study (39 of 45) have reported that they use monitoring systems for determining levels of cyanide toxicity in water prior to effluent discharge. Further, an operation will recycle as much usable cyanide as possible but the spent solution must be treated before discharge. Financing cyanide treatment is
costly, and only 2 of 13 (15 percent) Junior Mining Operations noted that multiple detoxification strategies were being deployed, compared to 40 percent (12) of the Senior Mining Operations. Of the thirteen operations of Junior Mining Companies, 8 reported using physical processes (e.g. dilution, membranes and electrowinning), indicating an obvious preference for less-expensive strategies. Only one operation of the Senior Mining Companies reported utilizing a physical process (although used in combination with activated carbon, an adsorption process). The balance employs expensive chemical, adsorption and oxidation methods to treat liquid cyanide. These processes have lower eco-efficiencies primarily because of their high costs, and potential threats to the environment. However, in combination, treatment technologies are highly effective. Thus, in the event that the effluent has not been fully treated, it is subject to treatment process again.

**AMD Treatment Technologies**

The most eco-efficient method for treating AMD discharge was determined to be biological (microbial) processes. The next best strategies include natural geochemical/biological processes, wetlands, and water covers. Of the Junior mine operations, 38 percent (5 of 13) make use of naturally occurring geochemical processes, compared to 56 percent (18 of 32) of the operations of the Senior Mining Companies. The difference, however, is that every Senior Mining Company operation utilizing natural geochemical/biological processes internally neutralizes AMD with lime before discharge. No Junior Mining operation reported such an effort. Eight (25 percent) of the sites operated by Senior Mining Companies use biological treatment to remedy AMD, two use watercovers, one uses chemical precipitation, and at the other sites, no AMD occurs. Of the remaining respondents from properties owned by Junior Mining Companies, one uses wetlands, and one uses a watercover, while the remaining six report no AMD discharges. An examination of AMD mitigation and prevention strategies being used at mines of Junior Gold Mining Companies shows a lower level of eco-efficiency compared to those of the Senior Gold Mining Companies (see Figure 14).
Figure 14: Acid Mine Drainage Treatment methods being used at mines.

Survey Non-Response Bias

Of the 45 respondents, 15 were based in Canada, and 30 in the US. The locations of the mines are Ontario, Quebec, BC, California, Nevada, South Dakota and North Dakota. It is felt that, given the wide range of respondents, that non-response bias is minimal if anything. Mines from all of the major gold mining provinces and states responded to the questionnaire, and there is no noticeable difference between the results obtained from Canadian and US respondents. Results obtained from both countries were very uniform for both the Junior Mining group and the Senior Mining group.

Assessment

From the results obtained from the questionnaires, it is clear that environmental management practices at the mines of Senior Mining Companies differ significantly to those of Junior Mining Companies. From the standpoint of eco-efficiency, there is strong evidence, based upon findings, of intensive in-house recycling, improved environmental management tools, and highly effective waste
treatment and control mechanisms at the gold mines of Senior Companies. In AMD management and
cyanidation practices, effective setups are being used to treat and prevent wastes at these mines but until
various obstacles are overcome with highly effective biological treatment methods, there will remain
considerable room to improve eco-efficiency of operations. Overall, however, Senior Mining Companies
have made important strides in improving eco-efficiency.

A different pattern of eco-efficiency exists at the mines of Junior Companies. Results indicate that
environmental management practices have improved, in-house recycling has begun, but that the
environmental technologies being used to mitigate problems with AMD and cyanide are not nearly as
effective as those being used at the gold mines of Senior Companies. The hypothesis, therefore, presented
in Chapter 3, which was that legislative and economic pressures impact a Junior Mining Company's
selection of environmental management practices at sites, was confirmed. Not only did mine managers
indicate that changing legislation and economic pressures have negatively impacted corporate
environmental management practices at sites but an assessment of environmental technologies being used
in AMD management and cyanidation practices confirms this. These properties, however, exhibit
substantially low eco-efficiency simply because less efficient technological setups are being used at Junior
Mines, suggesting that resource shortages and legislative stringency have prevented the adoption of the
most eco-efficient technologies. For eco-efficiency to improve at Junior Mining operations, outside
assistance is needed.

As far as location on the CESPS is concerned, it has been concluded, from these results that the
North American gold mining industry has entered Stage III ("Transitional Environmental Management"),
since each respondent provided evidence of improved environmental management practices at its mine. All
of the mines (13) belonging to the Junior Companies, because of obvious restrictions, can be placed in
Stage III. The mines of the Senior Companies (32), however, can be placed between Stage III and Stage IV
("Accommodative Environmental Management") because each has more eco-efficient technological setups
in place, and have begun extending social responsibility. It would be incorrect to place all of the industry
in Stage IV or Stage V ("Proactive Environmental Management") simply because there is still much room
for environmental improvement at gold mines, in spite of the important strides that have already been
made.
Conclusion

This chapter has summarized the findings from the questionnaire distributed to the North American gold mining industry. Of the 148 initially sent out, 45 were received, 32 from properties belonging to Senior Mining Companies, and 13 from properties owned by Junior Mining Companies. While evidence of eco-efficiency exists at all of the mines from which results were received, levels of eco-efficiency are higher at the properties of Senior Companies. It is clear that Junior Mining properties have been impacted by the recent economic problems in the gold industry (outlined in Chapter 4) to a great degree. Cash flow problems has, in some cases, necessitated having to commit to mere environmental legislative compliance as opposed to proactive environmental management. Further, legislative pressures (identified in Chapter 5) have caused operational adjustment problems for these sites, which already work with limited resources and personnel.

This study has shown that, since the passing of major environmental legislation circa-1970, environmental management has improved in the North American gold mining industry, and that it has progressed to Stage III of the CESPS ("Transitional Environmental Management"). Further, it has shown that different levels of eco-efficiency exist at the mines of Junior Companies and Senior Companies, principally because of legislative and economic pressures.
Chapter 9: Discussion, Conclusions, and Opportunities for Further Research

Outlook

It can be inferred from the results that clearly, the properties of North American Senior Mining Gold Mining Companies have, from an environmental management perspective, been impacted minimally by the recent economic problems in the gold market and the legislative changes. Conversely, the properties of the Junior Mining Companies have suffered, unable to allocate the funds toward continuously improving environmental performance. In Chapter 2, an analogy was drawn between the SME and the Junior Mining property. It was suggested that Junior Mining properties, if exposed to significant economic and legislative pressures, like the SME, could face problems with implementing particular environmental management strategies. It is clear, based upon the findings in this study, that the gold mines belonging to the Junior Mining Companies of North America suffer from the same environmental management difficulties as the SME.

The Junior mining companies examined in this study have been unable to fully improve the eco-efficiency of its operations because like the SME, they lack the resources (e.g. time, money, personnel, etc.), and have financial, technical, and manpower capability to implement environmental measures (Chiu et al., 1999), and remain consistently proactive. Because they have proven to be more susceptible to the changes in market prices outlined in Chapter 4, along with the changing legislative conditions identified in Chapter 5, they have become, as one mine manager noted, “more profit-oriented than environmentally-conscious”. Due to a shortage of resources, these Junior mining companies, like the SME, tend to have a short-term view on their business (Verheul, 1999).

Clearly, the results presented in this paper show that North American Junior Gold Mining Companies are not highly anticipatory when it comes to environmental issues, often investing in the least expensive technologies, which, overall, are not highly effective. Economic problems in the gold mining industry have complicated these environmental investments.
Gombault and Versteeg (1999) report that many SMEs still live by the misconception that pollution prevention (highly eco-efficient) measures only cost money. This has not been the case with the Junior Gold Mining Companies examined in this study, which appear to recognize the environmental impacts of mining and the importance of eco-efficiency. It is not a question of understanding but a question of ability. Quite simply, financial problems, along with legislative difficulties have hindered chances of being proactive, and the result, in many cases, has been the use of an environmental technology or strategy that has a greater chance of causing environmental degradation.

While findings show that North American gold mines have begun practicing eco-efficiency, it has been concluded that it would be most correct to place the industry in Stage III of the CESPS. While Senior Mining Companies have exhibited higher levels of eco-efficiency and extended responsibility, frequent changing legislation, along with recent economic pressures have effectively halted the pattern of environmental improvement at the properties of Junior Mining Companies. This pattern will continue into the next century because the economic climate is not expected to change, and regulations are still being amended.

Can the Gold Mining Industry Become Fully Eco-Efficient?

Market forces influence mining productivity (Hurlburt, 1995) and if present conditions prevail, the North American gold mining industry has no chance of fully entering Stage IV of the CESPS, let alone Stage V. Clearly, an insufficient supply of resources – primarily finances – is impeding the diffusion of eco-efficiency in the industry. In order for it and other industries to learn more about eco-efficiency, and to implement more effective environmental safeguards, outside assistance is required. For substantial improvement in environmental management to occur, some party must take initiative, and since it cannot be taken by the industry, the government must step in and play an expanded role.

While North American governments are active in the regulatory environment, they are less active in promoting industrial environmental improvement. Based upon the pattern of environmental performance to date, if the gold mining industry could become eco-efficient, it would since operating at a high level of environmental management makes good business sense, and at the same time, provides
maximum protection to the environment. How, however, can the gap between Stages III, IV and V of the CESPS be bridged? The only logical answer is government. In order for gold mines to become more eco-efficient, regulatory bodies must aid in financing environmental training, technologies, and planning for mines. Examples include:

- Disseminating appropriate information concerning eco-efficient technologies and their contribution to economic aims.
- Providing assistance to overcome financial barriers.
- Aiding in the development of management plans in all facets of mining operations.
- Financing a research centre that investigates environmental technologies and strategies.
- Arranging a series of demonstration projects at sites.
- Sponsoring joint work between the industry and universities.
- Providing training, technical assistance and consultation to operations.

These and related efforts would put the industry on an eco-efficient pathway.

**Opportunities for Further Research**

Using the North American gold mining industry as a case study, this paper has explained some of the problems faced by industry in its attempt to improve environmental performance. Further, this paper has provided a case study of environmental management in the gold mining industry, which itself has been explored minimally in the literature. From the reviews and discussion presented in this paper, many areas in need of further research can be easily identified.

First, while many theories have been produced in the literature outlining why sound environmental management makes good business sense, authors have failed to provide concise methodologies for environmental improvement. How, for example, can businesses currently in Stage II of the CESPS move to Stage III? What must be accomplished? What is needed? Presenting a methodology or testing a framework in the field before presenting it in the literature can be the difference between an unrealistic theory and an effective strategy.
Second, as this study has shown, barriers exist in many industries that work to prevent the widespread adoption of ecotechnologies. The obvious obstacles are legislative and economic ones but technological availability can also play an important role in preventing movement towards improved environmental management. Researching methods – such as the governmental analysis already identified – to overcome these barriers is of great need. Often, worldwide, these barriers are generic, and the development of concise plans could benefit thousands of industries around the globe.

Finally, more eco-efficient assessments of other industries are needed. In this paper, an effective evaluation of practices in the North American gold mining industry is provided, and, in the process, important groundwork has been laid for research in the arena of Eco-efficient Management. By assessing different aspects of environmental management, researchers can identify opportunities for further improvement, which, in the end, would help push global industry into Stages IV and V of the CESPS: Accommodative and Proactive Environmental Management.
Appendix I: Listing of the Mines Surveyed in this Study

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<td>Lone Tree</td>
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<tr>
<td>Santa Fe Pacific Mining Corp</td>
<td>Trenton Canyon</td>
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<tr>
<td>Siskon Gold Corp</td>
<td>San Juan Ridge Mine</td>
</tr>
<tr>
<td>St George Metals Inc</td>
<td>Dean Mine</td>
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<tr>
<td>Stibnite Mine Inc</td>
<td>Stibnite Mine</td>
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<tr>
<td>Sunshine Mining Company</td>
<td>Sunshine Mine</td>
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<tr>
<td>Company Name</td>
<td>Mine Name</td>
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<tr>
<td>TECK CORP</td>
<td>DAVID BELL MINE</td>
</tr>
<tr>
<td>TREMINCO RESOURCES LTD</td>
<td>PTARMINGAN MINE</td>
</tr>
<tr>
<td>TVX GOLD INC</td>
<td>NEW BRITANNIA MINE</td>
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<tr>
<td>TVX GOLD INC/GOLDEN KNIGHT</td>
<td>CASA BERARDI MINES</td>
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<tr>
<td>U S ANTIMONY CORP</td>
<td>YELLOW JACKET MINE</td>
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<td>CASTLE MOUNTAIN MINE</td>
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<td>BREWERY CREEK MINE</td>
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<td>WHARF RESOURCES</td>
<td>WHARF MINE</td>
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<tr>
<td>WILLIAMS OPERATING CORP</td>
<td>PAGE-WILLIAMS MINE HEMLO</td>
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Appendix II: Industrial Questionnaire

Section A: General Environmental Management and Operations

A) What type of mine is at this site (e.g. placer mine, open pit mine etc.)

B) At this mine site, you are aiming to (please check one):
   □ Comply with environmental legislation
   □ Operate beyond compliance in selected areas
   □ Significantly exceed environmental compliance wherever possible

C) In your opinion, have recent economic pressures prevented investment in proactive environmental technologies at the mine site?
   Yes □ No □ Don't Know □

D) In your opinion, has changing legislation affected the mine site's ability to invest in proactive environmental management measures, and to set environmental goals?
   Yes □ No □ Don't Know □
Section B: Corporate Environmental and Social Responsibility

1) Does this site have an Environmental Management System (EMS) in place?
   YES □ NO □ DON'T KNOW □

   If "yes", in what year was it implemented? ______
   If "Yes", is it certified? YES □ NO □

   Please check if this site has the following environmental management tools:

   ○ environmental management/ sustainable development officer
   ○ environmental training programs for employees
   ○ pollutant monitoring stations
   ○ an environmental reporting system
   ○ an environmental auditing system

2) Please rank, in order of importance, the reasons why has this site invested in the environmental management tools checked above (1 = most important; 8 = least important).

   □ Legislation
   □ Community pressures
   □ Shareholder pressure
   □ Corporate desires
   □ Employee concerns
   □ Insurance
   □ Banking
   □ Other ________________________

3) What is the time scale for environmental planning at this site? In other words, at this site, for each stage in the mining process (e.g. exploration, extraction, refining, decommissioning), how far in advance were/are environmental plans devised?

   ________ DON’T KNOW □

   How often are these plans reviewed and revised (e.g. annually, biannually, etc.)?

   ________ DON’T KNOW □
Section C: Eco-efficient Management

1. Reducing Material Intensity

1.1 Water

Approximately what percent of wastewater is reclaimed at your company sites for reuse in operations? _____

List the methods your company uses to recover wastewater for reuse (e.g. settling ponds, tailings compression techniques etc.)

a) ___________________________  b) ___________________________

c) ___________________________  d) ___________________________

1.2 Mining Tailings

At this site, are tailings reprocessed to remove “undi[covered]” gold and additional heavy metals? YES □ NO □

Are tailings revegetated at mine sites? YES □ NO □

List the major uses (if any) of waste tailings in your company’s industrial operations?

a) ___________________________  b) ___________________________

c) ___________________________  d) ___________________________
2. Reducing Energy Intensity

2.1 Waste Heat

Does your company reuse waste heat? YES □ NO □

If “Yes”, for what applications?

a) __________________________ b) __________________________

c) __________________________ d) __________________________

2.2 Conservation Practices

Please check the boxes that apply to your company under the theme of “energy conservation”.

☐ energy efficient lighting exists at this site
☐ waste heat is utilized at this site
☐ renewable energy sources have been substituted for fossil fuels at this site
☐ insulation has been upgraded in the buildings at this site
☐ the monitoring of energy consumption has improved at the buildings at this site

List the important energy-efficient technologies your company has invested in for use in extraction, refining, and smelting processes at this site.

_________________________________  __________________________________

_________________________________  __________________________________

Do your operations reuse mine “wastes” (gases, liquids or solids) as fuels (e.g. SO₂ to power furnaces, waste tailings to power autoclaves)?

YES □ NO □

If so, which wastes, and for what uses?

<table>
<thead>
<tr>
<th>Waste</th>
<th>Use(s)</th>
</tr>
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<tbody>
<tr>
<td>____________________________</td>
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</table>
3. Reducing Toxic Dispersion
3.1 Acid Mine Drainage (AMD)

Please check the methods and strategies used at this site to treat and or prevent AMD. Please use an asterisk (*) to indicate which method is used the most.

- ☐ internal neutralization before discharge
- ☐ alkaline treatment in discharge water bodies
- ☐ bacteria and algae pH treatment
- ☐ naturally occurring geochemical/biological processes (e.g. carbonate rocks)
- ☐ electrochemical methods
- ☐ slag treatment
- ☐ wetlands/limestone drains
- ☐ membrane filtration
- ☐ evaporation/crystallization
- ☐ ion exchange
- ☐ chemical precipitation
- ☐ fluidized bed-ion
- ☐ plasmotech
- ☐ biological methods
- ☐ Other ____________

3.2 Managing Cyanide

Please check the methods used by your company for treating cyanide?

Please use an asterisk (*) to indicate which method is used the most.

- ☐ dilution
- ☐ electrowinning
- ☐ volatilization
- ☐ floatation
- ☐ minerals addition
- ☐ resins
- ☐ catalysis
- ☐ photolysis
- ☐ membranes
- ☐ acidification
- ☐ metal addition
- ☐ solvent extract
- ☐ activated carbon
- ☐ bioxidation
- ☐ electrolysis
- ☐ OTHER ______________
3.3 Heap Leaching

Approximately what percentage of cyanide is used to recover gold?

___

Does the mine use methods to monitor cyanide to ensure no escapes? If “yes”, please explain.

_________________________________________________________________________________

_________________________________________________________________________________

Has there been physical measures constructed (e.g. containment methods) to deal with spills or leaks of cyanide? If “yes”, please explain.

_________________________________________________________________________________

_________________________________________________________________________________

What types of liners and liner designs are used at your ponds/heaps (e.g. single liners, compact clay liners, geomembrane liners, composite liners, double liners)?

_________________________________________________________________________________

_________________________________________________________________________________

4. Increasing Recyclability

4.1 Cyanide recycling

Approximately what percentage of the cyanide at this site is recycled for reuse? ____ %
4.2 Waste Reprocessing and Reuse

List the methods used at this site to remove and reprocess trace metals from tailings and discharge water bodies.

a) __________________  b) __________________

c) __________________  d) __________________

5. Renewable Resource Use and Resource Replenishment

5.1 Energy

(If applicable) Please indicate where renewable energy is being used in your mining operations (for generating heat, light etc.).

a) __________________  b) __________________

c) __________________  d) __________________

6. Additional Comments

Please feel free to provide any additional comments in the space provided below.
Thank you very much for completing this questionnaire. Your feedback will be very valuable, I am sure. My email address is gavin.hilson@utoronto.ca or ghilson@idirect.ca or hilsong@cirque.geog.utoronto.ca, my fax number is (905) 828-3717 my phone number is (905) 273-3762 and my home address is:

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Canada
L4Z 1P8
Appendix III: A Qualitative Eco-Efficiency Assessment of Technological Setups used in AMD Management and Cyanidation Practices at Gold Mines

A qualitative scale was used to assess these setups. Beginning from the least eco-efficient category to the most eco-efficient category, the scale is as follows: (1) No eco-efficiency – provides virtually no environmental protection and cost savings, (2) Low eco-efficiency – minimal environmental protection and cost savings, (3) Average eco-efficiency – average environmental improvement and cash savings, (3) Above-average eco-efficiency – significant environmental protection and provides sufficient economic savings, (4) High eco-efficiency – is highly environmentally benign and cost-effective, and (6) Cleaner technology – exceptionally environmentally friendly, and cost-efficient.

1. Pad Liners
a) Clay liners: Due to cracking and susceptibility to degradation, these have questionable production efficiency, and have limited longevity but are highly inexpensive. As far as environmental risk is concerned, clay liners naturally and chemically degrade the easiest, which presents the highest chance for contamination to surrounding environments. Using clay liners presents the greatest risk to surrounding natural resources such as trees, soil, and water, again because of their susceptibility to natural and chemical degradation. Low eco-efficiency.

b) Geomembrane Liners: These perform better than clay liners but require extra maintenance, which can complicate production economically. However, the added efforts result in a longer lasting system, which, over the long term, profits the firm. These systems are relatively expensive to implement and maintain and must be in place for a long period to be economically viable. From an environmental standpoint, these systems are less susceptible to chemical and natural degradation, and therefore a lower level of environmental risk and lower level of resource mismanagement is associated with their use. Average eco-efficiency

c) Composite Liners: These provide less maintenance per unit of space since setups consist of part clay and part geomembrane. They are the longest lasting but are the most costly to implement initially, although the least expensive overall in long-term. It is not risky (environmentally) to use these liners nor does their use present a high risk to surrounding natural resources. These are the most eco-efficient pad liner setups. High eco-efficiency

2. Heap Treatment Technologies
a) Dilution (Physical): Process compounds the production process since it only accomplishes part of the treatment process (not a highly effective treatment strategy). Highly inexpensive but its ineffectiveness necessitates having to implement additional treatment strategies over the long term, thereby rendering the return on investment (ROI) minimal. This strategy is not energy intensive but if a cyanide solution is only diluted, it poses an enormous environmental risk and can potentially damage resources. No eco-efficiency

b) Membranes and Electrowinning (Physical): Both of these processes are inefficient from a production standpoint because neither fully treats the cyanide waste stream. In addition to being environmentally ineffective, both technologies are highly expensive. No eco-efficiency
c) Acidification (Chemical): The strategy is not highly cost effective but cheaper than membranes or electrowinning, and an ROI in this case takes less time. The biggest problem with the process is that it is energy intensive, requiring acidification, and, once cyanide is volatized, neutralization. There is a low environmental risk associated with this strategy but it is only effective as a standalone remedy. No eco-efficiency

d) Adsorption Methods: Since these methods do not completely remove cyanide from solution, each is highly inefficient from a production standpoint. Each is relatively cheap but require use of complementary treatment processes, making them questionable long-term investments. Each method requires few energy inputs, and since each removes select species of cyanide, individually, using each is environmentally risky and poses a high threat to natural resources. No eco-efficiency

e) Oxidation methods (includes catalysis, electrolytic, chemical, photolytic processes): Collectively, the efficiencies of these technologies are moderate at best since each cannot fully detoxify cyanide waste streams. Neither is cost-effective, nor is each a profitable long-term investment, seeing as how each requires long-term financing. Most are energy intensive, requiring extensive monitoring, and there is a high level of environmental risk associated with each, and their use potentially threatens resources such as water and soils because the degree of treatment. No eco-efficiency

f) Floatation (Chemical): The addition of surfactants complicates the production process, and again, this method is not highly cost-effective. Over the long term, flotation does not profit the firm since it does not detoxify all of the cyanide present in the waste stream, therefore requiring use of additional treatment methods. The process is not highly energy intensive, but since it does not remove all cyanide species, discharges pose a moderate threat to the environment and natural resources. Low eco-efficiency

g) Alkaline Chlorination: A well established technique but since using it creates a number of additional environmental problems, the cleanup costs for which the firm must finance. production efficiency is very low. The technology is very inexpensive, and an effective short-term solution for the firm that creates immediate savings. Environmentally, minimal energy is expended but there is a high level of environmental risk and high probability for resource destruction and mismanagement associated with alkaline chlorination technologies. Low eco-efficiency.

h) Hydrogen Peroxide: Has a significantly higher production efficiency than alkaline chlorination, as it does not lead to additional problems. It, however, is not cost-effective at all, and a ROI would take a long time. It is not energy intensive, is not an environmentally risky technology, and imposes little threat to natural resources. Low eco-efficiency.

i) Natural degradation: Is ineffective from a production standpoint since degradation is often not fast enough to enable the firm to comply with regulations. The technology is initially inexpensive but over the long term, can incur maintenance costs, therefore resulting in a minimal ROI. Virtually no energy loss results, and with the exception of accidental drinking from birds which mistake cyanide pools as drinking pools, setups pose a small environmental risk and small threat to resources. Average eco-efficiency

j) SO2-INCO Process: Average production efficiency, very expensive initially and over the long term, royalty payments to INCO can further cut into profitability. The process is relatively energy intensive but is only environmentally risky if sulphates are mismanaged, and if monitored, pose a minimal threat to natural resources. Average/Above average eco-efficiency

k) Biological processes: Very efficient in terms of production. Highly cost-effective but site specificity and additional constraints could produce limited rewards in the long run. The technology is not energy intensive, not environmentally risky to use, and poses no threat to natural resources. Biological processes can be used to treat cyanide-contained wastewater as well. High eco-efficiency
3. Acid Mine Drainage Mitigation Technologies

a) Active Methods: Each of these strategies is not efficient from a production standpoint because each requires investment in multiple technologies, and additional cleanup practices since each creates new environmental problems. Neither process is cost-effective, and over the long term, the continuous monitoring and maintenance required negates profit. Generally, these are highly energy efficient processes, pose a risk to the environment and consume secondary resources. **Low eco-efficiency**

b) Limestone drains: An efficient technology but not cost-effective. Over the long-term, ROI is average because the setup requires maintenance but is durable and therefore, long-lasting. Minimum energy inputs are required, with the exception of labour but the system can be environmentally risky if pH of the AMD is too great and ends up exceeding the buffering capacity of the system. If pipes and channels are designed properly, limestone drains avoid contact with other resources. **Low eco-efficiency**

c) Wetlands: Treatment of wetlands is a very slow process but is very inexpensive. Over the long term, results are satisfactory since all AMD will be neutralized and heavy metals removed. Minimal energy inputs are required by the firm but use of natural wetlands (as opposed to constructing industrial wetlands) wetlands shows ignorance toward other natural resources, particularly water, soils and plants, which can become contaminated. The entire apparatus, to be effective, must be monitored frequently, which, in most cases, does not happen. **Average/Above-average eco-efficiency**

d) Water covers: A highly effective preventative method that serves as better protection than soils. Not cost-effective because it requires excavation of a large area to store tailings. Over the long term, however, it is a worthwhile investment it serves as an excellent preventative method. Water cover designs, however, are highly energy intensive to design, implement and maintain. They do not pose a threat to the environment but require continuous replenishment with water resource. **Average/Above-average eco-efficiency**

e) Geochemical/biological processes: Taking advantage of natural processes for AMD treatment requires minimal adjustments on the part of the firm. Effectiveness of these processes is questionable if the AMD is too toxic for the natural processes to handle. These strategies are highly cost-effective since no funds are required but over the long term, these strategies require complementary treatment processes. No energy inputs are required by the firm, except for monitoring but environmental risk could be high if buffering capacity is exceeded, which, in most cases, is. No additional resources are required, however. **Average/Above-average eco-efficiency**

f) Biological (Microbial) Processes: These are the most practical methods available. Using algae and bacteria cultures to treat AMD is highly efficient, cost-effective and an excellent long-term strategy if obstacles are overcome. These require no secondary energy inputs, do not pose a risk to the environment, nor do they use additional resources. **High eco-efficiency**
References


