Portfolio submitted in part fulfilment of the requirements for the Degree of Engineering Doctorate in Environmental Technology

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Sustainable Development and the Global Mining Industry

University of Surrey

August 2000

VOLUME 1 OF 4

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Acknowledgements

Most doctoral acknowledgements pages read like an Oscar ceremony speech. Too many names to mention, too many people to remember. This researcher is unapologetic for following the tradition.

In particular, I would like to thank the three ‘wise men’ charged with supervising me over the past four years – Roland Clift from the Centre for Environmental Strategy, Jonathan Rainer from Borax, and Peter Southern from Rio Tinto. They have provided humour, patience, counsel and support in equal measure and have been an inspiration throughout.

I would also like to thank Sophie Lock and Julia Tibbs at Borax and Sheila Sutherland, Marilyn Ellis, Janet Martin, Helen Vart, and Sallie Symes at the Centre for Environmental Strategy. That this portfolio is here at all is testament to their unwavering support.

Special thanks go to all at Borax Europe, US Borax, Borax Argentina, Quebec Iron and Titanium, Kennecott Energy & Coal, Kennecott Utah Copper Corp, Argyle Diamonds, Rio Tinto Technical Services in Bristol, Rio Tinto Services in Melbourne, and Rio Tinto Head Office in London who have given so willingly of their time to help, and to Sutcliffe’s Catering for making the past four years one long reason to get more exercise.

For their friendship I’d like to thank all residents past and present of the Hotel Splendide in Sunbury, the Guardians of Time, the Brecon Tremblers, the Janice Challengers, the 20 Mule Hash House Harriers, the SkiBor crew, the Dartmoor Blunderers, the Heathland Hackers, Jack Charlton, and especially the young-lady from Lowestoft who won the hula-hoop contest. For their support and encouragement I am indebted to my family, even though I have all but deserted them over the four years of this research.

Finally, my thanks to all involved with the EngD, for winging it all with such flair.
Guide to the Portfolio

The Engineering Doctorate submission is based upon a portfolio of work developed over the period from October 1995 to December 1999. This portfolio includes both research project documentation and supporting documentation such as six-monthly progress reports.

The portfolio has been arranged into four volumes to assist in its exploration. Volume 1 contains the Executive Summary, a portfolio navigation document, and an exposition of the relationship between mining and sustainable development. Volumes 2 and 3 contain the subsequent body of research to explore the central theses carried out as three research projects. Each article includes references appropriate to that document at its conclusion. In addition, the combined bibliography for the portfolio is included at the end of Volume 3.

Volume 4 contains the papers published in the course of this research, the twenty-four appendices to these projects and the compulsory elements of the Engineering Doctorate such as the six-monthly progress reports.

Seven types of articles are included as follows (abbreviated as shown in parenthesis):
1. Portfolio Navigation Document (PN)
2. Project Documents (PD)
3. Bibliography (BIB)
4. Published / Presented Papers (PP)
5. Internal Papers (IP)
6. Six-Monthly Reports (6MR)
7. Appendices (APD)

Where it has been considered appropriate to refer to other articles in the portfolio, the volume, article type and article number are given. For example, Project Document 3, located in Volume 3, is referenced as: Vol.3, PD3. Where reference is made to specific information in other articles; the chapter number and / or page number are included as appropriate.

The following main documents support the research findings:

Volume 1
- Executive Summary

- Portfolio Navigation Document 1, Portfolio Navigator, outlines the development of the theses as the research has progressed and summarises the research and findings which support them.

- Project Document 1, The Relationship Between Mining and Sustainable Development, investigates whether mining can be seen as compatible with sustainable development. This document sets out the case for the first component of the research thesis – that mining is compatible with sustainable development, but only under certain conditions.
Volume 2

- Project Document 2, *Key Environmental Performance Indicators*, investigates the need for global mining companies to develop environmental performance indicators informed by the principles of sustainable development established in project document 1. This project investigates what such indicators might be, how they might be arranged, and then examines how they might be used in one of the world's largest mining organisations – Rio Tinto – and one of its subsidiaries – Borax.

Volume 3

- Project Document 3, *Environmental Management in a Global Mining Company*, investigates the need for global mining enterprises to implement formalised environmental management systems. A case study of Borax – a global mining company within the Rio Tinto Group – is used to explore the issues surrounding assessment, selection and implementation in a multi-cultural organisation. Then a case study of energy, operations and logistics examines the environmental burdens in a multi-national mineral processing organisation – Borax Europe. This establishes the importance of addressing downstream activities by examining the first post-processing step – distribution.

- Project Document 4, *A Global Mass Balance for Boron*, presents the findings of the first research project conducted in this programme. Its aim was to identify the main reservoirs and fluxes of boron in the environment and quantify them. Particular attention was paid to the relative magnitude of natural flows and anthropogenic flows of boron.

- Portfolio Bibliography. This contains bibliographic details for all works referred to in the course of this research.

Volume 4

- Published Papers:


- Internal Papers
- Appendices
- Compulsory Elements of the Portfolio (six-monthly reports)
Executive Summary

Introduction

In 1995 Natural Resources Canada (NRCan) published a discussion paper on minerals and metals and sustainable development (See Natural Resources Canada, 1995). This was subsequently refined into a federal policy entitled, ‘The Minerals and Metals Policy of the Government of Canada: Partnerships for Sustainable Development’ (See Government of Canada, 1996; Shinya, 1998). In their discussion paper, NRCan proposed that a sustainable metals and minerals industry must address economic, environmental and social challenges in an integrated manner. NRCan went on to outline that for this to be successfully done the metals and minerals industries and the Government of Canada must consider five issues: improved decision making, sustainable operations, social infrastructure, international leadership, and science and technology.

This research addresses two following questions. Firstly, were Natural Resources Canada correct to assert that sustainable development requires the resolution of social, economic and environmental issues? Secondly, if they were correct, what does focusing on the key issues identified by Natural Resources Canada show the global mining industry about how they approach and address their environmental responsibilities?

The thesis of this research is that Natural Resources Canada were correct, insofar as sustainable development is interpreted for the global mining industry. Furthermore, taking an approach to discharging environmental responsibilities inspired by sustainable development requires a dramatic shift in the global mining industry.

This portfolio presents the research conducted to test this thesis, conducted between 1995 and 1999, sponsored by and explored with Borax Europe and its parent company Rio Tinto. Borax is a global industrial minerals subsidiary of Rio Tinto, one of the world’s largest mining organisations. The majority of this research has been conducted from Borax’s European technical and commercial head-office in Guildford, Surrey, including that portion of the research conducted on behalf of Rio Tinto, based in London. Field research has been conducted at Borax’s global subsidiaries in Argentina, California, France, the Netherlands and Spain, and at one of Rio Tinto’s other subsidiaries – Kennecott Energy and Coal Company – in Wyoming and Colorado.

Aims of the Research

Originally the aim of the research was to carry out three separate projects, each of which was envisaged as contributing to knowledge in a unique way. The first related to management of material flows in the environment for a specific element – boron; the second related to environmental management and systems in industrial minerals operations; the third theme related to ‘clean technology’ and life cycle assessment of the production and use of boron based products.
However, it became clear during the early stages of this work that there was a fourth, unarticulated, theme that underpinned the three projects originally identified. This theme was the relationship between minerals and metals and sustainable development, and required examination at the level of the global mining industry, through one of its leaders – Rio Tinto. Thus the management of mined materials in their environment, the management of mining operations, and the measurement and management of environmental performance in the context of sustainable development, became the foci of research – each providing a unique insight into the relationship between mining and sustainable development. The interaction of these themes is shown in Figure 1.

**Figure 1 Inter-relationships between research projects and the sustainable development agenda for mining**

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**Key Research Findings**

This research has allowed a number of key findings to be made. The first is that mining is compatible with principles of sustainable development as understood by society at large through the work of the World Commission on Environment and Development – namely that sustainable development is “development that meets the needs of the present without compromising the ability of future generations to meet their needs” (World Commission on Environment and Development 1987, page 43), premised on the belief that society could “build a future that is more prosperous, more just, and more secure” (World Commission on
Environment and Development 1987, page 1). However, this research has found that mining is not, ab initio, compatible with sustainable development, but requires social, economic and environmental challenges to be addressed. In this regard, this work concurs with some views of sustainable development, but differs with many others.

This conclusion is based upon the premise that there are certain ecosystem functions that cannot be replaced by man-made innovations, but that there are certain aspects of natural capital that can be substituted. Sustainable development, in so far as it relates to mining, depends upon stewardship of both natural and human capital, ensuring that:
1. mining provides improvements in economic and social conditions without undermining non-substitutable ecological functions;
2. mining provides improvements in economic conditions without undermining social conditions;
3. if improvements in economic and social conditions require non-renewable resources to be used, the means of substituting that natural capital for human capital must be delivered.

What has followed from this thesis is a number of findings. They suggest that mining companies and those that regulate it have a number of challenges to overcome. The central challenge is how to translate a belief that mining can be compatible with sustainable development into demonstrable action and progress towards such a goal, or at least away from unsustainable development.

The first, second, third and fourth such findings relate to the management of the operations that extract, refine, process and distribute minerals and metals for use in society. The development of environmental management systems such as ISO 14001 has allowed mineral operations to focus systematically on addressing and improving those aspects of their activities that impact the environment. Through examination of the European production and distribution functions of a global mining company – Borax – this research has found that environmental impacts in the delivery of products to consumers may considerably outweigh the impacts currently addressed – namely the production processes managed on-site. Energy use in distribution, for Borax Europe, for example, has been found to exceed on-site energy use by a factor of three. The sustainable management of mining operations must consider the impacts that occur downstream and upstream of the operating site. By looking at just one further step in the life cycle of mineral products – distribution – this research has shown the significance of activities currently disregarded in the environmental management of mineral processing operations.

This has been supported by findings made in the development of environmental performance indicators for global mining companies – the third phase of this research. The management of environmental impacts for mining operations requires information which legitimate stakeholders can use to influence the environmental performance of that operation. Currently used indicators in one global mining company – Rio Tinto – do not allow such information to be generated, disseminated, and acted upon. An example relates to power generation where the current limit for consideration is the operating site. This research has found that if consideration were given to power generation ‘upstream’ of the operating site the trends
currently reported for global issues such as greenhouse gas generation would be reversed in certain instances.

Current management approaches are inconsistent with sustainable development because they consider only the directly manageable effects of a mining operation, rather than the effects that occur as a result of that mining operation’s activities. In the case of power generation, for example, it should not matter where that power is generated from a sustainable development perspective. However, currently operations which purchase power from electrical utilities misleadingly appear to have better performance than those that produce their own. This is because the latter include the emissions from power plants in their management systems but the former do not.

Furthermore, this research has found that any approach to the measurement and reporting of environmental performance adopted by a global mining company, if informed by the principles of sustainable development for mining, must be consistent with other companies at the sectoral level. Many mining operations are joint ventures between risk sharing entities. This research has found that reporting practices in global mining companies for financial performance reflect ownership of assets, while those for environmental performance reflect managerial control of the assets. The two approaches are not compatible. This research has found that for a sustainable metals and minerals industry to communicate meaningfully on its performance, it must report on those assets it owns a portion of, but does not necessarily manage. This requires global mining companies to agree to share performance data with each other to allow each to report its contribution throughout its asset base, not just those it manages – the current practice in the industry.

This research has also found that the measures used at the level of the global mining company may be meaningless in the context of environmental performance at the local level. This research has found that there are many broad themes, from a technical perspective, which apply to all mining operations, and may therefore be considered as ‘global’ – such as acidification, water management, ecotoxicity and biological diversity. However, the current approach to reporting advocated by many institutions – aggregation and simplification – may disguise actual performance. Biological diversity and acidification, for example, may be global issues, but they require measurement and management at the local level, since this is where their impacts are felt. Others, such as global warming, do have global effects, and it is therefore meaningful to aggregate the performance of a number of sites to report global performance for a mining company.

The fifth finding relates to the perception of society regarding the stewardship of mineral products that follow pathways into the environment. By examining the flows of boron in the environment, from natural and anthropogenic sources, this research has demonstrated that natural reservoirs and flows of a naturally occurring mineral such as boron far outweigh any flows arising from the extraction and use of commercial deposits of borates. This provides a counterpoint to approaches to mineral regulation that treat minerals such as borates as synthetic chemicals, and therefore attempt to control levels of boron in the environment through regulation of the use of borates in commercial applications.

*Executive Summary*
In short, this research finds that NRCan were correct to assert that, for mining, sustainable
development requires the management of social, economic and environmental challenges.
This research shows that the implications of implementing such an understanding for global
mining companies are many and various. Taking a sustainable development approach to
decision making 'moves the goalposts' away from compliance based management of mining
operations. In some instances, such as managing mineral products, the industry is found to
have a role to play in educating regulators about the relationship between minerals and metals
and the physical environment. In others, such as managing the impact of operations, the
industry must recognise that the impacts of its activities may occur away from the operating
site, but can be substantial nonetheless. In others still, such as the measurement and
communication of progress, the industry must work in harmony to ensure that stakeholders
are provided with meaningful and complete information at both global and local levels. The
performance currently measured and reported by the global mining industry is not compatible
with the principles of sustainable development for mining. In this context claims that mining
is contributing to sustainable development cannot be supported by demonstrable progress.

Applications and Outcomes of the Research

There are numerous issues not explored by this research. A framework has been proposed by
which mining companies can address the environmental aspects of their understanding of
sustainable development, and has shown why this framework differs from current approaches,
emphasising the importance of stakeholder engagement. This is particularly important for
prioritising action. The stakeholders, rather than the mining company alone, must determine
the priorities at the local level for the mining organisation as it contributes to sustainable
development. However, this research has not demonstrated how this engagement is to be
realised.

The research has identified the environmental themes a sustainable mining organisation must
address, and how broadening its understanding of its sphere of influence shifts the way the
industry understands the extent of its impacts on the environment, and has demonstrated that
this must also include economic and social metrics. That the preferred economic metric –
contribution to sustainable economic welfare – is as yet insufficiently developed to allow it to
be used, resorting to measures of earnings instead. However, this research has not addressed
how sustainable economic welfare might be developed to allow the global mining industry in
particular, or society at large, to use it in performance measurement.

The research has not attempted to develop measures of sustainability in mining organisations.
Instead, in the context of environmental technology, this research has focussed on
environmental performance informed by an awareness of the broader demands of sustainable
development. The challenge of developing sustainable development measures for the mining
industry is being pursued by others. Nonetheless, this research has a number of applications,
and has played its part in the realisation of a number of specific outcomes.

Specifically, the executive chairman of Rio Tinto, Robert Wilson, announced in the autumn of
1999 that he was to lead an industry-wide initiative, consisting of the chairmen and CEOs of
the world's leading mining companies – Anglo American, Asarco, BHP, Newmont, Noranda, Phelps Dodge, Placer, Rio Tinto, and WMC – in partnership with the United Nations and the World Bank among others. The aim is to develop the case for mining in sustainable development, identifying such a process as critical to the long-term future of the industry. Such an undertaking will require these actors to confront difficult questions in difficult political circumstances, but the rewards to society at large, and the mining industry in particular, will be substantial if the industry is successful in taking forward the issues identified as part of this research. (see Rio Tinto 1999d)

Rio Tinto is also carrying forward the implementation of environmental performance indicators based on the findings in this research. In its 1998 Social and Environmental Report, the company remarked that, "Rio Tinto's thinking on appropriate global HSE indicators is well advanced". A section specifically discussing environmental performance indicators committed Rio Tinto to producing specific reports at the level of local operations and a Group report publishing aggregated measures and generic issues that are meaningful. The Report concluded that, "The final list of indicators would number about ten, but these would not apply everywhere" (Rio Tinto 1999b, page 19).

On the basis of the research on environmental management systems, all Borax group companies committed in 1996 to the implementation and verification of ISO 14001 based systems. Borax group companies in the United States were subsequently amongst the first in the mining industry to achieve certification to ISO 14001, in 1997. In 1999 Rio Tinto established certification to ISO 14001 as a group-wide target by the year 2002, six years after the commitment from Borax was given and five years after the first Borax sites achieved certification (see Rio Tinto 1999c).

The work on boron flows is now in wide use in the regulatory arena. The research findings are in use by the International Programme on Chemical Safety (IPCS) at the global level, and by the European Council for Environmental Toxicology of Chemicals (ECETOC) to assess the extent to which borates should be regulated in aqueous media. Proposals in place to reduce the limit level for boron in drinking water from 1mg/l to 0.3 mg/l at the start of this research programme were dropped in 1998. The work on boron flows in the environment formed part of the scientific argument to reject the proposed new standard.

Concluding Remarks

The relationship between mining and sustainable development is complex, and yet is often poorly understood by those who ultimately determine the contribution a mining company makes towards or away from global sustainable development and the contribution a mining operation makes to local sustainable development – the officers and legitimate stakeholders of mining companies. For an industry whose role has been central to the development of current civilisation, this situation must be resolved. The signs from within the industry, in the form of the sustainable development initiative, are that this is becoming increasingly recognised. It is to be hoped that this recognition leads to understanding and principled action both on the part of the industry and those who have a legitimate stake in its actions.

Executive Summary
For its part, this research has offered an analysis of the relationship between mining and sustainable development and, more importantly, has demonstrated some of the implications of using sustainable development principles as the basis for future environmental management in the industry. There is much that the research has not resolved — sustainable economic welfare, discount factors for future environmental costs, indicators of sustainable development, meaningful stakeholder dialogue, as examples — but the research provides a basis for action and understanding upon which future work can build.

One of the objectives of the Engineering Doctorate programme is to build bridges between industry and academia. It is hoped that the progress made as a result of this research programme will help future research addressing sustainable development in the mining industry to be endorsed and acted upon with determination by the industry and its stakeholders.
Portfolio Navigator

1. Overview

The objective for this navigation document is to outline the theses under examination in this portfolio, and to serve as a pathfinder for readers reviewing the various projects undertaken to explore the theses. This document covers the twin theses of this research, and outlines the objectives and components of the four research projects conducted to explore them. The key findings for each project and the main conclusions for the research are introduced.

The twin theses of this research are derived from Natural Resources Canada’s (NRCan) 1995 publication, entitled ‘Sustainable Development and Minerals and Metals: An Issues Paper’ (Natural Resources Canada, 1995). In this work, NRCan presented the view that sustainable development could be delivered through integration of economic, social and environmental issues in policy making. For the minerals and metals industry, NRCan proposed, this would require the Canadian industry and Government to focus efforts in five areas: a sustainable development approach to decision making, sustainable operations, social infrastructure, international leadership (by government), and development of science and technology.

1. Implementing a sustainable development approach to decision making;
2. Promoting products, markets and stewardship;
3. Promoting a positive business climate for mineral investment;
4. Promoting Aboriginal involvement in the minerals and metals industry;
5. Fostering innovation through science and technology;
6. Providing international leadership.

The research presented in this portfolio firstly explores NRCan’s assertion that delivery of sustainable development is dependent on integration of economic, social and environmental issues, specifically with reference to the mining industry (Vol.1 PD1). The research goes on to provide insights into the implications of the first two of the Government of Canada’s elements of policy: a sustainable development approach to decision making and promoting products, markets and stewardship. For example, the research includes findings relevant to the debate on the implications of sustainable development for decisions regarding the use of environmental performance indicators to help decision making (Vol.2 PD2), the environmental management of mining and the management of processes requiring energy relating to the processing and delivery of mineral products (Vol.3 PD3), and the regulation of mineral products in the environment (Vol.3 PD4).
2. Mining and Sustainable Development (Project Document 1)

2.1 Overview

The central thesis of NRCan is that mining is consistent with the principles of sustainable development (as presented in terms of maximising economic, social and ecological returns from mining investments). This is explored in Project Document 1 "Mining and Sustainable Development" (Vol.1 PD1). NRCan argue not only that mining can be compatible with sustainable development; they suggest that it requires the integration of economic, social and environmental dimensions. This cannot be accepted without validation. Mining coal, for example, depletes natural resources at a far greater rate than they are formed by natural processes. QED, mining coal cannot be sustained indefinitely. Miners involved in metals extraction might argue that since they do not destroy the metals they mine, merely refine and relocate them, the argument is slightly different for them. However, mining metals can only be sustained indefinitely if the metals extracted are subsequently recovered and returned to the mine (or some equivalent repository). In a thermodynamically closed system, it is difficult to see how this might be achieved indefinitely.

Clearly, if NRCan are correct, their interpretation of sustainable development must go beyond the physical sustainability of mining a particular ore-body. This project in the research portfolio provides the platform for the remaining body of work. It explores what sustainable development might mean for the mining industry, and whether sustainable development for mining can be compatible with the World Commission on Environment and Development (1987) definition of sustainable development as

"Development that meets the needs of the present without compromising the ability of future generations to meet their needs.” (World Commission on Environment and Development 1987, page 43).

The historical role of mining is introduced (PD1, Section 1.3.2) as an engine for the growth of world powers, followed by an exploration of the physical limits to such growth – as hypothesised by Malthus in 1798 and refined in the 20th century by Meadows et al (1972). According to the 'limits-to-growth' position, exhaustion of the earth’s finite resources is an inevitable consequence of continued economic growth. The limits-to-growth theorem requires population and pollution to be limited and economic growth to be suspended to avoid collapse.

Mining, which exists to extract scarce (a relative term) resources from the earth, appears to run counter to this. Therefore, in physical resource terms mining could be presented as wholly inconsistent with sustainability or sustainable development. The semantics of terms such as sustainability and sustainable development are explored (PD1, Section 1.3.5), concluding that there is more to sustainable development than either sustainable growth or sustainability per se. Project Document 1 explores circumstances where an ultimately physically unsustainable activity such as mining could be seen as compatible with the principles of sustainable development.

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1 Given that current estimates of economic reserves for many commodities are growing more rapidly than consumption (see also Vol.2 PD2 – Key Corporate Environmental Performance Indicators for Sustainable Mining Organisations – Section 2.8), mining is unlikely to be seen as increasingly sustainable.
development articulated by the UN General Assembly (see General Assembly of the United Nations 1987) and subsequently the World Commission on Environment and Development in 1987 (see also Published / Presented Paper 1 – “Sustainability and the Primary Extraction Industries: Theories and Practice” – Vol.4 PP1; and Published / Presented Paper 2 – “In for the Long Haul: Sustainable Development and the Global Mining Industry” – Vol.4 PP2).

The ecological, philosophical and economic bases for interpretations of sustainable development are explored (see PD1 Sections 1.3.3 to 1.3.9); in particular, the conflict between the argument that socio-economic forces act to promote more sustainable patterns of consumption and the argument that socio-economic forces act to undermine them, together with the conflict between Deontological (Pure Reason) and Teleological (Utilitarian) philosophical approaches to sustainable development. Further, the underlying tensions and weaknesses in various economic approaches to sustainable development are explored (see PD1 Sections 1.3.8 and 1.3.9).

It is concluded that while mining makes a substantial economic contribution to both global and local communities, economic measures alone will not discriminate mining practices compatible with sustainable development from those that are not. Furthermore, an entirely ecological approach will not identify which mining practices contribute to sustainable development, although such an approach has the potential to illustrate which mining practices are more ‘unsustainable’ than others.

Where mining is perhaps unique amongst industrial actors is in the durability of its activities and the legacy of those activities. Mines run by the global mining corporations will last decades, in rare cases centuries. While mining’s contribution to global society is most noticeable through the role of mined products, at the local level the contribution will be made by the people and the legacy their actions and interactions pass on to local communities. Such a legacy may be positive – through a mutually beneficial exchange of skills and opportunities – or negative – through cultural, social, physical or economic degradation. In either scenario, the legacy will endure far beyond the operating life of the mine (see PD1, Section 1.4). Case studies from Australasia demonstrate the impact mining can have upon local society (see PD1, Section 1.4.2)

2.2 Key Findings
The NRCan thesis - that mining can be compatible with sustainable development provided its relationship is understood in terms of physical, economic and social aspects - is supported. There are aspects to sustainable development - particularly ecosystem ‘services’ such as climate and ecosystem stability – that are wholly ecological in their nature. The literature suggests that these cannot be substituted by human innovations brought about through economic and social progress facilitated in part through mining. These aspects of sustainable development and sustainability are incommensurable with measures of economic and social progress since no amount of progress in the latter will compensate for losses of the former.

Physically unsustainable in the short term. Given the finite nature of the planet, however, physical unsustainability of mining in the longer term seems inevitable.
However, there are also aspects that are commensurable. For example, the depletion of fossil fuel sources to provide energy is physically unsustainable, but can lead to less unsustainable patterns of consumption if the energy allows social and economic progress that includes the development of non-fossil fuel energy systems. At the local level, mining activities can contribute to the prospects of future generations, provided that the legacy of diversified economic activity and social development offsets the loss of a physical asset or provides techniques to optimise the use of those assets. Focussing solely on the physical dimensions of sustainable development presents an incomplete indication of the extent to which mining activities are contributing to sustainable development.

A ‘sustainable development rule’ for mining is proposed in Project Document 1:

“Sustainable development for mining must pursue economic, ecological and social objectives, with the following conditions:

• Any improvement in economic and social conditions must not undermine those ecological functions that are non-substitutable;
• Any improvement in economic conditions must be achieved without undermining social conditions, such as values, traditions, institutions, cultures (equity);
• Any improvement in economic and social conditions which requires the use of non-renewable natural resources must deliver the means to substitute that natural capital with human capital.” (see Vol.1 PD1, Section 1.3.9.4.3)

This understanding of sustainable development for mining provides the platform for the projects which follow. The remainder of the research portfolio is concerned with the exploration of the implications of sustainable development – as understood here – for global mining companies: particularly how they measure and communicate their performance (Vol.2 PD2); how they manage the impact of their activities (Vol.3 PD3); and how their products are managed (Vol.3 PD4).
3. Implementing a Sustainable Development Approach to Decision Making - The Development of Key Corporate Environmental Performance Indicators for Sustainable Mining Organisations (Project Document 2)

3.1 Overview
Understanding the principles of sustainable development for mining will not ensure that a mining organisation contributes to sustainable development; that requires measurement of performance and action based on measured performance. Many of the leaders of global mining companies have made statements to this effect documented in the literature, particularly the leaders of Rio Tinto, Broken Hill Proprietary (BHP), Anglo American, Western Mining Company (WMC) and Placer Dome (see Rio Tinto 1998b, Broken Hill Proprietary 1998, Anglo American Corporation 1998, Morgan 1998, Placer Dome 1998). Placer's Jim Cooney has articulated the view held by his company thus, "We will be judged by performance, by how we operate mines and by what remains after mines close" (Cooney 1998 and Placer Dome 1998, page 2).

The objective of “The Development of Key Corporate Environmental Performance Indicators for Sustainable Mining Organisations” (Vol.2 PD2) is to examine the implications of sustainable development as explored in Project Document 1 (Vol.1 PD1) for the measurement of the environmental performance of diverse operations in global mining organisations. This has involved an assessment of the need for environmental performance indicators in sustainable mining organisations (see PD2 Section 1.1), together with an assessment of institutional and industrial initiatives to develop measures of environmental performance in terms of their relevance to global mining organisations and to sustainable development (see PD2 Section 1).

This is followed by the development of key environmental themes appropriate specifically to global mining organisations (see PD2 Section 2). The dimensions proposed by NRCan and validated in Project Document 1 – physical, economic and social – are reconciled with performance in the relevant environmental themes, to produce indicators of environmental performance for mining informed by the principles of sustainable development (see PD2 Section 3). To investigate the implications of such indicators two case studies were made; firstly of Rio Tinto, one of the world's largest diversified mining organisations; and secondly of Borax, a global mining company in its own right but a subsidiary of Rio Tinto in the Industrial Minerals product grouping (see PD2 Section 4). Of particular emphasis in the case studies were the extent to which the organisation supported the performance indicators – both absolute expressions of performance and expressions normalised for economic, physical or social dimensions – the extent to which the organisation is systemically prepared to implement such indicators, and the implications for managing operations revealed by such indicators.
3.2 Key Findings
Wide consensus was found in the importance of performance indicators (see Vol.2 PD2 Section 1), with primary roles including enhancing the significance of information through appropriate quantification and improved communication through simplification of information about complex phenomena. A host of initiatives to develop indicators supporting these roles exist. However, they can be categorised in a variety of ways. In this work, their relationship to sustainable development as understood in Project Document 1 (Vol.1 PD1) is critical. In this work, indicators are examined on the basis of whether they are indicators of sustainable development (see PD2 Section 1.2.1), environmental indicators informed by the principles of sustainable development (see PD2 Section 1.2.2), or environmental indicators not informed by the principles of sustainable development (see PD2 Section 1.2.3).

Five findings were made in the light of the examination of environmental performance indicators in practice (PD2 Section 1):
1. Performance Indicators have a role to play in sustainable mining organisations (see PD2 Section 1.4.1);
2. Any indicator framework should follow a logical hierarchy. Data should be used in a more selective fashion as well as in a more aggregated fashion as indicators become more concentrated towards the corporate level away from specific sites (see PD2 Section 1.4.2);
3. How sustainable development is understood and incorporated into the indicators makes a significant impact upon the indicators that result (see PD2 Section 1.4.3);
4. Indicators should focus on environmental performance rather than management performance (see PD2 Section 1.4.4); and
5. There are numerous issues that depend on local circumstances (see PD2 Section 1.4.5) - a cautionary point against over-simplifying indicators to express global performance in organisations whose activities have local effects.

This provides the basis for the assessment of environmental themes for use in indicators of physical environmental performance (see PD2 Section 2). A range of indicator themes is considered, based upon the work of institutions involved in performance indicator development (see, for example, Udo de Haes 1996, Gouzee 1996, Group on the State of Environment 1993, Hammond et al 1995, Opschoor and Reijnders 1991, Clarke et al 1997, Unilever 1997, Peck 1997). These are described in Table 1 (see also PD2 Section 1.3.2, Table 14).

While broad consensus is found for some themes, widespread dissonance can be found for others (see PD2, Section 2.1). Each potential theme is explored to identify the extent of its relevance to global mining organisations and the extent to which performance can be expressed meaningfully using indicators (see PD2, Sections 2.2 to 2.17). Numerous challenges are exposed; particularly relating to global themes with local effects – such as water use (see PD2, Section 2.9), ecotoxicity (see PD2, Section 2.13), acidification (see PD2, Section 2.12), biological diversity (see PD2, Section 2.15), sedimentation (see PD2, Section 2.16), and dust (see PD2, Section 2.17). On the basis of the exposition in Project Document 2, the physical environmental performance measures described in Table 2 are proposed (see also PD2 Section 2.18, Table 25).
### Table 1 Extent to which various indicator frameworks agree on appropriate key environmental performance categories

<table>
<thead>
<tr>
<th>Theme</th>
<th>SETAC</th>
<th>UNCS</th>
<th>OECD Short Term Indicators</th>
<th>World Bank</th>
<th>Opschoor and Ruland</th>
<th>ICI</th>
<th>Unilever</th>
<th>Peck</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acidification</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Biological Diversity</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Casualties</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Dust</td>
<td>No</td>
<td>No</td>
<td>Yes (a)</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Eco-toxicity</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Energy Use</td>
<td>No (d)</td>
<td>No</td>
<td>Yes (e)</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Eutrophication</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Greenhouse Effect</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Hazardous Waste</td>
<td>No (f)</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Human Toxicity</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes (k)</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Land Condition Changes</td>
<td>No</td>
<td>Yes</td>
<td>No (l)</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Land Use Changes</td>
<td>Yes (n)</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Noise</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Non-renewable resources depletion</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Odour</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Ozone depletion</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Photochemical Ozone Formation</td>
<td>Yes</td>
<td>No</td>
<td>No (p)</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Radioactive Waste</td>
<td>Yes (q)</td>
<td>Yes (r)</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Renewable resources depletion</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Sedimentation</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Water Use</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

**Notes**

(a) Part of ‘Urban Environmental Quality’ Issue

(b) Although ICI identify this category in ‘Future Considerations’, it is not included in their Environmental Burden framework.

(c) Indirectly – as part of ‘Soil Pollution’

(d) Although SETAC deem energy to be an important factor, they do not consider energy all the way up to the system boundary.

(e) Indirectly – as part of “Energy Supply and Structure”

(f) In the SETAC framework, only ‘solid waste’ is considered and, as for energy, is not considered all the way to the system boundary.

(g) ICI monitor hazardous waste, but note that regulatory definitions of the term vary from country to country.

(h) Unilever refer to ‘solid waste’—arguing that regulatory regimes differ in classification of the waste.

(i) Indirectly— as part of total ‘Process Wastes’.

(j) As ‘Occupational Exposures’ component of ‘Health’.

(k) OECD would like to include Land Condition, but argue that there is, as yet, insufficient data at an international level to include it yet.

(l) Indirectly – as part of ‘Soil Pollution’

(m) SETAC consider ‘land’ as an input into any system, but recognise that this is an all encompassing term that does not adequately reflect the issues associated with land use.

(p) An ‘Urban Environmental Quality’ category exists, but for the OECD, this is limited to SO$_2$, NO$_x$ and particulates in the short term.

(q) SETAC consider ‘radiation’ rather than radioactive waste.

(r) The UNCSD identify ‘safe and environmentally sound management of radioactive wastes’ as an important component of a sustainable development indicators framework, but have been unable to determine appropriate indicators for this category.
Table 2 Summary of Key Physical Environmental Performance Indicators for Global Mining Organisations

<table>
<thead>
<tr>
<th>Category</th>
<th>Primary Indicator</th>
<th>Spatial Scope</th>
<th>Location of Discussion in Project Document 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-Renewable Resources Depletion</td>
<td>Mining company [commodity] extraction as % of global [commodity] reserves</td>
<td>Global</td>
<td>Section 2.8</td>
</tr>
<tr>
<td></td>
<td>Mining company [commodity] extraction as % of global [commodity] reserve base</td>
<td>Global</td>
<td>Section 2.8</td>
</tr>
<tr>
<td>Energy</td>
<td>Primary Energy Required</td>
<td>Global</td>
<td>Section 2.10</td>
</tr>
<tr>
<td>Global Warming</td>
<td>Absolute Global Warming Potential</td>
<td>Global</td>
<td>Section 2.11</td>
</tr>
<tr>
<td>Acidification</td>
<td>Total Atmospheric Acidification Potential</td>
<td>Global</td>
<td>Section 2.12</td>
</tr>
<tr>
<td></td>
<td>Total hectares soil exceeding critical acid load from deposition</td>
<td>Local – Regional</td>
<td>Section 2.12</td>
</tr>
<tr>
<td></td>
<td>Total cubic metres water exceeding critical acid load from deposition / drainage</td>
<td>Local – Regional</td>
<td>Section 2.12</td>
</tr>
<tr>
<td>Water Use</td>
<td>Total Water Abstracted</td>
<td>Local – Regional</td>
<td>Section 2.9</td>
</tr>
<tr>
<td></td>
<td>Total Normalised Water Abstracted</td>
<td>Global</td>
<td>Section 2.9</td>
</tr>
<tr>
<td>Ecotoxicity</td>
<td>Total Aquatic Ecotoxicity Potential</td>
<td>Local</td>
<td>Section 2.13</td>
</tr>
<tr>
<td></td>
<td>Total Terrestrial Ecotoxicity Potential</td>
<td>Local</td>
<td>Section 2.13</td>
</tr>
<tr>
<td>Land Use</td>
<td>Total Area Disturbed</td>
<td>Local</td>
<td>Section 2.14</td>
</tr>
<tr>
<td></td>
<td>Area of Permanent Reclamation</td>
<td>Local</td>
<td>Section 2.14</td>
</tr>
<tr>
<td></td>
<td>Land Use of Permanent Reclamation</td>
<td>Local</td>
<td>Section 2.14</td>
</tr>
<tr>
<td>Biological Diversity</td>
<td>Relative Densities for Secondary Species (as % all species) in impacted and non-impacted areas</td>
<td>Local</td>
<td>Section 2.15</td>
</tr>
<tr>
<td></td>
<td>Number of species recorded in impacted areas relative to those in mature areas of target land conditions</td>
<td>Local</td>
<td>Section 2.15</td>
</tr>
<tr>
<td>Sedimentation</td>
<td>Gross weight of suspended solids in aqueous discharges</td>
<td>Local</td>
<td>Section 2.16</td>
</tr>
<tr>
<td>Dust</td>
<td>Total particulate matter released from operations</td>
<td>Local</td>
<td>Section 2.17</td>
</tr>
</tbody>
</table>

Section 3 of Project Document 2 explores how these physical measures of performance can be informed by the principles of sustainable development. In Project Document 1 sustainable development is understood in terms of physical, economic and social dimensions. Accordingly, these dimensions are explored to identify metrics with the potential to normalise environmental performance in unitary terms (e.g. area of land disturbed per tonne of ore). The need for such metrics is explored first (see PD2, Sections 3.1 and 3.2), followed by each of the three dimensions – economic (see PD2, Section 3.3); social (PD2, Section 3.4); and physical (PD2, Section 3.5).

Under the economic dimension themes such as contribution to Gross Domestic Product (see PD2, Section 3.3.1); turnover and revenue (see PD2, Section 3.3.2); net income (see PD2, Section 3.3.2); net present value (see PD2, Section 3.3.3); economic value added (see PD2, Section 3.3.4); and contribution to sustainable economic welfare (see PD2, Section 3.3.5) are
explored. Under the social dimension themes such as financial investment in community programmes (see PD2, Section 3.4.1), knowledge for development (see PD2, Section 3.4.2); and investment of human resources (see PD2, Section 3.4.3) are examined. Discussion on the physical dimension centres on tonnes product milled or produced (see PD2, Section 3.5.1); tonnes material moved (see PD2, Section 3.5.2) and the need to avoid double counting (see PD2, Section 3.5.3).

This exposition leads to the presentation of key environmental performance indicators for global mining companies informed by the principles of sustainable development for mining (see PD2, Section 3.6). They are intended for use at the corporate level, and are classified into global performance and local/ regional performance indicators for global issues. They are presented here in Table 3 and Table 4 (see also PD2 Section 3.6, Tables 34 and 35).

**Table 3 Normalised key environmental performance indicators for issues with global effects for global mining companies**

<table>
<thead>
<tr>
<th>Indicator Normalised Against Economic Criteria</th>
<th>Indicator Normalised Against Social Criteria</th>
<th>Indicator Normalised Against Physical Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mining company [commodity] extraction as % of global [commodity] reserves per US$m value added</td>
<td>Mining company [commodity] extraction as % of global [commodity] reserves per 1000 man-hours invested in community programmes</td>
<td>Mining company [commodity] extraction as % of global [commodity] reserves per Kt material moved</td>
</tr>
<tr>
<td>Primary Energy Required (Gj) per US$m value added</td>
<td>Primary Energy Required per 1000 man-hours invested in community programmes</td>
<td>Primary Energy Required per Kt material moved</td>
</tr>
<tr>
<td>Absolute Global Warming Potential (MtCO2e) per US$m value added</td>
<td>Absolute Global Warming Potential per 1000 man-hours invested in community programmes</td>
<td>Absolute Global Warming Potential per Kt material moved</td>
</tr>
<tr>
<td>Total Atmospheric Acidification Potential per US$m value added</td>
<td>Total Atmospheric Acidification Potential per 1000 man-hours invested in community programmes</td>
<td>Total Atmospheric Acidification Potential per Kt material moved</td>
</tr>
<tr>
<td>Total Normalised Water Abstracted per US$m value added</td>
<td>Total Normalised Water Abstracted per 1000 man-hours invested in community programmes</td>
<td>Total Normalised Water Abstracted per Kt material moved</td>
</tr>
</tbody>
</table>
Table 4 Normalised key environmental performance indicators for issues with regional / local effects for global mining companies

<table>
<thead>
<tr>
<th>Indicator Normalised Against Economic Criteria</th>
<th>Indicator Normalised Against Social Criteria</th>
<th>Indicator Normalised Against Physical Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total hectares soil exceeding critical acid load from deposition per US$m value added</td>
<td>Total hectares soil exceeding critical acid load from deposition per 1000 man-hours invested in community programmes</td>
<td>Total hectares soil exceeding critical acid load from deposition per Kt material moved</td>
</tr>
<tr>
<td>Total cubic metres water exceeding critical acid load from deposition / drainage per US$m value added</td>
<td>Total cubic metres water exceeding critical acid load from deposition / drainage per 1000 man-hours invested in community programmes</td>
<td>Total cubic metres water exceeding critical acid load from deposition / drainage per Kt material moved</td>
</tr>
<tr>
<td>Total Water Abstracted per US$m value added</td>
<td>Total Water Abstracted per 1000 man-hours invested in community programmes</td>
<td>Total Water Abstracted per Kt material moved</td>
</tr>
<tr>
<td>Total Aquatic Ecotoxicity Potential per US$m value added</td>
<td>Total Aquatic Ecotoxicity Potential per 1000 man-hours invested in community programmes</td>
<td>Total Aquatic Ecotoxicity Potential per Kt material moved</td>
</tr>
<tr>
<td>Total Terrestrial Ecotoxicity Potential per US$m value added</td>
<td>Total Terrestrial Ecotoxicity Potential per 1000 man-hours invested in community programmes</td>
<td>Total Terrestrial Ecotoxicity Potential per Kt material moved</td>
</tr>
<tr>
<td>Total Area Disturbed per US$m value added</td>
<td>Total Area Disturbed per 1000 man-hours invested in community programmes</td>
<td>Total Area Disturbed per Kt material moved</td>
</tr>
<tr>
<td>Area of Permanent Reclamation per US$m value added</td>
<td>Area of Permanent Reclamation per 1000 man-hours invested in community programmes</td>
<td>Area of Permanent Reclamation per Kt material moved</td>
</tr>
<tr>
<td>Land Use of Permanent Reclamation per US$m value added</td>
<td>Land Use of Permanent Reclamation per 1000 man-hours invested in community programmes</td>
<td>Land Use of Permanent Reclamation per Kt material moved</td>
</tr>
<tr>
<td>Relative Densities for Secondary Species (as % all species) in impacted and non-impacted areas per US$m value added</td>
<td>Relative Densities for Secondary Species (as % all species) in impacted and non-impacted areas per 1000 man-hours invested in community programmes</td>
<td>Relative Densities for Secondary Species (as % all species) in impacted and non-impacted areas per Kt material moved</td>
</tr>
<tr>
<td>Number of species recorded in impacted areas relative to those in mature areas of target land conditions per US$m value added</td>
<td>Number of species recorded in impacted areas relative to those in mature areas of target land conditions per 1000 man-hours invested in community programmes</td>
<td>Number of species recorded in impacted areas relative to those in mature areas of target land conditions per Kt material moved</td>
</tr>
<tr>
<td>Gross weight of suspended solids in aqueous discharges per US$m value added</td>
<td>Gross weight of suspended solids in aqueous discharges per 1000 man-hours invested in community programmes</td>
<td>Gross weight of suspended solids in aqueous discharges per Kt material moved</td>
</tr>
<tr>
<td>Total particulate matter released from operations per US$m value added</td>
<td>Total particulate matter released from operations per 1000 man-hours invested in community programmes</td>
<td>Total particulate matter released from operations per Kt material moved</td>
</tr>
</tbody>
</table>

With this theoretical framework established, two case studies are presented to illustrate how the arguments developed in Project Document 1 and Sections 1 to 3 of Project Document 2 can be validated in practice (see PD2, Section 4). The first is Rio Tinto, one of the world’s leading mining organisations (see PD2, Section 4.4); and the second is Borax, a global subsidiary of Rio Tinto (see PD2, Section 4.5).

Both case studies are divided into qualitative and quantitative elements. The qualitative elements include the extent to which the organisations support the principles of sustainable development for mining (see PD2, Section 4.4.2) and the extent to which the organisations support the use of environmental performance indicators and normalisation as proposed in Project Document 2, Sections 1 to 3 (see PD2, Sections 4.4.3, 4.4.4, and 4.5.2). This qualitative assessment provides insights from the two specific organisations on how the indicators might be implemented in practice. It also provides the platform for quantitative
assessment of performance data from the case study organisations comparing currently reported performance with performance indicated by the measures proposed in this research.

A number of findings were made on the basis of the case studies for Rio Tinto (see PD2, Section 4.4.6) and Borax (see PD2, Section 4.5.4) and conclusions drawn (see PD2, Section 4.6 and Section 5). These relate to the difficulty large mining organisations have in presenting meaningful data on their performance in the context of sustainable development; the need for a unified reporting framework to be used by all mining companies, especially in the case of joint ventures; the importance of recognising local conditions; the weaknesses in data availability and use; and the need to focus on areas where intelligence is needed, rather than where it is easy to gather.

Taken as a whole, Project Document 2 concludes that mining organisations see their activities as potentially compatible with the principles of sustainable development, but depend upon human agency to realise that potential. This is considered as critical to such development. The work also concludes that, for mining in particular, decisions may affect both global and local environmental performance. In both instances decision-makers require information upon which action can be taken. It is concluded that indicators and relative measures of performance are valuable sources of such information. The indicators proposed and tested in this research relate to global actors in the sustainable development agenda but it is concluded that such indicators will form only part of an overall indicator framework informed by a host of actors with a legitimate stake in the performance of mining activities.

The research also reveals a number of challenges for future research. These include the resolution of the current incompatibility of financial and environmental performance reporting in mining companies arising largely from historically different decision audiences (see PD2, Section 5.3.1). Other challenges relate to systemic 'blind-spots' such as failures to communicate local performance to the global organisation; failures to address meaningfully the need for information on local sensitivity to acidic discharges, biological diversity, and local water availability. Still other challenges relate to failures of large mining organisations to share information between them about performance at operations in which they have a financial and reputation stake (and therefore a responsibility) even if they do not have managerial control (see PD2, Section 5.3.2).

Specific areas for future research identified include deposition and sensitivity (see PD2, Section 5.3.3.1), biological diversity (see PD2, Section 5.3.3.2), discount factors (see PD2, Section 5.3.3.3), social welfare (see PD2, Section 5.3.3.4), validation (see PD2, Section 5.3.3.5), and extending the indicators (see PD2, Section 5.3.3.6).

Project Document 2 shows that it is meaningful and possible for a global mining company to take a sustainable development approach to decision making, and has supported the argument that sustainable development is consistent with mining, within given parameters. Furthermore, this research demonstrates that the approach currently taken by the industry to managing the impact of its operations is not consistent with sustainable development.
This research proposes a framework to be used, and shows through case-study the implications and requirements for implementation of such a framework. Definitive conclusions about the actual environmental performance of the mining companies in the case studies are not desired. It is argued that such conclusions are precluded by the assumptions in the methodology used in the case-studies.

Instead, this research shows the need for the framework proposed. It also shows the need for the sector to co-ordinate its effort to allow stakeholders to make decisions about the performance of the actors in the sector. Such efforts should be made regardless of whether they manage the assets they own, and regardless of whether they manage the utilities which cause impacts related to their operations. Thus decisions made regarding the environmental performance of the mining industry can be made with the principles of sustainable development at the forefront.
4. Implementing a Sustainable Development Approach to Decision Making - Environmental Management (Project Document 3)

4.1 Background
Taking the conclusion of Project Document 1 as a starting point, this project took as its thesis the following: “A sustainable development approach to decision making requires a shift from compliance based environmental management to improvement based environmental management in mining.”

4.2 Research
To explore this thesis, this project examines the way in which formalised environmental management systems (which frequently take continuous improvement as a central position) would change environmental management approaches in a diverse mining organisation – Borax. Specifically, this project examines the purpose and benefits of a formalised environmental management system to a diversified mining company like Borax (Vol. 3, PD3, Section 2), the different environmental management system standards (PD3, Section 3), and existing company structures through fieldwork throughout the global operations of Borax (see Vol.4 APD 6–11) and for the Group taken as a whole (Vol.3 PD3, Sections 4 and 5). Then the research assesses the reporting requirements imposed upon Borax (PD3, Section 6), and examines how Borax might implement formalised environmental management systems (see Vol.3 PD3, Section 6 and Vol.4 IP1).

The changing business environment and the business need for environmental management are reviewed (see Vol.3 PD3, Section 2.1). This is followed by a review of the ethical issues involved in business taking a responsible approach to the environment (see PD3, Section 2.2). This broad exposition is followed by a discussion of the need for environmental management in the mining industry covering wider industrial drivers such as the increasing prominence of the environment as a general issue.

Industry specific issues related to the mining industry are also introduced (see also Vol.2 PD2, Section 2), including the environmental effects of minerals operations and the response of the mining industry to the changing business environment regarding environmental issues. In addition, the processing and distribution activities which follow from the extraction phase will have attendant environmental issues. Energy consumption in processing, together with any process losses of materials, and the environmental effects of a transportation system which relies heavily on the road network must also be considered.

Section 3 of Project Document 3 focuses upon the different internationally recognised approaches to environmental management, particularly the Eco-Management and Audit Scheme (EMAS) and the International Organisation for Standardisation’s ISO 14001:1996. Both are formal management systems based upon the principles of Plan, Do, Check, Act.

The research includes a review of the origins and nature of the main environmental management system standards (see Vol.3 PD3, Section 3). Each is based upon the principles.
of continuous improvement. A company environmental policy is formulated, providing a statement of intent for the organisation. A review is carried out to examine the most important environmental issues arising from the organisation's activities, and to gain an understanding of the legal requirements the organisation must meet. An environmental management programme is then established, with objectives and targets defined, management structure and responsibility set, action plans developed and operating, communication and training procedures established. Review mechanisms are implemented to audit the systems and manage preventative and corrective action. All these systems require thorough documentation.

Fieldwork is carried out in the form of site visits to determine the extent to which such systems were implemented throughout the Borax Group: at the four mines in Argentina and USA, the four chemical processing operations in Argentina, France and USA, the six materials handling and distribution activities in Spain, Netherlands, France, UK, USA and Argentina, and the technical centres in UK and USA. The findings of these reviews are presented as appendices (see Vol.4 APD 6 –11) with Group-wide findings summarised in the main project document (see Vol.3 PD3, Section 5).

Once the review was complete a management meeting was organised in the Netherlands, attended by the research engineer and EHS managers from all the operating companies. Also present were representatives of Rio Tinto corporate EHS, Borax corporate EHS, a number of the group company managing directors and production managers, and the European director of operations and distribution. The findings were reviewed and a decision was taken to proceed with the implementation of an environmental management system across the Group. The recommendations to Borax to implement a formalised environmental management system are included as Internal Paper 1 – “Recommendations to Borax on the Selection and Implementation of a Formal Environmental Management System” - see Vol.4 IP1. The process of change that led to the decision to implement ISO 14001 is reviewed in Published / Presented Paper 3 – “Implementing Change – Gaining Commitment and Putting an EMS into Operation” – see Vol.4 PP3.

The hypothesis of this project is not that implementing formal environmental management systems would provide a framework by which Borax could become sustainable, or contribute to sustainable development, since this phase of the research portfolio has not addressed social and economic issues. Rather, this project examines whether implementation of formalised environmental management systems might help diversified mining operations such as Borax move in a less unsustainable path, by considering environmental issues in terms of their impact, rather than exclusively in terms of meeting regulations.

This is explored further through the case of energy use relating to Borax Europe operations (see PD3, Section 9). The basis of formalised environmental management systems is the continuous improvement of performance through effective management of significant impacts. However, although referring to supply chain issues occasionally, the main focus of such systems is the operation itself. The thesis of the case study builds upon findings in “The Development of Key Environmental Performance Indicators for Sustainable Mining Operations” (see Vol.2 PD2, Section 4.5) that the scale of off-site impacts relating to the
provision of energy can be moving in an entirely different direction from those on-site. Here the thesis tested is that, in the case of energy, managing site-based consumption effectively may not reduce the potential overall environmental impact as effectively as focussing on energy use in other parts of the supply chain. In this example, the distribution of processed borate products is examined, and energy requirements assessed in comparison with those arising on-site.

The environmental effects associated with energy consumption and logistics are introduced (see PD3 Section 9.3), followed by environmental policy issues connected with those effects (see PD3 Section 9.4). Thereafter energy and logistics inventories are compiled for the European operations of Borax (see PD3 Section 9.5 and also Vol.4 APD 20 - 21). This is done through energy audits carried out at each operating site, and distribution databases maintained by the Group’s logistics functions. These inventories are then analysed using standard life-cycle-analysis software, to compare the contributions to environmental themes from energy use on site and from product distribution (see PD3 Section 9.6).

4.3 Key Findings
Implementing a formal environmental management system requires a change in philosophy from compliance with legislation to continuous improvement beyond legislation. This process has required a recognition of the need to change and has required activity to bring the change about. The Borax response to the increasing influence of external drivers has been to realise that the historical approach to environment, health and safety, that of systems based around compliance with local, national, and international regulations, will be unable to satisfy the increasingly well informed interest groups in the immediate future. In addition to this, there is an internal recognition that good environmental performance will be critical for business success. Ultimately, one could argue that Borax will need to be able to demonstrate its contribution to sustainability, not straightforward for a minerals extraction group, but moving from a compliance approach to a continuous improvement approach in itself represents a substantial shift in outlook by the organisation.

It is found that the implementation of formalised environmental management systems in Borax requires significant systemic change within the organisation. The site reviews in particular find that current systems are strong on compliance, but weak on identifying significant environmental aspects, setting locally relevant targets, training employees and raising their awareness of environmental issues, documentation, monitoring and measurement, and reviewing its procedures (see Vol.3 PD3, Section 5 and also Vol.4 APD 6-11). Formalised environmental management systems would require such issues to be addressed. However, the formalised environmental management systems themselves are found to be overly focussed on site performance, rather than environmental impacts in a broader supply-chain associated with operations. The case study confirms this hypothesis (see Vol.3 PD3 Section 9).

The analysis of the site-energy and logistics inventories discussed in PD3 Section 5 led to the comparison shown in Table 5 (see also PD3 Section 9.6.2.5.2, Tables 20 and 21). As the
Tables show, in many environmental themes the contribution to environmental themes from the distribution phase far outweighs the impact from the original processing phase.

As an example, on the processing side, generating and supplying the energy required to ship 1 tonne of product from the operating site involves, on average, the release of acidic gases equivalent to 0.246 kg SO\textsubscript{2} per tonne of product shipped\textsuperscript{2}. To deliver this tonne of product to a customer releases on average 0.483 kg SO\textsubscript{2} per tonne of product delivered\textsuperscript{3}, almost double the potential contribution to acidification associated with the use of energy to process the product.

### Table 5 Processing versus Distribution Environmental Burdens, Per Functional Unit, Borax Europe 1995/6 (presented here to 4 significant figures)

<table>
<thead>
<tr>
<th>Activity</th>
<th>Units</th>
<th>Processing</th>
<th>Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land Use</td>
<td>(m\textsuperscript{2})</td>
<td>0.022</td>
<td>15.364</td>
</tr>
<tr>
<td>Smog</td>
<td>(kg NO\textsubscript{x})</td>
<td>0.126</td>
<td>0.454</td>
</tr>
<tr>
<td>Landfill</td>
<td>(dm\textsuperscript{3})</td>
<td>0.691</td>
<td>-</td>
</tr>
<tr>
<td>Radioactivity</td>
<td>(kBq)</td>
<td>30.26</td>
<td>10,377</td>
</tr>
<tr>
<td>Resource Depletion</td>
<td>(/year)</td>
<td>0.258</td>
<td>0.317</td>
</tr>
<tr>
<td>Greenhouse</td>
<td>(kg CO\textsubscript{2})</td>
<td>47.72</td>
<td>41.632</td>
</tr>
<tr>
<td>Acidification</td>
<td>(kg SO\textsubscript{2})</td>
<td>0.246</td>
<td>0.483</td>
</tr>
<tr>
<td>Ecotoxicity</td>
<td>(m\textsuperscript{3})</td>
<td>0.069</td>
<td>0.012</td>
</tr>
<tr>
<td>Eutrophication</td>
<td>(kg PO\textsubscript{4})</td>
<td>0.016</td>
<td>0.06</td>
</tr>
<tr>
<td>Greenhouse (indirect)</td>
<td>(CO\textsubscript{2})</td>
<td>1.307</td>
<td>6.921</td>
</tr>
<tr>
<td>Human Toxicity</td>
<td>(kg/kg)</td>
<td>0.353</td>
<td>0.996</td>
</tr>
<tr>
<td>Odour</td>
<td>(kg NH\textsubscript{3})</td>
<td>0.001</td>
<td>0.092</td>
</tr>
<tr>
<td>Ozone Depletion</td>
<td>(kg CFC 11)</td>
<td>5.114 *10\textsuperscript{-7}</td>
<td>1.813 *10\textsuperscript{-6}</td>
</tr>
<tr>
<td>Smog</td>
<td>(kg ethene)</td>
<td>0.021</td>
<td>0.082</td>
</tr>
</tbody>
</table>

The processing phase of the supply-chain is directly managed by Borax, and thus an assessment of significant impacts under formalised environmental management systems would be likely to examine the use of energy on site. It would identify, for example, that the use of natural gas in the process at Borax Français accounts for approximately 80% of processing energy used at Borax Europe (see Vol.3 PD3 Section 9.5.1), and could set up improvement targets designed to reduce this use (see PD3 Section 9.6.4). However, the distribution phase of the chain is not always managed by Borax. Often customers collect product, or contractors are used, yet the environmental impacts of distribution phase are frequently dominant. Further steps in the supply chain, such as subsequent use of the product, may be even more significant than the directly managed processing step.

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\textsuperscript{2} 0.061 kg (as sulphur dioxide equivalent) of acid gases through the use of natural gas, 0.179 kg through the use of electricity, and 0.006 kg through the use of diesel in process equipment (such as forklift trucks and front-end loaders)

\textsuperscript{3} 0.277 kg through the use of trucks, 0.099 kg through the use of trans-oceanic ships, 0.078 kg through the use of inland water vessels, and 0.029 kg through the use of rail
An example of the importance of focusing on the distribution phase in mineral operations is presented in PD3 Section 9.6.4. Foret, a major customer for Borax España, currently collects borates by truck and hauls them overland to Zaragoza, some 280km away. If Borax Espana managed the delivery leg and utilised the rail-head at its warehouse, delivery by rail would reduce environmental burdens substantially. For example, shifting from truck to rail for delivery to Foret would reduce emissions of nitrous oxides by approximately 8.5 tonnes per year. The generation and delivery of electricity to run the Borax España operations, by comparison, amount to just over 3.5 tonnes per year. So shifting the mode of transportation of product to one major customer would reduce emissions in one environmental theme by more than double the total emissions associated with electrical energy used on site.

4.4 Conclusions

Natural Resources Canada (1995) assert that energy efficiency and sound environmental management are core components of sustainable mining operations (see Natural Resources Canada 1995, pages 35 to 36). The findings of this project concur with this view, but go on to highlight the implications of sound environmental management and energy efficiency for mineral operations operating under the principles of sustainable development. Sound environmental management extends beyond the factory gate. This project has shown that more important than doing things right – reducing energy use per tonne of product shipped – is doing the right things – focussing attention on ‘downstream’ processes such as distribution which may have a greater impact on the environment than the processing step. Current practices in the case study of Borax Europe, for example, show that such an assessment is not currently carried out even in an organisation that is among the pioneers in Rio Tinto in implementing formalised environmental management systems (see Rio Tinto 1999b, page 20).

For the first part of this project the findings most relevant to the overall thesis derived not from the main research itself, but from the response of the organisation as a result of the research. For example, the research found that there was a clear need to implement formalised environmental management systems at Borax, that current systems were overly compliance focussed (particularly those in the United States) and were not likely to bring about continuous improvement and move the environmental performance of mining companies in a less unsustainable direction\(^4\). However, the response of the mining organisation to the research project itself is significant also. The implementation of the research findings is leading towards a shift in culture at Borax which, it is argued, is more likely to lead to organisational behaviour consistent with the principles of sustainable development than the implementation of formalised environmental management systems themselves.

In recent years a number of major organisations have felt compelled to review their cultures and management systems in the wake of corporate shocks of one kind or another: Exxon after the Valdez oil spill of the coast of Alaska, Shell after Brent Spar and the ongoing dispute with

\(^4\) There are some historical reasons for this. Improvements in safety systems have been a pressing concern for many mining companies in recent years, with the result that compliance based approaches to safety have been adopted in environmental management.
the Ogoni in Nigeria (see Lofstedt & Renn 1998a or Lofstedt & Renn 1998b; Burke & Logsdon 1996; Walden & Schwartz 1997; Patten & Nance 1998; Elkington & Trisoglio 1996). These shocks need not be specific to environmental issues: the mining industry continues to restructure after one of the largest scandals in its recent history, one that has become synonymous with the company at its centre – Bre-X. According to Gooding (1997), “The Bre-X fraud was exceptionally damaging, not only because of its scale but also because it seemed to provide confirmation for some of the industry’s critics that mining companies are run by greedy and stupid people” (Gooding 1997, page ix).

These examples have focused the attention of other companies, Borax included, who recognised that the absence of major incidents in their operations thus far was no guarantee that they had the necessary systems to prevent incidents occurring. This has provided the impetus to examine the entire culture of the organisation and to recognise the need to change the approach from compliance to continuous improvement. While challenging, such an exercise is more likely to bring about sustainable development than attempting to maintain the status-quo.

The use of formal environmental management systems, if implemented with the principles of sustainable development in mind, will require a minerals operation to identify downstream impacts as significant, even if they are not currently managed by the operation. The case study of distribution in a European minerals organisation has demonstrated just how important consideration of downstream activities may be. Sound environmental management and energy efficiency, while clearly components of more sustainable mining industry, must be addressed with the aim of reducing the impact of mining, rather than just the impact of mining operations.

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5 In 1995 Bre-X claimed to have discovered in Busang, Indonesia, the world’s biggest gold deposit. From being worth only a few million dollars on the Toronto Stock Exchange, Bre-X became a US$4billion company. Then, early in 1997, due diligence work established that there was virtually no gold in the Busang deposit and that all previous samples had been ‘salted’. Bre-X quickly went bankrupt. The scandal shook the whole mining sector. Many small companies subsequently found it almost impossible to raise capital for exploration and their share prices collapsed (see Gooding 1997). Brown (1998) concludes that the “biggest gold fraud of all time” inadvertently triggered the “biggest boom in mining mergers and acquisitions.” (Brown 1998, page ix)
5. Implementing a Sustainable Development Approach to Decision Making - Products and Stewardship (Project Document 4)

5.1 Background

According to NRCan (1996),

"Metals [and minerals] are, in some cases, toxic. At the same time, however, they occur naturally in the environment and are in trace amounts essential to life. As we do not live in a risk-free environment, the question for society is how to deal with naturally occurring substances that are, at the same time, and under certain circumstances, potentially harmful to life" (Natural Resources Canada 1996, page 36).

Shinya (1998) notes that minerals and metals are frequently classified as chemicals in regulatory exercises, with the result that approaches used relating to minerals and metals are often based on models developed for synthetic chemicals. He observes that,

"An example [of inappropriate action based on this premise] would be the misconception that the presence of a mineral or metal in the environment, no matter how small an amount, represents some form of contamination, and that the source of the contamination must be as a result of human activity" (Shinya 1998, page 99).

A sustainable development based approach to decision making in the regulatory arena, however, would focus upon all sources of a mineral, both natural and anthropogenic. The key issues are whether human activity is disrupting the balance of ecological systems, and if it is, whether the benefits brought to humankind from activity which disrupts ecological systems will allow humankind to develop alternatives to those systems which are substitutable, or stop harm being caused to those which are not. To explore the validity of Natural Resources Canada and Shinya's thesis that minerals and metals should not be classed as contaminants, and as such be regulated differently from synthetic chemicals, a case study of boron is made.

Boron based minerals are used widely in commercial applications such as insulation fibreglass, textile fibreglass, oven-ware, ceramics, enamels, detergents, fertilisers, wood preservation, flame retardants (see Vol. 3 PD4 - Section 5). Epidemiological studies, however, have shown developmental effects relating both to boron deficiency (See Fort et al 1998) and to boron toxicity (See Price et al 1998, Narotsky et al 1998, Chapin et al, 1998), with some research concluding that there may be a 'U' shaped relationship between boron intake and developmental effects (See Rowe et al 1998).

Whilst research into the effects of borates is limited to fish, rats, frogs etc, concern for public safety prompted the International Programme for Chemical Safety (IPCS) to propose a reduction in the allowable level of boron in drinking water from 1mg/l to 0.3 mg/l. A broad range of research projects were initiated by industry to establish whether such a reduction is appropriate. This research project aims to identify the reservoirs and flows of boron in the environment and to quantify those flows. The objective is to establish whether natural or
anthropogenic flows of boron are dominant and thus indicate whether a reduction in anthropogenic flows is likely to reduce the amount of boron in the environment.

If NRCan and Shinya are correct in their thesis that minerals are not contaminants but naturally occurring substances found throughout the environment, then this would imply that natural flows of borates would outweigh flows related to commercial use of borates. Here a sustainable development approach to decision making need not include regulation of natural systems by human beings. However, if Shinya and NRCan are incorrect in their thesis commercial flows of borates would outweigh natural flows; thus it would be legitimate to view them as contaminants if any harm arising from their extraction and use compromised ecosystem functions, or outweighed the social and economic benefits brought.

While such an argument might hold at the global level, it may not necessarily be automatically valid at a more local level. Particular watercourses – such as the Rhine – may provide exceptions to the global rule. In areas where one particular reservoir – such as a lake or river – is subject to high levels of boron loading from human sources like industry and households the majority of boron present could arise from anthropogenic sources. In these cases it is entirely possible that the levels of boron present do present an ecological risk and in such cases it would be appropriate to regulate borates.

5.2 Research
The case study to investigate the flows and reservoirs of boron in the environment is presented in Vol.3 PD4 – *A Global Mass Balance for Boron*. The research investigates boron chemistry (Vol.3 PD4 – Section 2), material pathways (Vol.3 PD4 – Section 3), natural boron sources (Vol.3 PD4 – Section 4), anthropogenic movement of boron (Vol.1 PD3 – Section 5), natural movement of boron (Vol.3 PD4 – Section 6), and then explores a specific geographical case study to identify and quantify natural and anthropogenic sources and flows to establish whether certain borate reservoirs are likely to be in balance over time (Vol. 4 APD 22 -23). On the basis of this research, a global mass balance for boron is calculated (Vol.3 PD4 – Section 7).

5.3 Key Findings
5.3.1 Anthropogenic movement of boron
One of the key objectives of this work has been to establish the importance of industrial activity and consumption of boron in the global system compared to the background natural processes. This has required an in-depth analysis of all the commercial applications using boron, the final fate of the products manufactured, and on the industrial processes involved, both in the extraction and refining of boron and in the production of boron-related products (Vol.3 PD4 – Section 5).
5.3.1.1 Boron Mining and Processing

Process research at Boron, California, has determined the level of losses during the mining and refining stage (see Vol.3 PD4 - Section 5.3). Such data has not been made available by other organisations due to reasons of commercial sensitivity. If the data for Boron are assumed to apply to other processes, then the following mass values arise:

- Global Commercial Borate Deposits: 30.75 to 64.4 million tonnes boron
- Boron Extracted Each Year: 370,000 to 410,000 tonnes boron
- Boron Not Recovered During Processing: 60,000 to 100,000 tonnes boron
- Boron Yield: 310,000 tonnes boron

5.3.1.2 Commercial Boron-Based Product Manufacturing

Thus each year just over 300,000 tonnes of boron is recovered from refined extracted deposits destined for the main product groups shown in Table 6 (see also PD4, Section 5.2.1, Table 5). Some of this material is lost into the environment during manufacturing processes. The production processes involved in commercial manufacturing of boron-related products have been analysed and emissions determined (see Vol.3 PD4 - Section 5.3). It should be emphasised, however, that different manufacturers produce products in different ways and at different levels of efficiency across the planet. However, where absolute accuracy of data cannot be assured, a range of values has been established for material flows.

Table 6: Global Industrial Boron Use Volume, to Nearest 5,000 Tonnes, 1994 (From Lawrence, 1995)

<table>
<thead>
<tr>
<th>Product</th>
<th>Total Sales Into Industrial Sector (Tonnes Boron)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insulation Fibreglass / Textile Fibreglass / Borosilicate Glass</td>
<td>120,000</td>
</tr>
<tr>
<td>Ceramics</td>
<td>40,000</td>
</tr>
<tr>
<td>Detergents</td>
<td>60,000</td>
</tr>
<tr>
<td>Fertilisers</td>
<td>15,000</td>
</tr>
<tr>
<td>Cellulose Insulation</td>
<td>5,000</td>
</tr>
<tr>
<td>Distributors / Other</td>
<td>70,000</td>
</tr>
<tr>
<td>TOTAL</td>
<td>310,000</td>
</tr>
</tbody>
</table>

Figure 1: Schematic Summary of Anthropogenic Boron Mass Flows) summarises boron mass flows arising from commercial activities (see also PD4 Section 5.4, Figure 15). Just under 70,000 tonnes of boron are designated for ‘other’ products. The majority of the boron in this sector is sold to distributors who then sell the boron on to small customer groups. Data is not available for this industrial group, so process losses for this group cannot be determined in this work. Boron remains in a soluble form in fertilisers and detergents, but becomes bonded into the ceramics, glass, and insulation product during the production phase.

To summarise, boron moves to atmosphere from stack emissions during the production of ceramics, glass and cellulose insulation; to water from the production of ceramics and fertilisers, and from the production and use of detergents; to soil from the use of fertilisers;

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6 See Harben & Dickson 1984, page 19
and to landfill from borate processing, from the production of ceramics and detergents, and from the disposal after use of glassware, ceramics, insulation, and the ‘other’ applications. It is possible that the boron in landfill may find its way into the soil and water systems. Work by the US Army Corps of Engineers has determined that boron from sources such as coal ash is highly mobile in landfill (Cerbus et al 1994), so any non-bonded boron in unconfined landfill could move into the soil system.

Figure 1: Schematic Summary of Anthropogenic Boron Mass Flows
5.3.2 Natural movement of boron
It has been shown that commercial processes are responsible for the movement of approximately 310,000 tonnes of boron each year, with circa 10,000 tonnes going to atmosphere, 60,000 tonnes going to surface waters, 15,000 tonnes going directly to soils as fertiliser, and the difference, some 225,000 tonnes going to landfills and tips. Specific figures are shown in the mass balance schematic, (Figure 2: Boron Mass Flow Schematic). The next step in the research required determination of the significance of these values when compared with natural processes.

For the purposes of this bridging document, the findings alone for natural systems will be introduced. For an explanation for each of the themes and how the ranges of values were determined, readers are directed to Vol.3 PD4, Sections 4 and 6. The main systems identified and analysed were tectonic systems, the hydrological cycle and organic systems.

5.3.3 Mass flow schematic
Figure 2 illustrates the major flows and reservoirs identified and analysed in the course of this research (see also PD4 Section 7.6, Figure 20).

Several observations can be made from the data on boron flows:
1. By the far the most dominant flows of boron arise from the movement of boron into the atmosphere from oceans (see Vol.3 PD4 – Section 6.1)
2. Boron mining represents a flow of boron out of the ground of a similar order of magnitude to volcanic eruptions, with boron mining estimated to represent a flow of approximately 4 \( \times 10^8 \) kg boron and volcanic eruptions estimated to represent a flow of around 3 \( \times 10^8 \) kg boron per year (see Vol.3 PD4 – Sections 4.3 and 6.1).
3. Coal mining represents a boron flow from the ground of similar magnitude to boron mining and volcanoes, with between 5 \( \times 10^7 \) kg and 6 \( \times 10^8 \) kg boron removed in coal each year (see Vol.3 PD4 - Section 6.1).
4. Anthropogenic activities associated with the conversion of borates to commercial products and the consumption of such products represent boron flows of orders of magnitude far lower than those associated with natural processes. Industrial activities such as production of glass and ceramics represent flows of boron to atmosphere of approximately 1 \( \times 10^7 \) kg, a small percentage (<0.56%) of the total boron flows to the atmosphere of between 1.8 \( \times 10^9 \) kg and 5.3 \( \times 10^9 \) kg per year (see Vol.3 PD4 – Section 5.3)
5. Process losses from industry and the use of detergents represent flows to aqueous systems of approximately 5.3 \( \times 10^7 \) kg per year. Drainage into the sea from rivers and groundwaters is estimated to represent anything from 3.9 \( \times 10^5 \) kg to as much as 1 \( \times 10^{10} \) kg of boron per year, much of which is boron which was previously moved into the atmosphere from the seas by natural processes (see Vol.3 PD4 – Sections 5.3 and 6.4 to 6.6).
Figure 2: Boron Mass Flow Schematic

All values are in kilograms.
Solid lines represent quantified flows, dotted lines represent known but unquantified flows.
5.4 Conclusions

It would be unscientific to draw anything more than broad conclusions from the data. The mass of boron in the crusts can be seen to be extremely large, but the data used to generate these figures are so speculative that the magnitude of boron in the crusts could vary by a factor of ten in either direction, a range that is larger than the sum of all the other reservoirs. The data for the continental and oceanic crusts are useful, however, in that they show that these systems are so large that the earth’s surface can, in fact, be considered a homogeneous mass. Borate deposits are substantial, but they are in the region of being of a magnitude one hundred million times less than in the crusts as a whole.

It must be recognised at all times when evaluating these mass values that there are insufficient data to define mass values with errors of less than ten percent. The mass of boron present in any given reservoir is obtained by multiplying together the mass of the reservoir and the concentration at which boron is present in this reservoir. Errors are brought into these calculations where accurate data for either, or both, these variables are not available.
6. Closing Remarks

The four main projects in this portfolio – exploring the case for mining and sustainable development, the development of key corporate environmental performance indicators for sustainable mining companies, the management of sustainable operations, and the regulation of minerals and metals – have explored the relationship between sustainable development and the mining industry. The two central theses were that:

1. Mining can be compatible with sustainable development, but
2. Sustainable development has profound implications for the management of mining.

Both theses are supported by the findings of the research projects. In the first instance, Project Document 1 has found that mining can be compatible with sustainable development, in principle, and concurs with the Natural Resources Canada (1995) and Shinya (1998) thesis that for mining sustainable development requires successful engagement along three dimensions – economic, social and physical (see Vol.1 PD1).

An industry that is in principle compatible with sustainable development is not necessarily in deed compatible with sustainable development. This hypothesis is supported by the findings of Project Documents 2, 3 and 4. Mining operations need to measure and communicate their performance in new ways as a basis for targeting areas where performance can be improved. The case studies in Project Document 2 underlined this point when they showed that currently reported performance may be improving whilst underlying performance is deteriorating (see Vol.2 PD2). This is especially the case when considering off-site impacts directly related to on-site performance.

Project Document 3 highlighted the danger of taking the Natural Resources Canada (1995) argument that sound environmental management and energy efficiency will lead to a sustainable operation too literally (see Vol.3 PD3). Sound environmental management goes beyond having a sound formal environmental management system in place. It requires a life-cycle approach, as intimated by the case study comparing the impacts from processing operations with those from downstream distribution impacts. Even implementing formalised environmental management systems provides a remarkable shift from compliance to improvement based management, but taking a sustainable development approach to decision making, in this instance, will require a shift in approach that goes beyond even continuous improvement.

Furthermore, through Project Document 4, this research has shown that the changes in approach to decision making in a sustainable mining industry go beyond even the mining companies themselves (see Vol.3 PD4). A more complete understanding of the nature of mined products is needed to avoid inappropriate classification of minerals and metals as synthetic chemicals and regulated as such. It would be unfortunate indeed if the mining industry takes to heart its responsibilities under sustainable development and endeavours to change the decision making approach it takes, only to find that society is unable to realise the benefits the operations bring because they have banned the products.
This research has found its place in the field of environmental technology, but has also identified areas where more work needs to be done in the future, particularly through intra-industry collaboration on sustainable development issues, the development of indicators that reflect progress towards sustainable development goals, dialogue with the public on the role and nature of mined products as well as the role of mining operations, and a shift in emphasis from compliance with regulations to engagement in legitimate stakeholder issues. The recently launched Global Mining Initiative (see Rio Tinto 1999d) may provide the platform to allow such progress to be made. The responsibility is now with the mining industry to play a full part in sustainable development.
THE RELATIONSHIP BETWEEN MINING AND SUSTAINABLE DEVELOPMENT

PROJECT DOCUMENT 1
(Vol.1 PD1)

June 1998
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1 Global Mining Organisations and Sustainable Development

1.1 Global Mining Organisations: Policy, Goals and Performance

Large mining companies discuss issues such as environmental stewardship, corporate responsibility, and sustainable development in a variety of ways. Anglo American, the giant South African mining corporation, states that, “There is a need for a global company with new business ventures both within South Africa and internationally to be able to point to policies and strategic goals, and to demonstrate capacity to meet its responsibilities in a sound business manner” (Anglo American Corp. 1998, page 54). Broken Hill Proprietary (BHP), the largest resources company registered in Australia, suggests that, “Our job is to provide the resources the world demands in a sustainable manner – in an economically, environmentally and socially responsible way” (Broken Hill Proprietary 1998, pages 7 to 8).

Hugh Morgan, the chief-executive of Western Mining Company (WMC), one of BHP’s Australian rivals, states that, “Sustainable development is emerging as part of our business strategy, and as a potential source of competitive advantage” (Morgan 1998), while London’s Rio Tinto argues that, “Mining, responsibly conducted, will play a fundamental role in meeting the challenge of sustainable development” (Rio Tinto 1998b, page 27). Canada’s Placer Dome recognises that, “We will be judged by performance, by how we operate mines and by what remains after mines close” (Placer Dome 1998, page 2).

But what is ‘responsible’ mining? And how might ‘sustainable development’ emerge as part of business strategy? And how can mining play a ‘fundamental’ role in sustainable development?

1.2 Aim of the Project Document

The aim in this project document is to establish whether there is a relationship between mining and sustainable development. The historical role of mining will be introduced, the possibility of limits to economic growth explored, and definitions of terms like sustainability and sustainable development examined. This project document aims to examine whether there are circumstances where an ultimately physically unsustainable activity such as mining can be seen as compatible with principles of sustainable development.
1.3 Sustainable Development and Mining

The objective of this section is to explore what sustainable development means in the context of the mining industry. This will provide a platform for later exposition on environmental performance indicators (see Vol.2 PD2). Wehrmeyer and Tyteca (1998) point out that, “Many sustainable development indicators, particularly from local communities but also from industry, have been developed without due consideration of the underlying definitions of sustainable development. Putting the cart before the horse has not helped the clarification.” (Wehrmeyer & Tyteca 1998, page 116)

1.3.1 The Aspirational Goal

In December 1987 the General Assembly of the United Nations acknowledged that, “Despite considerable advances in dealing with the problems of health and human settlements, the environmental basis for improving the situation is deteriorating. Inadequate shelter and basic amenities, rural underdevelopment, overcrowded cities and urban decay, lack of access to clean water, poor sanitation and other environmental deficiencies continue to cause widespread disease and death, ill health and intolerable living conditions in many parts of the world. Poverty, malnutrition and ignorance compound these problems” (General Assembly of the United Nations 1987, paragraph 48).

The General Assembly proposed that, “The overall aspirational goal must be sustainable development on the basis of prudent management of available global resources and environmental capacities, and the rehabilitation of the environment previously subjected to degradation and misuse” (General Assembly of the United Nations 1987, paragraph 2).

The most widely disseminated definition of sustainable development is that proposed by the World Commission on Environment and Development (WCED) in 1987, frequently referred to as the ‘Brundtland Definition’ after the chair of the Commission, Gro Harlem Brundtland. The WCED define sustainable development as, “Meeting the needs of the present without compromising the ability of future generations to meet their needs.” (World Commission on Environment and Development 1987, page 43)

1.3.2 Mining and Empires

To understand the implications of this kind of philosophy for global mining organisations, it is necessary to understand how this philosophy has come about.

The history of mining is as old as ‘history’ itself. Warren (1973) records that Ancient Egyptians quarried turquoise and copper ores in Sinai, and the gold of Punt and Ophir supplied Egyptian needs and those of Old Testament Israel (see Warren 1973, page 1). In Ancient Greece Herodotus (see de Selincourt, 1954) notes in ‘The Histories’ the wisdom of Themistocles who persuaded Athens after the battle of Marathon (with Persia) to use the
revenue from its silver mines in Laurium to fund a ship-building programme (see de Selincourt 1954, page 463). According to Thucydides (see Warner, 1954), picking up in ‘The Peloponnesian War’ where Herodotus leaves off states, “It proved that the fate of Hellas depended on her navy,” (Warner 1954, page 79) when the Athenians defended themselves from a subsequent Persian attack by naval superiority. When hostilities finally broke out between Athens and Sparta, the Spartans realised that the mines at Laurium were so significant that they must be prised away from Athens if they were to be victorious (see Warner 1954, page 469).

One of the most bloody conquests in history, that of the Spanish Conquistadors over the Incas in South America, has its origins in mining. In 1526 Sebastian Cabot departed for South America from Spain after hearing various rumours from previous expeditions of great riches to be found there. According to Metraux (1965), on arrival he encountered survivors of a Portuguese ship-wreck at Santa Catarina who assured him that,

“If he sailed up the River Plate, even if his ships were larger, he would easily fill them with gold and silver, for the Parana and the streams flowing into it led to a mountain that the Indians were in a habit of visiting, where there were many kinds of metal and much gold and silver as well as another metal whose properties were unknown to them” (Metraux 1965, pages 8 to 9).

Although Cabot’s expedition to find such a mountain failed, the Spanish returned, in force, and by 1572 had slain five successive Incas: Atahualpa, Manco Capar, Sayri Tapac, Titu Cusi, and finally Tupac Amaru. With the death of Tupac Amaru came the final conquest of the Incas and the riches of South America fell to the Iberians. According to Metraux,

“The conquest destroyed the social and economic order of the Inca Empire... The most terrible form of mita1, the one that came to symbolise for the Indians all the horror of foreign domination, was in the mines. One seventh of the whole population of Peru, from Cuzco to Tarija, worked in relays in the Potosi mines, some 15,000 feet above sea-level, and in the mercury mines” (Metraux 1965, pages 162 to 163).

The Spanish disregarded all the laws the Inca had set up to protect the miners, they kept villagers away from their homes for long periods, they with-held wages, they imposed impossible work loads – each miner had to haul twenty-five sacks of ore, each weighing over one-hundred pounds, in a twelve-hour shift – all after a journey of up to three months for the villagers up to the mines. As Metraux observes, “The Potosi became a voracious monster, devouring the Indian population” (Metraux 1965, page 163).

The impact upon nations from appropriating these, and other, natural resources were huge. As Jevons is reported as declaring for Great Britain in 1865,

“The plains of North America and Russia are our corn-fields; Chicago and Odessa our granaries; Canada and the Baltic are our timber forests; Australasia contains our sheep-farms; and in Argentina and on the western prairies of North America are our herds of oxen. Peru sends her silver and the gold of South Africa and Australia flows

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1 The mita was the obligatory labour that all subjects owed to the Inca. The Spanish quickly turned this system to their advantage.
to London; the Hindus and the Chinese grow tea for us, and our coffee, sugar and spice plantations are all in the Indies. Spain and France are our vineyards and the Mediterranean our fruit garden, and our cotton grounds, which for long have occupied the Southern United States, are now being extended everywhere in the warm regions of the world.” (see Hyam, 1975, page 47)

### 1.3.3 Limits to Growth?

Jevon’s wrote his triumphant prose at a time when the population of Europe, according to Kennedy (1993), was growing at a phenomenal rate – from around 100 million in 1650 to beyond 200 million by 1800 (see Kennedy 1995, page 8) – matched by demand for food, clothing, heat, and shelter. One of the most enduring debates concerning human perfectibility has its origins in this era. At around the turn of the 18th into the 19th century, optimists such as Godwin and Condorcet were arguing along the lines that,

> “While things were troubled at the moment, the growth of human understanding, the capacity for self-improvement, and breakthroughs in knowledge would one day lead to a society that was much more equitable, free of crime and disease, free even of war” (Kennedy 1994, page 5)

In response to such optimism came Thomas Robert Malthus’ ‘Essay on the Principles of Population as It Affects Future Improvement of Society’ (1798), which argued along the lines that, by contrast, population growth meant that the human condition would worsen, with the existing gap between the “haves” and the “have-nots” exacerbated by the pressures upon the earth’s resources. (See Kennedy 1993, ibid.)

This debate has resurfaced in modern times, largely as a result of the work of Meadows et al (1972), whose work is widely referred to as ‘The Limits to Growth Theory’. This theory was articulated by MIT’s Meadows et al. based on their findings using a large-scale computer model to simulate likely future outcomes of the world economy (See Figure 1).

Tietenburg (1992) explains that they reached 3 main conclusions:

1. There are limits to growth presented by resource exhaustion, terminal pollution, and overpopulation.
2. Removing one limit will simply cause the system to hit another one.
3. Overshoot and collapse can only be avoided by an immediate limit on population and pollution, as well as a cessation of economic growth.
Figure 1: Basic world dynamics model behaviour showing the mode in which industrialisation and population are suppressed by falling natural resource, after Randers and Meadows (1971)

These conclusions have considerable significance, so perhaps some elaboration is required to explain how they were reached. On the first conclusion, Tietenburg explains that,

“In a time span of less than 100 years with no major changes in the physical, economic or social relationships that have traditionally governed world development, society will run out of the non-renewable resources on which the industrial base depends. When the resources have been depleted, a precipitous collapse of the economic system will result, manifested in massive unemployment, decreased food production, and a decline in population as the death rate soars. There is no smooth transition, no gradual slowing down of activity; rather the economic system consumes successively larger amounts of the depletable resources until they are gone” (Tietenburg 1992)

On the second conclusion, Randers and Meadows (1971) show that if a 75% reduction in resource use through more effective technology is introduced in 1971 with no change in the material standard of living, there will be a pollution induced disaster instead of a resource exhaustion induced disaster as the absorptive capacity of the environment is passed. Fish stocks and crop returns decline, while food, water and air contamination occur – the result being collapse. If in 1971 a 50% reduction in pollution generation occurs along with a reduction in the capital investment rate to offset a decline in quality of life, together with the previous 75% reduction in resource use, then disaster occurs though population growth – 20 years later than the pollution scenario, but the disaster still happens eventually (See Figure 2).
Randers and Meadows conclude that,

“If we attempt to continue growth by removing one set of pressures, for instance by introducing complete pollution control – we alleviate the situation only until we encounter the next constraint. And so on. Because the environment is finite, physical growth will always bring us into conflict” (Randers & Meadows 1971).

1.3.4 The Role of Technological Innovation

The ‘limits to growth’ is a powerful argument to constrain economic growth, perhaps. However, there is no shortage of arguments in favour of economic growth, or rather, against the theory of limits to growth. For example, Solow (1973), puts it in these terms,

“The basic assumption is that stocks of things like the world’s natural resources and the waste disposal capacity of the environment are finite, that the world economy tends to consume the stock at an increasing rate (through the mining of minerals and the production of goods) and that there are no built-in mechanisms by which approaching exhaustion tends to turn off consumption gradually and in advance” (Solow 1973).

Solow argues that this fails to take account of the price system, whereby a fall in supply relative to demand would act to increase price. Solow suggests that,

“As the earth’s supply of a particular natural resource nears exhaustion, and as natural resources become more and more valuable, the motive to economise those resources should become as strong as the motive to economise labour” (Solow 1973).
Coombs et al (1987) explain the significance of technical change, held constant in the limits to growth theorem, thus,

"In neo-classical models of economic growth a production function can be defined for the whole economy: \( Q = f(L, K) \). This production function fixes the maximum output \( Q \) which can be obtained with given levels of inputs, \( L \) labour and \( K \) capital."

(Coombs et al 1987, pages 140 to 142)

They preferred to think in terms of \( Q = f(L, K, t) \) where \( t \) represents time. The variable \( t \) allows for technical change, which provides a shift in the production function — a higher level of maximum output at the same inputs of capital and labour, or the same level of output at lower levels of capital and / or labour.

This is not a minor argument against the resource exhaustion argument in the limits to growth theorem. The two most regarded economists concerned with the implications of technical change are Schumpeter (1934; 1943) and Schmookler (1966). The arguments with which they have become most widely associated are, respectively, 'technology-push' and 'demand-pull'. In his early work Schumpeter was concerned with long term growth and placed an emphasis on the role of entrepreneurs as innovators or implementers / marketers of innovations. The reward for entrepreneurs in overcoming resistance from a sceptical market and society is temporary monopoly profit. Later, as Schumpeter realised that the high capital costs of innovation were a barrier to technical change, he placed an emphasis on the role of large institutions with higher financial resources at their disposal. Schmookler, however, is best known for his argument that the market and society were the force behind innovation — based on his study of investment cycles and economic peaks and troughs, he found that upswings in inventive activity responded to upswings in demand, rather than the reverse.

The implication of the works of Schumpeter and Schmookler, however, is that technical change can have a strong role to play in resource consumption. If innovative enterprises detect monopoly profits are available in resource-efficient products and processes, then Schumpeterian theory would suggest that there will be technical change in this direction. Alternatively, if society demonstrates a high demand for resource-efficient products and processes through the price system, then Schmooklerian theory would suggest that there would equally be change in this direction. The same would be true for pollution, or food production and thus the arguments of Meadows et al. could fail, or at least be almost indefinitely postponed.

The work of Herman Daly is instructive in this area. Daly (1992) points out,

"We can conceive of technology as a sort of anti-body to the pollution and depletion germs. Ultimately, we conclude that depleting and polluting activities (production and consumption) can continue to grow exponentially, because we have a problem solving anti-particle, technology which can also grow exponentially.” (Daly 1992)

Daly introduces the views of Royall, who stressed that,

"Sheer ‘knowledge’ means nothing for the world system until it enters one of the other constituents and the tacit assumption that all technical knowledge necessarily enters as a good is unwarranted. Is the technical knowledge that performance of
gasoline engines can be improved by adding tetraethyl lead to their fuel a ‘good’?”
(Royall 1972)

1.3.5 Understanding Sustainability and Development

By the time the Brundtland report was published in 1987 this debate had been complemented by an additional discussion concerning the inter-relationship between ecological sustainability and socio-economic development. O’Riordan (1985) had described sustainable development as a contradiction in terms, taking development to be synonymous with growth in material consumption, a trend that as has been illustrated by the arguments of Meadows et al, and Malthus before them, as being incompatible with ecological sustainability in the long term.


“There is now a growing consensus that many environmental problems in developing countries originate from the lack of development, that is from the struggle to overcome extreme conditions of poverty, that environmental degradation impoverishes those dependant directly on the natural environment for survival, and conversely, that development must be environmentally sound if it is to be permanent. Thus, environmental quality and economic development are interdependent and in the long term mutually reinforcing, and the question is no longer whether they contradict each other but how to achieve this (environmentally) sustainable (form of) development” (Lele 1991, page 612).

Lele illustrates his position with the following map:

**Figure 3: The semantics of sustainable development** (from Lele 1991, page 608).

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As can be seen, Lele concurs with the O'Riordan view that sustainable growth is not a useful interpretation of sustainable development, but suggests that if sustainable development is interpreted as encompassing ecological and social sustainability, within a development framework which emphasises meeting basic human needs, then it is a useful concept. However, having identified that there are ecological and social elements to sustainability, there followed wide differences in interpretation in the literature after the publication of the Brundtland Report concerning the relationship between ecological factors and social factors.

1.3.6 Sustainability Rules

Daly (1990) suggests that sustainable development (as distinguished from sustainable growth) requires:

1. That harvest rates should equal regeneration rates
2. That waste emission rates should equal the natural assimilative capacities of the ecosystem into which the wastes are emitted.

I.e. the ecosystem provides two basic functions: resource provision and waste management. These ‘regenerative and assimilative’ capacities represent the ecosystem’s ‘natural capital’. Ekins and Simon (1998) suggest that in fact there are three functions – with the third being “basic ‘environmental services’, including ‘survival services’ such as those producing climate and ecosystem stability... and ‘amenity services’ such as the beauty of the wilderness and other natural areas” (Ekins & Simon 1998, page 149).

Subsequently Daly refined this requirement with Serageldin and Goodland (1994) to provide criteria for environmental sustainability:

- Output Rule: Waste emissions from a project should be within the assimilative capacity of the local environment to absorb without unacceptable degradation of its future waste absorptive capacity or other important services;
- Input Rule 1: Harvest rates of renewable resource inputs would be within the regenerative capacity of the natural system that generates them;
- Input Rule 2: Depletion rates of non-renewable resource inputs should be equal to the rate at which renewable substitutes are developed by human invention and investment.

Daly focussed on the ecological elements of sustainability because he believed that human made capital (the tools of transformation, i.e. the capital derived from human technical and social knowledge and values) could not be substituted for natural capital, preferring instead to think of them as complementary. Daly (1995) uses the analogy of a forest (natural capital) and a saw mill (human capital) to illustrate the point. He asks, “What good is a saw mill without a forest?” (Daly 1995, page 51) Earlier Daly (1990) had argued that development is limited by the stock of capital in shortest supply, and that natural capital is rapidly becoming the limiting factor (see Daly 1990, page 4).

Beckerman (1994) however, suggests that in fact there are examples where human capital can be substituted for natural capital. He suggests that labour is complementary to machinery
where it is an input into the production of machinery, but a potential substitute for machinery in the production of something else. Holland (1997) argues that whether or not one believes that substitution between human and natural capital is possible depends on the degree of precision which is demanded. His example concerns apples. He suggests that,

“If it is nutritional properties we are interested in, then one apple may be as good as another. But if we are concerned about flavour, then we may think that there is no substitute for a Cox's Orange Pippin. ... One item is usually regarded as a substitute for another if it is sufficient for the purpose” (Holland 1997, pages 122 to 123).

Taking the example further, then, if our purpose is nutrition, then a human-made alternative to fruit – developed through application of human capital – could be sufficient for purpose.

Before attempting to side with one position or the other, it is necessary to consider the practical aspects of substitution. If one's objective is to leave future generations with prospects at least as good as our own, then it seems reasonable to take the view that the overall stock of capital must not be diminished. Regardless of whether one sides with those that believe in substitution of human capital for natural capital or not, some sort of decision tool is needed; i.e. how much human capital represents an acceptable substitute for a given unit of natural capital, or how much natural capital of one kind might be needed to offset losses of another kind (if dolphin populations are dropping, but pine forests are on the increase, is this a net gain or loss in natural capital?)

1.3.7 Enter the Philosophers

To consider the nature of the response to the challenge of maintaining the stock of capital available to future generations, it is essential to understand the philosophical foundations of any response. Specifically, deontological and teleological perspectives will be considered.

1.3.7.1 Deontology

Deontology determines actions to be either right or wrong in themselves, regardless of the outcome of the actions. In other words,

“It is solely in the virtue of being an activity of a certain kind that the action is right or wrong ... Consequences play no part in deciding whether or not an action is right or wrong” (Chryssides & Kaler 1993, page 88).

The approach of philosophers like Immanuel Kant was to use absolute rules for morality. Acton (1970) states that,

“The various rules of Morality are based upon a Moral Law that is pure and a priori. It is pure in that it does not contain concepts borrowed from experience of the world and based upon natural inclinations, and it is a priori in that it is necessarily valid always and for everyone” (Acton 1970, page 60).

This approach divorces action from experience and consequence. Either an action, in itself, is right, or it is not. Kant defined this approach in terms of ‘the categorical imperative’, the supreme principle of morality. For an action to be accepted as ethical, according to Kant, it had to be universal, i.e., “Act only according to the maxim by which you can at the same time will that it should become a universal law” (Acton 1970, page 28)
If one takes the following categorical imperative from Kant, “Act so that you treat humanity, whether in your own person or that of another, always as an end and never as a means only” (Scruton 1982, page 70) and apply it to the biosphere, then one must, ‘Act so that you treat the environment, whether in your own person or that of another part of the environment, always as an end and never as a means only.’

1.3.7.2 Teleology (Utilitarianism)

The thesis of utilitarianism is that, “It is the usefulness of actions which determines their moral character rather than anything in the nature of the action itself” (Chryssides & Kaler 1993, page 91).

Mill suggested that usefulness should be interpreted in terms of pleasure and that, “Pleasure and freedom from pain are alone desirable as ends; all desirable things are therefore desirable either for the pleasure inherent in them, or as a means to the promotion of pleasure and the prevention of pain” (Mill 1988, page 26). Bentham preferred to think that “Utility is one thing only, it is happiness.” (see Chryssides & Kaler 1993)

Utilitarians suggested that the concept of happiness should apply at the level of society. In other words, as Chryssides and Kaler explain, “We should aim for the greatest happiness of the greatest number. In this our own happiness should have no priority. If our own happiness can only be enhanced by diminishing the total sum of happiness, then it must be sacrificed for the greater happiness” (Chryssides & Kaler 1993, page 91)

The hedonistic response to these philosophies can be referred to as ethical egoism. In other words, the only happiness that an individual can measure is their own, and therefore, they will act to maximise it. As Margaret Thatcher has been quoted as saying, “There is no such thing as society - just individuals and their families”. The writing of Adam Smith has often been credited with providing an early definition of the benefit of such an approach. Smith (1776) suggested that, “Every individual is continually exerting himself to find out the most advantageous employment for whatever capital he can command. It is his own advantage indeed, and not that of society, which he has in view. But the study of his own advantage naturally, or rather necessarily, leads him to prefer that employment which is most advantageous to the society.” (Smith 1776, Chapter II, Book IV)

The thesis of this philosophy is that if every individual focuses their energies towards areas where their comparative advantage is greatest, and utilise resources as efficiently as possible in pursuit of individual profit, society as a whole must benefit.

Applying these perspectives further then, from a decision making standpoint, it can be seen that both those in favour of maintaining natural capital and those in favour of maintaining total capital through substitution where necessary have a Utilitarian basis for their actions. In
both instances, the long term basis for action is sustainable development of humanity, through prudent management of available capital. While it is clear that the preservation of natural capital is more consistent with Deontology than the more anthropocentric view that substitution is possible, the key difference is not philosophical - it is practical.

1.3.8 Enter the Economists

A practical application of utilitarianism is economics, defined in Spurling (1986) as “The allocation of scarce resources... It deals with the ways in which human beings obtain resources, the ways in which they make decisions about production and the ways in which these products are distributed to consumers” (Spurling 1986, page 9). The principle behind economics is that of utility maximisation. The higher the utility, as Douglas (1987) puts it, the greater “the psychic satisfaction, or feeling of well-being that a consumer derives from the consumption of goods and services” (Douglas 1987, page 71)

1.3.8.1 The Free Market?

There are different views on how decisions concerning production and distribution should be made, but the most widely used framework is capitalism. This system is based on the principles of Adam Smith described earlier and is based on the free workings of a market based on supply and demand. If a good is desirable, then it follows that people are willing to pay for that good. If supply cannot meet demand then there is scarcity, and that scarcity creates competition. The consumer who is willing to pay the highest price (reflecting the utility it represents) will get the scarce good. The profit to the supplier represents the price paid by the consumer less the costs of production.

If such a framework is so popular, then why did the United Nations General Assembly make its observation that despite considerable advances in dealing with the problems of health and human settlements, the environmental basis for improving the situation is deteriorating? (see General Assembly of the United Nations 1987, paragraph 48).

The first reason is that there are some resources which do not have an economic price attached. For example, how would the pollution absorbing capacity of the environment be priced? Who pays for pollution? There are some goods that, under a free market economic system are used by all but paid for by no-one. Which leads to the second difficulty with capitalism. Little account is taken of future generations in the equation. Unrestrained use of resources and destruction of those resources which have no economic value at this present time, and the use of resources which do not have to be paid for at this present time, is unsustainable in the longer term. Smith (1984) argues,

“In its uncontrolled drive for universality, capitalism creates new barriers to its own future. It creates scarcity of needed resources, impoverishes the quality of those resources not yet devoured, breeds new diseases, develops a nuclear technology that threatens the future of all humanity, pollutes the entire environment that we must all consume in order to reproduce, and in the daily work process it threatens the very existence of those who produce the vital social wealth” (Smith 1984, page 59)
Those who believe the environment should be protected from an anthropocentric perspective feel that actions must not be assessed in terms of the consequences they have for the individual carrying them out, or in terms of the other members of the society of which they are part at the time. Consideration must be given to those generations that will come after a decision is taken, and who may well be the generations who have to carry the costs associated with an action carried out now.

Norgaard (1995) suggests that sustainability is, “A matter of equity, the distribution of rights between generations, not a matter of the efficient use of resources” (Norgaard 1995, page 152). The problem is articulated by writers such as O’Riordan (1991), who stresses that capitalism, “Draws more from the environment than it returns yet does not pay for the loss of that environmental capital” (O’Riordan 1991, page 13). An alternative to the present free market system that requires continuous economic growth to function, is the possibility of sustainable development. Repetto (1986) refers to, “A development strategy that manages all assets: natural resources, and human resources, as well as financial and physical assets, for increasing long term wealth and well being. Sustainable development, as a goal, rejects policies and practices that support current living standards by depleting the productive base, including natural resources, and that leaves future generations with poorer prospects and greater risks than our own.” (Repetto 1986)

1.3.8.2 The Flawed Market?

The implication is that capitalism is inherently at odds with sustainable development. There is, however, a substantial body of thought to support the view that it is not capitalism, per se, that is at odds with sustainable development, rather that societies have failed to ensure that capitalism functions effectively. Hanley et al (1997) refer to five different types of failure in markets under the capitalist model which could compromise sustainable development:

1. Incomplete markets
2. Externalities
3. Non-exclusion and the commons
4. Non-rivalry and public goods
5. Asymmetric information (see Hanley et al 1997, pages 22 to 57)

1.3.8.2.1 Incomplete markets

According to Hanley et al (1997) markets can be identified as incomplete when institutions have failed to establish well-defined property rights. Examples include rivers or the air – which are not generally owned by private individuals. Thus, it would be difficult for people living downwind from an industrial facility to halt any harm done to them by the plant in a free-market. Simply, the plant operator does not bear the down-wind costs, so he ignores them (see Hanley et al 1997, page 25). However, Coase (1960) has argued that this problem can be overcome if a third party in such a dispute could introduce property rights (which could be assigned to either party). This would introduce the principle of supply and demand (for clean
air). A socially optimal level of pollution will establish itself which reflects the balance of supply and demand (i.e. the amount the polluter is able to pollute at the price per unit pollution he is willing to pay the affected parties, or the amount of clean air the affected parties are able to buy at the price per unit clean air they are willing to pay the polluter).

1.3.8.2.2 Externalities

Pearce and Warford (1993) describe an externality as “Any impact on a third party’s welfare that is brought about by the action of an individual and is neither compensated nor appropriated” (Pearce & Warford 1993, part II) An example of an external cost could be pollution from a paper mill that damages fish stocks downstream, with a result in lost commercial and recreational fishing. If the paper mill pays no compensation, then society suffers an overall loss of welfare compared with a desirable or optimal level of welfare. However, Pearce and Warford argue that market based instruments, such as tradable permits, could be used to resolve the problem of externalities. Under this arrangement, a limit to the amount of pollution would be set by society, and a market set up for the rights to this pollution. In the case suggested, if the paper mill wished to carry on polluting, it would need enough permits to do so, if the fisherman wished to prevent that pollution, they would have to be willing to pay more for the permits than the mill.

1.3.8.2.3 Non-exclusion and the commons

This issue was set out clearly and starkly by Hardin (1968). In this case, the ‘commons’ are ‘common property resources’ where no single individual has control over the use of, or access to, a particular resource, with a result in over-use. Using Daly (1990) again, a renewable resource such as a fish stock is only sustainable if harvest rates do not exceed regeneration rates. Fish must not be harvested at a greater rate than fish regeneration. However, under a capitalist model, since more fish caught by one party implies less fish for all others, all fishermen or women (according to Hanley et al. 1997) have an incentive to increase their fishing effort beyond the point where the market price for the fish equals the marginal cost of harvesting (see Hanley et al 1997, page 39).

However, examples do exist illustrating how such difficulties could be addressed. In the Scottish crofting counties access to grazing land is essential to success for crofters. A system of common grazing exists on hillsides and mountainsides. However, to avoid the risk of over-grazing, crofters must be registered, and a maximum number of cattle or sheep that may be placed on any one hill by any one crofter is imposed by a crofter council which exists for a small geographic grouping of crofts (see Hanley et al 1997, pages 37 to 39).

1.3.8.2.4 Non-rivalry and public goods

There are also market failures associated with goods where one person’s benefit or loss from a function does not restrict the benefit or loss to others. These are the public goods and bads – such as the beauty of country-side and the role that forests play in erosion resistance – as well as the public nuisances such as noise. The aesthetic pleasure one citizen enjoys from beautiful
scenery is not ‘owned’ by that individual, and will not prevent another individual from getting the same pleasure from the same view without any loss to the first individual. This leads to ‘free-riding’ where goods are undervalued by the market because individuals conceal their preferences in order to avoid paying for them.

1.3.8.2.5 Asymmetric Information

Asymmetric information means that one individual in a transaction does not have complete information about the other. An example would be where the seller of a product has more information about the likely harm that will arise from the product than the buyer. Harm to the environment can occur when the resulting price does not fully reflect the costs that the buyer will have to bear in relation to the use of that product. This is a form of market failure that leads to inefficient allocation of resources.

Does this mean, then, that if the difficulties described above could be overcome, then sustainable development could result? If the market could be made to function perfectly, then prices would be found which fully reflected the value of environmental services such as life support and which fully reflected the cost of pollution and resource use. Wouldn’t this, then support Solow’s view that while individual resources are limited, the process of the market would ensure, as Chryssides and Kaler (1993) put it,

“When human-kind is about to fell its last tree, that tree, being such a scarce commodity, would have become so expensive that it would have priced itself out of the market in favour of some substitute material, such as metal or plastic?”

(Chryssides & Kaler 1993, page 458).

1.3.9 Buying Out of Trouble (Economic Growth and Sustainable Development)

1.3.9.1 Investing in the Future

In the UK Government’s 1998 Consultation Paper for Sustainable Development, ‘Sustainability Counts’, the Government’s first headline indicator of sustainable development was economic growth, expressed in terms of gross domestic product (GDP), arguing that, “Growth in gross domestic product is a direct measure of the central economic objective. Economic growth is necessary to generate new job opportunities; to ensure everyone can share in high living standards; and to pay for the investment required to deliver continuing improvements in the economy and social progress” (Department of Environment Transport and the Regions 1998)

Is this view supported in the literature? On the UK Government’s last point, concerning economic growth paying for investment in economic and social progress, it may be instructive to consider the work of Simon Kuznets, whose work was concerned with income distribution. He developed a model which related per capita income and the degree of inequality in the distribution of income. It hypothesises an ‘inverted-U’ relationship in which inequality at first increases during the course of economic growth, and then decreases (see Abler 1999). In other words, GDP growth ultimately translates into per capita GDP growth across society. This was applied subsequently to the environment – whereby the relationship between per capita
income and environmental degradation was proposed to follow a similar ‘inverted-U’ shaped path. (Figure 4) Thus rising GDP would translate into a decline in environmental degradation once that GDP growth had translated into per capita GDP growth beyond a theoretical ‘turning point’.

**Figure 4: Environmental Kuznets Curve**

![Environmental Kuznets Curve](image)

The theoretical basis for the Environmental Kuznets Curve is that of derived demand for pollution. As per capita income increases, people consume more goods and services, leading to an increase in the release of pollutants associated with the provision of these goods and services, together with an increase in pollution associated with the use of these goods and services (automobile pollution, power station emissions etc). In other words, while there is no direct demand for pollution in itself, a priori, there is a demand for the goods and services that have pollution as a co-product. However, as per capita income increases, the demand for environmental quality by society increases by a greater than proportional amount (through environmental policies and through increasingly stringent legislation). The turning point occurs when the demand for environmental quality equals the derived demand for environmental pollution (See Figure 5)

Empirical support or opposition to the theoretical turning points is mixed. Cavenay (1998), argues that in the petroleum industry, “Companies are reducing emissions from their own operations, both in response to regulations and through voluntary programs. One company alone cut emissions by more than one million tonnes of carbon these last three years. Gasification technology has been developed to turn feedstock like coal, coke and heavy oil into clean synthetic gas, significantly reducing emissions. Companies are becoming more energy efficient – one company reduced fuel use at seven US refineries by 25% these last 15 years - and companies are investing in the development of the next generation of fuel and vehicle technologies, such as fuel cells, which hold great promise for improvements in energy efficiency and emissions reductions” (Cavenay 1998)
However, according to the Sierra Club (1999), “For some air pollutants ... emissions levels don’t follow an inverted U-curve, but follow an S-curve which starts to rise again as incomes rise. For instance, sulphur dioxide emissions start to rise above [per capita income] of $14,000. The implication is that efficiency gains from improved technology at medium levels of per capita income are eventually overwhelmed by the growing size of the economy” (Sierra Club 1999)

1.3.9.2 Flaws in the System of National Accounts

There is a second issue concerning GDP and sustainable development, aside from the debate over whether rising GDP will allow a community to develop a more sustainable path, and that relates to the use of GDP itself. A number of authors have wrestled with this issue. Hanley et al (1997) express consternation that

“A country can fell its forests, erode its soils, exhaust its minerals, pollute its aquifers and erase its wildlife, without adversely affecting its national income. By failing to recognise the asset value of natural resources, the UN System of National Accounts (UN SNA) misrepresents the policy options which nations face. Although the model balance sheet in the SNA recognises land, minerals, timber and other environmental resources as economic assets to be included in a nation’s capital stock, the SNA’s income and product accounts do not. This mismatch can hide permanent losses of wealth beneath an illusion of gains in income” (Hanley et al 1997, pages 434 to 435)

This is the crux of the issue. Any argument in favour of using changes in national income as an indicator of changes in environmental conditions only has merit if rising national income can be shown to correspond to rising environmental quality. As Daly and Townsend (1993) put it,

“In the minds of many people, growth has become synonymous with increase in wealth. They say that we must have growth to be rich enough to afford the cost of cleaning up and curing poverty. That all problems are easier to solve if we are richer
is not in dispute. What is at issue is whether growth at the present margin really makes us richer. There is evidence that in the US it now makes us poorer by increasing costs faster than it increases benefits. In other words, we appear to have grown beyond the optimal scale” (Daly & Townsend 1993)

Van Dieren (1995) outlines the flaws in the use of national accounts in modern society. He argues that

“Until 1945, the notion of economic growth was used differently from today. .. It was not until about 1932 that several economists came up with the idea of measuring a country’s economic performance and not until 1950 that the ensuing system was introduced in most industrialised countries. It was thus inevitable that the costs of production growth would be encountered, costs that for decades the theory had termed negative external effects. In former times these effects had been happily accepted, but when production as a whole is encapsulated in a profit-and-loss account, the costs, or negative expenditure, automatically appear on the balance sheet. And that is where we stand today.” (Van Dieren 1995)

Whitworth (1996) puts the argument very clearly,

“Imagine a factory that produces $1 million worth of goods in a year. This $1 million will be added to Gross Domestic Product. However, it also produces pollution that costs $250,000 to clean up every year. If the factory had to take responsibility for cleaning up its mess, then this figure would be deducted from the factory’s profits. However, the $250,000 of cleaning up is added to GDP. Any business that attempted to calculated its profitability in this way would soon grow bankrupt. Similarly, no account is taken of asset depreciation such as the use of non-renewable resources. The more wasteful we are, the more GDP rises” (Whitworth 1996).

1.3.9.3 Parallel Environmental Accounting, Index of Sustainable Economic Welfare and the Green Development Index

Perhaps unsurprisingly a number of individuals and groups have proposed alternatives to the current system of income accounting to better reflect the environmental consequences of socio-economic activity. They vary in scope from incremental change to step change. An early attempt to document Parallel Environmental Accounting (PEA) was by Alfsen et al (1987) for a project in Norway to extend the scope of National Accounts. PEA extends traditional economic accounts to cover natural resources such as minerals, oil, and even air and water. At a slightly more radical level, in 1989 in ‘For the Common Good’, Herman Daly, John Cobb and Clifford Cobb proposed an Index of Sustainable Economic Welfare (ISEW), which, according to Friends of the Earth, “Corrects GDP over a range of issues such as income inequality, environmental damage, and depletion of environmental assets, to create an indicator which better measures how our economy delivers welfare for people” (Friends of the Earth 1998)

A more radical approach still, is the Green Development Index (GDI), documented in Ul-Haq (1989), which proposes a system based on components such as human freedom, income shares, educational enrolment, life expectancy, fertility, fresh-water abstraction, output
efficiency, energy consumption per capita, among others. The results of an analysis for 64 countries gave Switzerland the highest GDI, followed by Denmark, Norway, Costa Rica, and Spain. The countries which score highest in GDP, however, such as the UK, Japan, Germany and Canada, for example, came in at 23\textsuperscript{rd}, 24\textsuperscript{th}, 34\textsuperscript{th} and 52\textsuperscript{nd} respectively on the GDI ranking. The other giant economies of Russia and the USA, came in 60\textsuperscript{th} and 61\textsuperscript{st} in the list of 64 countries for GDI.

There are, then, two central issues relating to the use of measures related to GDP in relation to sustainable development. The first concerns the relationship between economic growth and the environment, and the second relates to the use of GDP specifically in an environmental indicator.

### 1.3.9.4 Limits to Economic Growth

#### 1.3.9.4.1 No Guarantees

There are a number that would argue that there are obvious physical limits to economic growth, and therefore it cannot be treated as compatible with sustainable development. Others argue while these physical limits exist, economic growth can continue, provided that efficiency improvements allow the rates at which we approach these limits to approach zero as they come near. Some forms of economic growth are clearly incompatible with sustainable development, identified by Friends of the Earth as:

- **Jobless**: growth which does not translate into jobs,
- **Voiceless**: growth which is not matched by the spread of democracy,
- **Rootless**: growth which snuffs out separate cultural identity,
- **Futureless**: growth which despoils the environment,
- **Ruthless**: growth where most of the benefits are seized by the rich.

On the other hand, there are forms of economic growth which could be seen as ‘friendly’ to the human and physical environment, those which utilise the revenues generated to invest in the development of new natural and human capital at a rate equal to or greater than the rate of consumption of natural capital - the Hartwick Rule (see Hartwick 1990) - i.e. growth which translates into jobs, is matched by the spread of democracy, celebrates cultural identity, does not despoil the environment, and where the benefits are distributed throughout society.

GDP has been shown to be a flawed expression for use in any correlation between economic growth and sustainable development. The use of contribution to GDP, as defined in the system of national accounts, as a proxy for an indicator of human and ecological progress, is most definitely not helpful, since it will, inevitably, favour only projects which have a measurable direct positive effect on national income. If these projects include air pollution, advertising for cigarettes, the destruction of forests, the production of toxic chemicals, weapons of mass destruction and so forth, then they are friends of national income, even though they are hostile to the natural and social environment.
So, will the use of economics help determine whether we are achieving our teleological objective to maximise happiness? If one attempts to correlate gross domestic product with sustainable development, then the answer is clearly no. Even if one modifies the framework currently used, and even if one attempts to address the causes of market failure, which are theoretically possible, there are still practical difficulties which may not so easily be overcome.

1.3.9.4.2 Valuing Natural Resources in Practice

For example, if in the course of its business, the mining company causes environmental damage in the form of pollution of a water body, then any penalty imposed by society for this will be deducted from turnover when calculating net income. If one considers that the cost of natural resource depletion is paid in the form of royalties to stakeholders and taxation to the government, then this aspect is also accommodated in net income. However, this assumes that the royalties determined and the pollution charges imposed accurately reflect the loss of welfare caused by the extraction of the natural resource, and the degradation in the quality of water.

In addition, the royalties and taxes paid must provide adequate compensation for issues such as noise pollution, air pollution, climate change, loss of natural habitats, land use etc which could be caused by the mining operation. In some jurisdictions, such as the State of Wyoming, the mining company must pay a bond of several million dollars to the State that they can only recover on closure of the mine if the State is satisfied that they have adequately rehabilitated the land used in the mining operation for closure. If not the State will use the bond to carry out the necessary clean up work itself. So, in addition to taxes and royalties for ongoing issues, there is also a guarantee in place to ensure the mining company cannot 'foul and flee'.

However, research reported by Kopp and Smith (1989) would suggest that there is rarely consensus on the valuation placed on natural resources or pollution incidents. For example, in 1978 it was discovered that hexavalent chromium was present in two new municipal water supply wells, 1600 feet west of the largest tailings pond for the Idarado mining and milling complex in the State of Colorado, USA. Calculating the past, present and future cost of this pollution, the mining company argued that the damage due to the contaminated aquifer corresponded to the cost of drilling new wells, approximately $205,000, while the damage due to soil contamination could be overcome by covering any affected areas with six inches of uncontaminated soil and planting grass – a procedure that would cost $275,000 – leading to a total damage assessment by the company of less than $500,000.

Meanwhile the State of Colorado, the trustee for the affected resources, calculated the costs as including building of a new water treatment plant, the amenity value of the aquifer – such as recreational fishing lost – the decline in property values etc, as over $40 million dollars. Kopp and Smith found that the main reason for this difference in valuation was that the State calculated that the damage must have commenced in 1951, while the mine assumed that there had been no past damages (see Kopp & Smith 1989, page 605).
1.3.9.4.3 Equity

However, even if this obstacle could be overcome, there are still possibly insuperable theoretical obstacles to the use of economic forces to drive sustainable development. These have been described by Welford as relating to ‘equity’ and futurity, elsewhere considered as intra-generational equity and inter-generational equity (see Gutes, 1996). These issues relate back to ethical foundation of neo-classical economics – Utilitarianism – introduced earlier. As Hodgson (1997) expresses it, “Utilitarianism side-steps the question of human needs that are not necessarily expressed in individual utility functions, the preservation of a sustainable environment for the future being a case in point” (Hodgson 1997, page 48). Pearce and Warford (1993) concur, critically suggesting that an attempt to overcome market failure through allocation of property rights “Has little or no relevance to situations in which the sufferers are future generations, since they have no bargaining power” (Pearce & Warford 1993)

On intra-generational equity, The General Assembly of the UN (1987) notes that, “The imbalance of present world economic conditions makes it extremely difficult to bring about sustained improvement in the world’s environmental situation; accelerated and balanced world development and lasting improvements in the global environment require improved world economic conditions, especially for the developing countries” (General Assembly of the United Nations 1987, paragraph 3b). (note the emphasis on economic conditions rather than economic growth). Even if one did support the Utilitarian objective of maximising total utility, there is no built-in mechanism which prevents 5% of the world population living in luxury and 95% living in poverty.

So which framework is more consistent with sustainable development then: the view that sustainable development depends on the use of natural capital to develop human capital which can ultimately be substituted for natural capital, or the view that sustainable development depends on the maintenance of natural capital?

Beckerman (1994) has said that supporting the latter view “Requires subscribing to a morally repugnant and totally impracticable objective” (Beckerman 1994, page 203). Goodland (1995) insists that “Sustainable development should integrate social, environmental and economic sustainability and use these three to start to make development sustainable” (Goodland 1995, page 4). He argues that social sustainability involves systematic community participation and strong civil society, a view supported by Barbier (1987), who defines social sustainability as “The ability to maintain desired social values, traditions, institutions, cultures, or other social characteristics” (Barbier 1987).

Thus, while there is no escaping the validity of the limits to growth argument, any framework which neglects social factors and factors relating to intra-generational equity as well as inter-generational equity is unacceptable. However, infinite substitutability is clearly not realistic either. As Ekins and Simon (1998) point out, “A moment’s reflection suggests that there are no obvious manufactured substitutes for the ozone layer, or for the varied functions of a tropical rainforest” (Ekins & Simon 1998, pages 148 to 149). Thus, perhaps the view of sustainable development is this: sustainable development must pursue economic, ecological and social objectives, with the following conditions:

*Project Document 1 - Global Mining Organisations and Sustainable Development*
- Any improvement in economic and social conditions must not undermine those ecological functions which are non-substitutable
- Any improvement in economic conditions must be achieved without undermining social conditions, such as values, traditions, institutions, cultures (equity)
- Any improvement in economic and social conditions which requires the use of non-renewable natural resources must deliver the means to substitute that natural capital with human capital.
1.4 Mining and Sustainable Development

Mining provides an informative case study which illustrates the principles discussed earlier.

1.4.1 The Contribution of Mining to the Economy

Mining makes a powerful contribution to economic growth. The Western Economic Analysis Centre has reported that America's Mining industry, with direct business revenues of approximately US$27 billion, directly and indirectly supported nearly 5 million Americans and their families, providing personal income of almost US$144 billion to US residents in 1995 (Learning 1997). In July 1999 Mining Journal reported that, according to the US Bureau of Labour Statistics (BLS), the mining sector had the highest average annual pay in the United States in 1997, and has held the top position since the BLS began compiling the figures in 1980. The average pay for US mineworkers in 1997 was US$ 49,995, 66% higher than the national average for private sector workers (Anon. 1999b)

By indirectly supporting the livelihoods of millions of people and by providing large quantities of personal income to individuals and tax revenues to government to invest in improvements in the standards of living of citizens now and for the future does the contribution made by mining outweigh any negative consequences it may have? Can an economic cost benefit analysis be carried out to show whether or not mining helps meet the needs of the present without compromising the ability of future generations to meet their needs?

1.4.1.1 Missing the Point

The use of economic criteria alone in assessing the seriousness of an environmental burden may be inconsistent with long term environmental sustainability, since it is governed entirely by human judgements of economic value, rather than an assessment of environmental value. It is entirely utilitarian in its approach since economic added value is driven by the principles of utility. Mining, in particular, has issues which are not easily reconciled with an index of added value, such as disturbance of the ecology at the mine site, and socio-cultural concerns such as mine siting on religious or culturally important locations.

On the other hand, using biophysical measures alone is as misleading as economic indicators when considering sustainable development. For example, some would suggest that in order to allow future generations to have the same opportunities as ourselves the natural and built environment must be protected (see Ackermann 1998), in other words - sustainability means living on nature's income rather than its capital.

The implications of such an assessment for extractive industries such as mining are clear to some - if the earth's stock of natural capital is to be preserved then we should stop mining altogether and focus effort on continuing to provide the benefits through a greater emphasis on recycling and through the use of renewable resources wherever possible. But there is an argument that mineral extraction does not necessarily conflict with conservation of natural
capital, if one emphasises the recyclability of metal and other mineral products (Anon. 1997d, page 3).

Some question the practicalities of exclusive use of renewable resources to satisfy needs arguing that, against a backdrop of continuing growth in population, to replace the value of goods and services provided by metals and minerals with those of biological origin would require major areas of land and disrupt the environment on a large scale (Rio Tinto 1998b).

Perhaps the discussion concerning environment and economics is misleading and may not be entirely helpful to actors in sustainable development (see Tilton 1996). As was seen in the earlier discussion, a key component has to be introduced - social development. Without consideration of the interaction between mining and society, any discussion about sustainable development in mining may lose focus.

1.4.2 Understanding Social and Community Sustainability Issues

As will be discussed in more detail later, the life of a mine depends on a number of variables unique to its location, geology, size, quality and environmental and cultural sensitivity, amongst others (see for example, Vol.2 PD2 Section 1.3.2.1). Extraction strategies will affect the rate at which ore is recovered and processed, the grade of ore recovered, and the cut-off point at which the mine is closed. Even as mining techniques and 'waste' ore processing techniques advance, there is still a point at which that particular ore-body can no longer be economically mined.

In this context, a discussion of sustainability takes on a new dimension. Whether or not an individual mine’s activities significantly affect the global availability of a natural mineral resource, from the point of view of the community local to the mine, the mining of that particular ore body is temporally finite. Regardless of the efficiency of the extraction techniques, their natural resource will eventually be removed from the ore body and will no longer be available to them. The challenge for mining operations, then, is to reconcile their activities with the principles of sustainable development, in the local context, where infinite recycling rates at a global level will still not alter the fact that the local community’s asset has been depleted.

1.4.2.1 The Relationship Between Industry and the Sustainable Development of Communities

The relationship between industry and sustainable development is at the heart of much activity within the United Nations. The UN Economic and Social Council (1998) argue that, “Industry and its impact on economic and social development and the environment has been at the centre of the debate on sustainable development since the term 'sustainable development' was brought into common use by the Brundtland Commission in 1987. There is now consensus among policy makers that in order to achieve sustainable development, Governments and non-state actors need to make...
greater efforts to integrate economic, social and environmental goals into industrial policy and decision making” (Economic and Social Council 1998, paragraph 1).

Industry’s roles, according to the Economic and Social Council, include the encouragement of an open, competitive economy, the creation of productive employment in order to provide sustained increases in household income and social development, and to protect the natural environment through the efficient use of renewable and non-renewable resources. The role of industry in the development and diffusion of environmentally friendly technologies is emphasised by the Council (see Economic and Social Council 1998, paragraphs 4 to 5).

1.4.2.2 **Foreign Direct Investment (FDI) and Technology Transfer**

Foreign Investment has an important role to play in sustainable development. The Economic and Social Council point to a number of benefits of foreign investment in developing countries and economies in transition, including:

- Capital
- New Technologies
- Organisation and Management Methods
- Access to Markets.
- Joint Ventures to promote backward and forward linkages (Economic and Social Council, paragraph 14).

They go on to conclude that,

“Social development goals are an integral part of sustainable development strategies... The primary force driving economic development has been industrialisation, which in turn has the potential for promoting, directly and indirectly, a variety of social objectives, such as employment creation, poverty alleviation, gender equality, and greater access to education and health care. There is a mutually reinforcing relationship between social and industrial development” (Economic and Social Council 1998, paragraph 24).

1.4.2.3 **Adding Value to Local Communities**

Mining activities will have an impact upon the communities local to the operations. Some of the potential impacts are negative: local air pollution, contamination of soils and rivers, loss of biodiversity, cultural disruption, exposure to new diseases. However, mining ventures can have positive impacts upon the local communities. The UN Committee on Natural Resources discusses a number of the possible ways in which sustainable development can be enhanced by the involvement of mining organisations in developing countries in particular (see Box 1).
Box 1 UN Committee on Natural Resources Recommendations for Social Policy Management Contracts (from United Nations Committee on Natural Resources 1996, paragraph 67).

It is now widely recognised by foreign investors that local communities must be involved in the decision process regarding the development of mineral resources in their own communities, and that sustainability comes with the development of local social, physical and business infrastructure, including the development of local enterprises.

Increasingly, technology transfer, contribution towards health, education and job training can be effected at the local level. This is being recognised in practice by many mining companies now operating in developing countries and economies in transition. For some, informal programmes have been started whereby scholarships are provided to promising high-school students in order to pursue education in neighbouring towns or outside the state or country at recognised universities; local health facilities are upgraded to include hospitals, doctors and first aid programmes; dental programmes are instituted within the village; drinking water facilities are installed etc.

Other companies have instituted more formal programmes under the auspices of foundations that go beyond job training and the provision of health facilities to include support to encourage local small business enterprises, opportunities for advancement of women.

As countries advance in setting up frameworks, it may be time to consider including some form of social contract within the overall mining contract that assists with the process of achieving sustainability within a community perhaps even after the original ‘engine for growth’ has departed.

The principle of the non-sustainable engine for growth driving the sustainable development process, when properly managed, finds support from the World Bank (1997) who stress that, “It is perfectly reasonable for countries to choose to develop and deplete non-renewable resources as a source of development finance. But this is only reasonable if the resource rents are in fact invested rather than being consumed” (Dixon et al 1997, page 15).

The World Bank suggest that nations who wish to develop have three broad forms of ‘endowment’:
1. Natural resources,
2. Raw labour,
3. Social capital (the result of the cultural traditions and historical experience of the nation in question)

These endowments, plus the historical accumulation of produced assets and human capital, represent the starting point for the development process (see Dixon et al 1997, page 28). The depletion of natural resources is seen as acceptable provided that the benefit accrued adequately compensates the lost future value of the assets. It cannot be overemphasised that the nature of the contribution of the mining company must add value to the local community. This will be discussed further in Project Document 2 (see Vol.2 PD2 Section 3 - “The Use of Normalisation Factors for Expressing Relative Unitary Environmental Performance Trends”).
1.4.2.4 Local Community Involvement

The UN General Assembly (1987) argue that,

"People are the most valuable resource in development, but in order for them to participate constructively in accelerating and sustaining development, environmental information must be made available in languages they understand and in a form that can help them relate it easily to their own situation. Governments should intensify their efforts to make this possible" (United Nations General Assembly 1987, paragraph 107).

In Papua New Guinea, for example, three tiers of Government (national, provincial and local) must be satisfied before land access is granted. Once a Special Mining Lease has been signed, a tax credit scheme is triggered which assists local communities impacted by the mine by re-investing proceeds from the mine directly back into community infrastructure projects. Also, independent environmental advisory committees have been created, composed of community, government, industry and external NGO stakeholders to assess and manage the environmental and social impacts of mining (Stevenson 1998).

It must be recognised that while mining projects have the potential to bring benefits to host countries and can help the sustainable development of economies and communities, even though they are not sustainable in the long term in themselves, they can also bring considerable physical and cultural harm to the environs of their activities, particularly when the needs and wishes of the local communities are not addressed.

The respective cases of Lihir Gold Ltd.’s gold mine on Lihir Island, Papua New Guinea, and Freeport McMoRan’s Grasberg copper and gold mine near Timika, West Papua, provide an insight into the potential difficulties.

1.4.2.4.1 Lihir

Lihir Island, 700 km north-east of mainland Papua New Guinea, is the site of a joint venture gold mining project that is expected to start production in 1998. Lihir Island has a population of about 5,500, the majority of whom live from subsistence agriculture. It was estimated in 1989 that the per capita income of Lihirians was approximately 100 dollars p.a..

An integrated benefits package was agreed by the mining consortium and the Lihir Landowner's Association in 1995 with the following key commitments, amongst others:
1. The company will provide 22 million dollars of funds for development of social and technical infrastructure;
2. In addition the company will provide average annual compensation and other payments of approximately 1 million dollars p.a.;
3. The landowners will have a 15% equity share in the project, paid for by a loan from the government which will be repaid from share dividends;
33% to 50% of the expected 1,200 jobs created will go to local people, who have formed an umbrella firm with approximately 2,500 shareholders to do business with Lihir Gold Ltd. The income of this firm, which represents about 80 companies on the island who supply goods and services to the mine, was approximately 50 million dollars p.a. during construction, with income expected to stabilise at approximately 25 million dollars p.a. once production starts at the mine (Bosshard 1996).

1.4.2.4.2 Grasberg

The Lihir case contrasts markedly with the experience of Freeport McMoRan at Timika. In 1996 Freeport was the top tax payer in Indonesia, a nation of some 200 million people. Indonesia was expected to receive $480 million in 1997 in royalties, taxes and benefits from the mine, and the Indonesian Government, which holds a 10% share in the project is a major beneficiary of the presence of Freeport on West Papua (Anon. 1998a).

However, the local tribes, such as Amungme, Dani, Moni, Komo, Ekari, Nduga, do not appear to be benefiting to quite the same extent. Freeport’s Grasberg mine is now guarded by government troops. Tom Beanal, a leader of LEMASA (the community organisation and governing council of the Amungme people) has been quoted as saying,

"These [mining and oil] companies have taken over our land. Even the sacred mountains we think of as our mother have been arbitrarily torn up by them, and they have not felt the least bit guilty ... Our environment has been ruined, and our forests and rivers polluted by waste ... We have not been silent. We protest and are angry. But we have been arrested, beaten and put into containers; we have been tortured, even killed" (Anon 1998a)

The situation at Grasberg is compounded by the ongoing conflict between West Papua and the Indonesian Government based on Jakarta, led by President Habibi and President Suharto before him. Although, as the United Nations (1998) observe, “In general, businesses should not be expected to perform tasks that other parts of society have been unable to deal with,” (Economic and Social Council 1998, paragraph 38) the issue of human rights cannot be overlooked by mining organisations operating in a multinational context.

The situation in Indonesia provides illustration of what can happen when the costs and benefits of mining operations within a developing country are not reconciled. The benefits to the local population at Lihir, in addition to direct financial benefit, should be access to skills, infrastructure, education, development of the business community etc. which will be exchanged for access to resources. When the mine does close, the local population should have the necessary skills and infrastructure to ensure that the development of their community is sustainable.

At Grasberg, the benefits to the nation of Indonesia are clear: direct finance which could then be reinvested at the national and local level. The costs to the local community are also clear - loss of assets and potential environmental and cultural disruption from the mine operations. However, what is not assured is that the benefits to the nation will be passed on the local
community, and thus it is difficult to see how sustainable development will be achieved in that situation.

1.4.3 Changing Attitudes

The pressure on global mining organisations is unrelenting. Hodges (1995) puts matters into perspective thus,

"Contrary to the mind set of 100 years ago, a growing segment of the US population today places higher value on natural assets other than gold, particularly on public lands. Where once mining was widely regarded as the 'highest and best' use of land, irrespective of its suitability for other purposes, federal lands are now valued for multiple resources: wilderness, historic sites, wildlife or scenery, for example" (Hodges 1995, page 1306)

Elsewhere, in the United Kingdom, attempts in the 1970s by the RTZ corporation to develop mineral deposits in Gwynedd and by the BP company to develop oil deposits in the New Forest were commented upon by the Duke of Edinburgh.

"Turning from the general to the particular, the Duke made it clear that he detects some change in popular attitudes. Without naming the companies concerned he said he believed that possible drilling for oil in the New Forest and mining for minerals in a Welsh beauty spot would have created no argument 50 years ago. Now there will be a hell of an argument. Well, this is quite an advance.” (Anon. 1971)

In Australia, the development of a uranium mine at the Jabiluka deposit in Northern Territory, surrounded by the Kakadu National Park, was resisted for more than a decade by the governing Australian Labour Party through a ‘three mine uranium policy’, brought into place because public concern over the environmental and social impacts of mining uranium was so great. This in a country where, as West (1972) put it, “The Australians, or ‘diggers’, grew to nationhood from the wealth of their mines” (West 1972, page 79). In fact, O’Neill (1997) reports a survey carried out by the Australian Resource Assessment Commission which Anderson (1991) described as follows,

"In the survey a random sample of 3,034 people were asked how much they would pay to stop mining in Kakadu. They volunteered figures between $52 and $128 each per year. This sort of money given by all Australians would dwarf earnings from the mine. Not surprisingly, the mining industry has called the survey results ‘nonsensical’ and ‘unscientific’” (Anderson, 1991, page 24).

Landmark rulings in Australia and Canada, illustrate just how far public sentiment is shifting away from a presumption in favour of mining. In Australia, the Mabo Ruling of 1992 led to the development of Native Title legislation in 1994, which allows Aboriginal Australians to claim title to lands controlled by Europeans since colonisation provided they can demonstrate historical, continuous links with the land (see Anon. 1997a). In Canada, in 1997, the Canadian Supreme Court established the principle that native Indian rights were not extinguished by European settlement of Canada (see Anon. 1997c).
In 1996 the Wik ruling in Australia, which extended native title from the 36% of vacant land owned by the government, to 78% of the land-mass by including land held under lease by mining companies and farmers, threatened to bring about an early general election in the country (see Anon. 1997b). The Native Title rulings in these countries will require mining companies to reach agreement with native title holders before they can pursue development of a mine, making it even more difficult for mining companies to bring mines into production. The mining industry needs to be able to demonstrate its responsible approach to ensure continuing access to mineral resources.
1.5 Summary

It is clear that any discussion of sustainable development in the context of mining requires an understanding of three components - economy, biophysical environment, and social impact. Bath University’s Mining and Environment Research Network (MERN), based at the International Centre for the Environment, propose that mine projects must consider the needs of stakeholders over time relating to social, economic and bio-physical dimensions using an ‘onion ring’ to represent different stakeholder groups.

Figure 6: MERN Mine Site Stakeholders & Dimensions (from Warhurst 1998)

For mining to be considered as compatible with sustainable development, the following rule must apply:

\[ \Sigma (\Delta \text{Economic Dimension} \pm \Delta \text{Social Dimension} \pm \Delta \text{Bio-physical Dimension}) > 0 \]

How one determines indices that allow such a calculation to be carried out is not clear, perhaps it is the principle that is the most important element. Wehrmeyer and Tyteca (1998) discuss sustainable development in similar terms, arguing that the dimensions of social, economic and environmental sustainability, derived from Goodland (1995) are compatible with the three interrelated elements of the Brundtland definition identified by Welford (1995), namely: environment, equity and futurity.

As has been shown, mining must consider a number of issues when looking at its environmental performance in the context of sustainable development. It will be important to identify how social, economic, and biophysical performance can be measured meaningfully within a global mining organisation, even though the eventual outcome of this particular
The project is likely to focus on biophysical measures of performance at the global level for the purposes of a case study. How various institutions have attempted to find ways to measure their performance related to different dimensions of sustainable development will be the focus of the next section of this portfolio (see Project Document 2 – Vol.2 PD2).
Portfolio submitted in part fulfilment of the requirements for the Degree of Engineering Doctorate in Environmental Technology

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Sustainable Development and the Global Mining Industry

University of Surrey

August 2000

VOLUME 2 OF 4

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THE DEVELOPMENT OF KEY CORPORATE ENVIRONMENTAL PERFORMANCE INDICATORS FOR SUSTAINABLE MINING ORGANISATIONS

PROJECT DOCUMENT 2
(Vol.2 PD2)

October 1999
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1. Review of Environmental Performance Measures Development

1.1 Introduction

1.1.1 Background

The gold mining company Placer Dome were quoted in Project Document 1 as saying, “We will be judged by performance, by how we operate mines and by what remains after mines close.” (Placer Dome 1998, page 2. See also Project Document 1 – Vol.1 PD1 Section 1.1)

This point is critical – mining companies will be judged on their performance. Traditionally, corporations have developed indicators of their underlying performance to help stakeholders make that judgement. Traditionally, those stakeholders have been financial shareholders, and the indicators have been economic – net turnover, net earnings, operating cash flow etc. However, as the mining companies above indicate, their performance now and in the future is likely to be judged by a far greater range of stakeholders than simply the shareholders. Demonstrating progress towards goals such as sustainable development may not be within the scope of indicators such as turnover and earnings.

Rio Tinto (1997a), for example, has set itself an objective to improve target setting, intending that,

“The system for both qualitative and quantitative target setting by the operations will be improved to achieve a consistent approach across the Group, with realistic but challenging objectives. Progress will be monitored through corporate HSE reviews and the annual plan reviews of the operations. In the longer term we aim to develop Group-wide targets which make sense in the context of our diverse businesses and geographical locations.” (Rio Tinto 1997a, page 5).

The aims of this research project are six fold. Firstly, the intention is to investigate why global mining companies should be interested in the development of group-wide indicators and targets. This will build upon the exposition of the relationship between mining and sustainable development in Project Document 1. Secondly, initiatives by international organisations such the United Nations, OECD, the World Resources Institute, the World Bank, etc will be reviewed to assess what they offer to global mining organisations endeavouring to address these challenges.

Thirdly, initiatives by international businesses such as Unilever, ICI, Storebrand and Dow Chemical will be reviewed to establish whether they offer anything to global mining companies. Fourthly, the indicators proposed by these groups will be selected, rejected, or adapted according to their relevance to mining. Factors unique to mining will be identified and indicators proposed for these issues. Fifthly, these indicators will be normalised according to the requirements of sustainable development – an innovation, which will be a contribution to knowledge in the field of environmental technology. It is important to emphasise that what will result will not be indicators of sustainable development, but indicators of environmental performance informed by an understanding of sustainable development.

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Then, a case study will be used to examine how such indicators might be used in practice. The case study will be Rio Tinto, one of the world's largest mining organisations, with a market capitalisation approaching $16 billion in 1998. The insights gained during this case study will be shown to bridge the gap between the numerous attempts to develop indicators of sustainable development, including an exciting project by the Mining and Environment Research Network at Bath University, and attempts by industry to implement indicators of performance which, it will be shown, thus far have completely failed to take account of the requirements of an understanding of sustainable development.

This will further emphasise the contribution to the field of environmental technology made by this project, as well as illustrating the challenges that organisations must overcome before they are able to implement key performance indicators informed by an understanding of sustainable development.
1.2 Why Develop Indicators of Performance?

One of the global mining companies, Rio Tinto, has identified a need to measure its performance in a manner which is meaningful across its operations. A question which must be addressed immediately is ‘Why develop measures of group-wide performance?’ In its HSE Report for 1997, Rio Tinto (1998b) comments that, “The potential for group-wide targets continues to be assessed” (Rio Tinto 1998b, page 5) So, in order to be able to set group-wide targets some form of measure of group-wide performance is needed. Hence the need for group performance indicators. But again, ‘Why is there a need to set group-wide targets?’

Taking the discussion wider, why should the mining industry in general be interested in performance indicators? Or wider still, why are institutions such as the World Business Council for Sustainable Development (WBCSD) (1998) concerned by both limited use of indicators and a lack of harmonisation in those used in practice by organisations, commenting that, “In actual practice, there is a limited use of relative environmental metrics and indicators…. In cases where metrics are used, a great diversity in their application (even within sectors) was observed, and the physical units sometimes differ within an individual report.” (Lehni 1998, page 18)

There must be some issue or issues that must be addressed that can only be tackled meaningfully if society, industry, a sector, or an organisation as a whole confronts the problem, at the global level as well as the local level. These might include global warming, ozone depletion, water use, for examples. There is, however, one issue which transcends all these themes, and that is sustainable development.

If one has group-wide performance measures, one can develop group-wide targets. But in order to set group-wide targets one must have group-wide objectives. A target to reduce energy use by 25%, for example, must have some form of basis. Without a basis, it is very difficult to determine what kind of measures would be helpful. Is sustainable development that basis for action and target setting? An understanding of sustainable development and its implications for mining is essential if useful performance indicators are to be developed.

The key conclusion that emerged from the discussion on sustainable development as it relates to the mining industry in Project 1 was that:

Sustainable development for mining must embrace ecological / biophysical, economic, and social dimensions, rather than focus on biophysical aspects to the exclusion of consideration of human social and economic development (see Vol.1 PD1, Section 1.5).

This Project Document will examine the implications of the hypothesis that any mining organisation which is committed to practices which support the principle of sustainable development must measure its progress in improving its environmental, social and economic performance so that it can act to improve its performance.

The emphasis of Project Document 1 was the relationship between mining and sustainable development and the need for measures of environmental performance. The emphasis of this
second project document will be to reflect upon the efforts that have been made to develop indicators of environmental performance by different actors.

Firstly, the nature of environmental indicators will be explained, by looking at how they are defined, their role, and features. A framework will be developed to allow the various attempts that have been made to organise environmental indicators to be reviewed secondly, followed by a review of the attempts that have been made in industry thus far to implement these indicators. This will involve an assessment of the strengths and weaknesses of the various indicator sets and their implementation by organisations. This will pay particular attention to the consistency of these indicators with the need to develop meaningful measures of environmental performance informed by the principles of sustainable development for the mining industry. This discussion will form the basis of an assessment of the implications of implementing environmental performance indicators in the mining industry.

1.2.1 The Need for Environmental Indicators

The German Federal Environment Ministry and Federal Environmental Agency (1997) put the case for performance indicators in these terms,

“For future oriented companies, i.e. companies aiming at preserving the environment while at the same time securing their own profits, it is essential to have access to broad environmental data. However, due to the extensive amounts of data available, one sometimes literally, “can't see the wood for the trees”. What is needed for effective controlling is concise and valuable information management. This is one reason why indicators have long been used in business management to summarise abundant data and support managers in their decision making.” (Bundesministerium fur Umwelt, Naturschutz und Reaktorsicherheir / Unweltbudesamt 1997, page 2).

Wright et al. (1998) make a similar argument based on their experience in the chemicals industry. They suggest that using primary data for communication and target setting is likely to confuse less expert members of any audience and have limitations when it comes to setting objectives, arguing that,

“Many companies .. have set corporate environmental goals for the reduction of environmental releases. If these goals do not distinguish among the potential environmental burdens of different environmental releases, they may not drive the most important emission reductions” (Wright et al. 1998, page 118).

Skillius and Wennberg (1998) conclude that indicators are needed to make such a distinction and help organisations with the following:

• The adoption of the most appropriate measures of environmental protection in terms of effectiveness and efficiency;
• The empowerment of environmental policy by a better definition and monitoring of environmental objectives;
• An effective definition of responsibilities and an aid for the implementation of the environmental management systems; and
• The improvement of external and internal communication on environmental achievements and programs (see Skillius & Wennberg 1998, page 6).
If a mining organisation wishes to pursue goals consistent with sustainable development, then it appears that the use of indicators which are consistent with the themes described by Skillius and Wennberg could play a valuable role in helping manage the performance of the organisation. However, any indicators used would have to provide information which could be used to assess whether or not performance is moving in a direction which is compatible with sustainable development. In order to evaluate the role that environmental performance indicators could play within a global mining organisation it is necessary to review the efforts that have been made to develop and implement indicators of environmental performance.

1.2.2 Function of Environmental Indicators

The OECD (1993) suggest that, “In a very general way, an indicator can be defined as a parameter or a value derived from parameters, which provides information about a phenomenon. The indicator has significance that extends beyond the properties directly associated with the parameter value. Indicators possess a synthetic meaning and are developed for a specific purpose” (Group on the State of the Environment 1993, page 5).

In the context of environmental indicators, Hammond et al. (1995) suggest that indicators have two defining characteristics:
1. Indicators quantify information so its significance is more readily apparent.
2. Indicators simplify information about complex phenomena to improve communication (see Hammond et al 1995, page 1).

Environment Canada (1991) emphasise that environmental indicators are selected key statistics which represent or summarise a significant aspect of the state of the environment, natural resource sustainability and related human activities. They focus on trends in environmental changes, stresses causing them, how the ecosystem and its components are responding to these changes, and societal responses to prevent, reduce, or ameliorate these stresses.

Pearce and Warford (1993) suggest that environmental indicators, “Do not attempt to measure sustainability as such, but rather to address some of the trends in the environment that can give rise to non-sustainability. Ideally, such measures should be associated with measures of pressure - the factors producing environmental change - a response - the ways in which societies react to changing environmental trends” (Pearce & Warford 1993, page 92).

Indicators, then, are distinct from the primary data upon which they are based. Hammond et al suggest that indicators and indices form the upper part of an information pyramid, whose base is primary data:
1.2.3 Features of Environmental Indicators

For environmental indicators to be effective, they must possess a number of characteristics. The OECD, when describing indicators for national and international policy making, identify requirements for indicators against three key categories:

1. Policy Relevance and Utility for Users

An environmental indicator should:
- Provide a representative picture of environmental conditions, pressures on the environment or society’s responses;
- Be simple, easy to interpret and able to show trends over time;
- Be responsive to changes in the environment and related human activities;
- Provide a basis for international comparisons;
- Be either national in scope or applicable to regional environmental issues of national significance;
- Have a threshold or reference value against which to compare so that users are able to assess the significance of the values associated with it

2. Analytical soundness

An environmental indicator should:
- Be theoretically well founded in technical and scientific terms;
- Be based on international standards with international consensus about its validity;
- Lend itself to being linked to economic models, forecasting and information systems

3. Measurability

The data required to support the environmental indicator should be:
- Readily available or made available at a reasonable cost/benefit ratio;
- Adequately documented and of known quality;
- Updated at regular intervals in accordance with reliable procedures (see Group on the State of the Environment 1993, page 7).
These principles are supported elsewhere. For example, Braat (1991) identifies eight requirements:

- The information must be presented in an attractive format
- The indicator must be representative for the chosen system
- The indicator must have a scientific basis
- The indicator must be quantifiable
- The indicator should include reference or threshold values
- The indicator should provide information without social bias
- The indicator must represent reversible and manageable processes
- The indicator should have a predictive meaning (see Braat 1991 and also Ackoff 1962; Bennett & Chorley 1978; Liverman et al 1988; Vos et al 1985).

Other works specify criteria for environmental indicators which are consistent with the OECD principles of policy relevance and utility for users, analytical soundness, and measurability (see Australian Department of Environment, Sport and Territories 1996; O'Conner et al 1995).

Braat (1991) suggested that the indicators themselves must be developed according to the target group:

**Figure 2 Relationships Between Indicators, Data, and Information (from Braat 1991, page 59)**

![Diagram of Indicator Relationships](image-url)
1.3 Organising Environmental Indicators

The hierarchical arrangements suggested by Hammond et al (1995), and by Braat (1991), can be combined as shown in Figure 3.

**Figure 3: Combined Hierarchy of Indicators**

For environmental indicators to be useful, they must meet the opening criteria specified by the OECD of providing a representative picture of environmental conditions, pressures on the environment, or society's responses, and they must be simple, easy to interpret and able to show trends over time. In order to fulfil these criteria, indicators must be organised and presented coherently. A number of options have been proposed to do this. When assessing whether indicators will provide a representative picture of environmental conditions, the first question to be asked is, “For what purpose?”

- Are the environmental indicators intended to illustrate whether or not a society is moving in a sustainable direction by themselves?
- Are the environmental indicators intended to be used in conjunction with indicators of socio-economic conditions to illustrate whether a society is moving in a sustainable direction?
- Are the environmental indicators un-informed by the principles of sustainable development and are intended to show whether policies are being implemented successfully or unsuccessfully?
- Are the indicators designed to be used by institutions acting at the global level, the regional level, or the local level?
- At what level in the indicators hierarchy are they intended to be applied?

For the purposes of this research, the area of specific interest is the environmental performance of the mining industry informed by the principles of sustainable development. Thus, the indicators must be designed to be used in conjunction with indicators of economic and social conditions, since for mining sustainable development requires natural capital to be transformed effectively into human capital. The mining sector is dominated by global actors, since large mining projects require economies of scale in finance that can only be realised by...
global operators. However, many of the environmental impacts of the industry will be felt at the local level. This research is concerned with indicators that can be used at the industry level. It is aimed for internal policy making at the corporate level of the organisation and at those members of the public with a stake in the performance of the organisation as it is argued that policy making depends on informed verification.

The objective here is to illustrate the variety of approaches that can be taken to developing measures of environmental performance in the light of these parameters. Those indicator frameworks whose objectives are not consistent with those of the mining sector, can still be useful to the mining sector where individual components in the framework overlap with the needs of the industry.

Thus, rather than using the combined hierarchy as a basis for introducing the indicators - i.e. who the indicators are designed for - of more significance will be the basis on which they were developed. Specifically indicators will be introduced in three categories:

1. Those which are expressed as indicators of sustainable development,
2. Those which are expressed as environmental indicators informed by sustainable development,
3. Those which are expressed as environmental indicators without any reference to sustainable development.

1.3.1 Indicators of Sustainable Development

Two frameworks will be introduced to illustrate the kind of approach which can be taken to indicators of sustainable development. Simply, they fall into two categories – those which believe that it is possible, within limits, to substitute natural and human capital, and those which do not.

1.3.1.1 Maintaining Steady State

Opschoor and Rejinders (1991) suggested a framework based on pressures on the environment (see Table 1). Their work was based on reporting deviations away from a steady state.
Table 1: Dimension and size of possible environmental pressure indicators reflecting compliance with a steady state (based on Opschoor & Reijnders 1991, page 24).

<table>
<thead>
<tr>
<th>Object</th>
<th>Dimension</th>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>use of non-renewable resources</td>
<td>% of total stock added or lost in a specified time span and area</td>
<td>Addition to stock - use - loss/ total stock</td>
</tr>
<tr>
<td>use of non-renewable resources</td>
<td>% of presumable reserves lost in a specified time span and area</td>
<td>Presumptable reserves minus use / presumable reserves</td>
</tr>
<tr>
<td>Species</td>
<td>number or percentage of species lost in a specified time span and area</td>
<td>Species originated minus species become extinct in a specified time span and area (may be divided by total number of species)</td>
</tr>
<tr>
<td>Acidification of soil</td>
<td>acid equivalents in a specified time span and area</td>
<td>neutralisation by soil minus acid deposition in a specified area and time span</td>
</tr>
<tr>
<td>Global Warming</td>
<td>W/m² or °C added in a specified time span</td>
<td>combined amount of greenhouse gases lost in sinks minus emission of greenhouse gases multiplied by global warming potential</td>
</tr>
<tr>
<td>Depletion ozone layer</td>
<td>ozone depletion (% or absolute) in a specified time span</td>
<td>combined amount of ozone layer depleting substances lost in sinks minus emission of ozone depleting substances multiplied by global warming potential</td>
</tr>
<tr>
<td>Soil pollution amount</td>
<td>quantity of pollutant in a specified time span</td>
<td>Amount of a pollutant eliminated from soil plus made inactive minus amount added to soil</td>
</tr>
</tbody>
</table>

Maintenance of a steady state has a number of implications (Box 1).

**Box 1 Conformity or deviation from steady state** (see Opschoor & Reijnders 1991, pages 20 to 21).

According to Opschoor and Reijnders, maintenance of a steady state in terms of resources, species and pollution implies the following:

- Use of (conditionally) renewable resources should - within a specified area and time span - not exceed the formation of new stocks. Thus, for instance, yearly extraction of groundwater should not exceed the yearly addition to groundwater reserves coming from rain and surface water;
- Use of relatively rare non-renewable resources, such as fossil carbon or rare metals, should be close to zero, unless future generations are compensated for current use by making available for future use an equivalent amount of renewable resources;
- Significant, though limited, use of relatively abundant non-renewable resources such as iron or aluminium meets the steady state criterion, provided that there is compensation for an increase in exploitation efforts following from exhaustion of easily accessible and mineable resources by this generation;
- Pollution that gives rise to accumulation of pollutants in one or more environmental compartments (e.g. atmosphere, sea, soil) in a first approximation violates a steady state operationalisation of sustainability. The same holds for long-lasting pollution (for instance, groundwater pollution; radioactive pollution around Chernobyl), the safety of which is not established. Exposure to human-made mutagens affecting the germ line (involved in reproduction) should be close to zero. Violations of these first approximations to a steady state may be acceptable if future generations are fully compensated for associated damages;
- As to natural species in a first approximation the rate of extinction of species should not exceed the rate of origin. Additional steady state requirements may relate to diversity of eco-systems, integrity of eco-systems and the conditions for development of ecosystems.

This framework is designed for policy makers concerned with sustainable development as represented by environmental conditions alone. Opschoor and Reijnders take care to emphasise that, “In a number of cases the situation (initial state) is such that a steady state with respect to this situation cannot be considered sustainable” (Opschoor and Reijnders 1991, page 25). However, while this framework considers environmental issues which are an important component of sustainable development, it is not consistent with the principles of sustainable development outlined for mining in Project Document 1 (see Vol.1 PD1).
Specifically, Opschoor and Reijnders argue that future generations can only be compensated for the use of fossil carbon, for example, through their replacement with an equivalent amount of renewable resources. While this is one way in which future generations could be compensated, the ‘substitution’ argument in sustainable development would suggest that compensation could also be achieved if the use of that fossil carbon assisted the development of alternative fuel systems or the development of energy efficiency techniques. This use of natural capital in this way would allow adequate development of human capital to compensate for its use.

1.3.1.2 Environmental, Social, Economic and Institutional Development

The United Nations Commission on Sustainable Development (UN CSD), for example, have developed a set of indicators based on the OECD’s Pressure-State-Response Framework. According to the Group on the State of the Environment (1993),

“The PSR [pressure-state-response] framework is based on a concept of causality: human activities exert pressures on the environment and change its quality and the quantity of natural resources (the “state”). Society responds to these changes through environmental, general economic and sectoral policies (the “societal response”). The latter form a feedback loop to pressures through human activities” (Group on the State of the Environment 1993, page 5).

Figure 4 illustrates the PSR framework.

Figure 4 OECD Pressure - State - Response Framework (from Group on the State of the Environment 1993, page 10)
Tables 2 to 5 illustrate how the UNCSD applied this framework to sustainable development indicators.

Table 2 UN CSD Social Pressure-State-Response Indicators of Sustainable Development (from Gouzee 1996)

<table>
<thead>
<tr>
<th>Social Categories</th>
<th>Pressure</th>
<th>State</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combating poverty</td>
<td>Unemployment rate.</td>
<td>Measures of poverty.</td>
<td>Ratio of average female wage to male wage</td>
</tr>
<tr>
<td>Promoting education, public awareness and training (including gender issues)</td>
<td>Rate of change of school age population. Primary school enrolment ratio (gross and net). Secondary school enrolment ratio (gross and net). Adult literacy rate.</td>
<td>Children reaching grade 5 of primary education. School life expectancy. Difference between male and female school enrolment ratios. Women per hundred men in the labour force</td>
<td>GDP spent on education</td>
</tr>
<tr>
<td>Protecting and promoting human health</td>
<td>Basic sanitation: % of population with adequate excreta disposal facilities. % of people with safe drinking water available in the home or with reasonable access. Life expectancy at birth. Adequate birth weight. Infant mortality rate. Maternal mortality rate. The nutritional status of children.</td>
<td></td>
<td>% of eligible population that have been immunised according to national immunisation policies. Contraceptive prevalence. Proportion of potentially hazardous chemicals monitored in food. National health expenditure devoted to local health care. Total national health expenditure related to GNP.</td>
</tr>
<tr>
<td>Promoting sustainable human settlement development (including traffic and transport)</td>
<td>Rate of growth of urban population. Per capita consumption of fossil fuels by motor vehicle transport. Human and economic loss due to natural disasters.</td>
<td>% of population in urban areas. Area and population of urban formal and informal settlements. Floor area per person House price to income ratio.</td>
<td>Infrastructure expenditure per capita.</td>
</tr>
</tbody>
</table>

Table 3 UN CSD Economic Pressure-State-Response Indicators of Sustainable Development (from Gouzee 1996)

<table>
<thead>
<tr>
<th>Economic Categories</th>
<th>Pressure</th>
<th>State</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>International co-operation to accelerate sustainable development</td>
<td>GDP per capita. Net investment share in GDP. Sum of exports and imports as a % of GDP.</td>
<td>Environmentally adjusted net domestic product per capita. Share of manufactured goods in total merchandise exports</td>
<td></td>
</tr>
<tr>
<td>Changing consumption patterns</td>
<td>Annual energy consumption per capita Share of natural resource intensive industries in manufacturing value added</td>
<td>Proven mineral reserves. Proven fossil fuel energy reserves. Lifetime of proven energy reserves. Intensity of material use. Share of manufacturing value added in GDP. Share of consumption of renewable energy resources.</td>
<td></td>
</tr>
<tr>
<td>Financial resources and mechanisms</td>
<td>Net resources transfer / GNP. Total ODA given or received as a % of GNP.</td>
<td>Debt GNP. Debt service / export.</td>
<td>Environmental protection expenditures as a % of GDP. Amount of new or additional funding for sustainable development.</td>
</tr>
</tbody>
</table>
Table 4 UN CSD Environmental Pressure-State-Response Indicators of Sustainable Development (from Gouzee 1996)

<table>
<thead>
<tr>
<th>Environmental Categories</th>
<th>Pressure</th>
<th>State</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water - Protection of the quality and supply of freshwater resources</td>
<td>Annual withdrawals of ground and surface water as % of available water</td>
<td>Groundwater reserves</td>
<td>Waste water treatment coverage</td>
</tr>
<tr>
<td></td>
<td>Domestic consumption of water per capita</td>
<td>Concentration of faecal coliform in freshwater bodies</td>
<td>Density of hydrological networks</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Biochemical oxygen demand in water bodies</td>
<td>-</td>
</tr>
<tr>
<td>Water - Protection of the oceans, all kinds of seas and coastal areas</td>
<td>Population growth in coastal areas</td>
<td>Ratio between maximum sustained yield abundance and actual annual abundance</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Discharges of oil into coastal waters</td>
<td>Deviation in stock of marine species from maximum sustained yield level</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Release of nitrogen and phosphorus into coastal waters</td>
<td>Algae index</td>
<td>-</td>
</tr>
<tr>
<td>Land - Integrated approach to the planning and management of land resources</td>
<td>Land use change</td>
<td>Land condition change</td>
<td>Decentralised local-level natural resource management</td>
</tr>
<tr>
<td>Land - Managing fragile ecosystems: combating desertification and drought</td>
<td>Population living below poverty line in dry-land areas</td>
<td>National annual rainfall index</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Satellite derived vegetation index value</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Land affected by desertification</td>
<td>-</td>
</tr>
<tr>
<td>Land - Managing fragile ecosystems: sustainable mountain development</td>
<td>Population dynamics in mountain areas</td>
<td>Assessment of the condition and sustainable use of natural resources in mountain areas</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Welfare of mountain populations</td>
<td>-</td>
</tr>
<tr>
<td>Land - Promoting sustainable agriculture and rural development</td>
<td>Use of agricultural pesticides</td>
<td>Arable land per capita</td>
<td>Agricultural education and extension</td>
</tr>
<tr>
<td></td>
<td>Use of fertilisers</td>
<td>Area affected by salinisation and water-logging</td>
<td>Agricultural research intensity ratio</td>
</tr>
<tr>
<td></td>
<td>Irrigation % of arable land</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Energy use in agriculture</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Other natural resources - Combating deforestation</td>
<td>Wood harvesting intensity</td>
<td>Forest area change</td>
<td>Managed forest area ratio</td>
</tr>
<tr>
<td></td>
<td>-</td>
<td>Threatened species as a % of total native species</td>
<td>Protected forest area as a % of total forest area</td>
</tr>
<tr>
<td>Other natural resources - Conservation of biological diversity</td>
<td>-</td>
<td>-</td>
<td>R&amp;D expenditure in the area of biotechnology</td>
</tr>
<tr>
<td>Other natural resources - Environmentally sound management of biotechnology</td>
<td>-</td>
<td>-</td>
<td>Existence of national bio-safety regulations or guidelines</td>
</tr>
<tr>
<td>Atmosphere - Protection of the atmosphere</td>
<td>Emissions of greenhouse gases</td>
<td>Ambient concentrations of pollutants in urban areas</td>
<td>Expenditure on air pollution abatement</td>
</tr>
<tr>
<td></td>
<td>Emissions of sulphur oxides</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Emissions of nitrogen oxides</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Consumption of ozone depleting substances</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Waste - Environmentally sound management of solid wastes and sewage related issues</td>
<td>Generation of industrial and municipal solid waste</td>
<td>Generation of hazardous wastes</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Household waste disposed per capita</td>
<td>Imports and exports of hazardous wastes</td>
<td>-</td>
</tr>
<tr>
<td>Waste - Environmentally sound management of toxic chemicals</td>
<td>-</td>
<td>Chemically induced acute poisonings</td>
<td>Number of chemicals banned or severely restricted</td>
</tr>
<tr>
<td>Environmentally sound management of hazardous wastes</td>
<td>Generation of hazardous wastes</td>
<td>Area of land contaminated by hazardous wastes</td>
<td>Expenditure on hazardous waste treatment</td>
</tr>
<tr>
<td></td>
<td>Imports and exports of hazardous wastes</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Safe and environmentally sound management of radioactive wastes</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
The significance of the pressure-state-response framework will be discussed later. At this time, however, it is important to distinguish the key differences between the two types of indicator framework illustrated here. Both frameworks are consistent with different interpretations of sustainable development. The former is broadly consistent with the view that sustainable development depends on preserving natural capital intact – maintaining the steady state – while the latter sides more heavily with the view that sustainable development depends on more than just ecological factors. The latter view is the one supported for the mining industry in Project Document 1 (Vol.1 PD1).

### 1.3.2 Environmental Indicators Informed by the Principles of Sustainable Development

The second category of indicator under discussion is that which is primarily intended to discuss environmental performance, but which is underpinned by an understanding of sustainable development.

#### 1.3.2.1 Pressure - State - Response and Impact

The World Bank (1995) suggest that, in addition to the variables of pressure, state, and response,

"Some have suggested an impact indicator as well to reflect the effects of environmental change on specific functions of the environment (such as the support of human health, fresh water availability, or climate stability). ... At this early stage of design and monitoring, most of the significant aspects of the theme or problem may be captured by a set of driving force, state and response indicators. But impact..."
indicators will be more important as one looks across issues” (O'Connor et al 1995, Appendix)

The World Bank developed a matrix (see Table 6) for environmental indicators that divides indicators onto four categories:
1. Source indicators
2. Sink or pollution indicators
3. Life support indicators
4. Human impact indicators.

Table 6 World Bank Matrix of Environmental Indicators (from Hammond et al 1995, page 14)

<table>
<thead>
<tr>
<th>Issues</th>
<th>Pressure</th>
<th>State</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source Indicators</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Agriculture</td>
<td>Value added / gross output</td>
<td>Cropland as % of wealth</td>
<td>Rural / urban terms of trade</td>
</tr>
<tr>
<td>Land Quality</td>
<td>Human induced soil degradation</td>
<td>Climatic classes and soil</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td>constraints</td>
<td></td>
</tr>
<tr>
<td>Forest</td>
<td>Land use changes, inputs for</td>
<td>Area, volumes, distribution;</td>
<td>Input/ Output ratio, main users, recycling</td>
</tr>
<tr>
<td></td>
<td>EDP</td>
<td>value of forest</td>
<td>rates</td>
</tr>
<tr>
<td>Marine Resources</td>
<td>Contaminant, demand for fish as</td>
<td>Stock of marine species</td>
<td></td>
</tr>
<tr>
<td></td>
<td>food</td>
<td>% coverage of international</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>protocols/ conventions</td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>Intensity of use</td>
<td>Accessibility to population</td>
<td>Water efficiency measures</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(weighted % of total)</td>
<td></td>
</tr>
<tr>
<td>Sub-soil Assets</td>
<td>Extraction Rate(s)</td>
<td>Subsoil assets % of wealth</td>
<td>Material balances / NNP‡</td>
</tr>
<tr>
<td>Fossil Fuels</td>
<td>Extraction Rate(s)</td>
<td>Proven reserves</td>
<td>Reverse energy subsidies</td>
</tr>
<tr>
<td>Metals and Minerals</td>
<td>Extraction Rate(s)</td>
<td>Proven reserves</td>
<td>Input / output ratio, main users, recycling</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>rates</td>
</tr>
<tr>
<td>Sink or Pollution</td>
<td>Emissions of CO₂</td>
<td>Atmospheric concentration of</td>
<td>Energy efficiency of NNP</td>
</tr>
<tr>
<td>Indicators</td>
<td></td>
<td>greenhouse gases</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Emission of SO₅, NOₓ</td>
<td>Atmospheric concentration of</td>
<td>% coverage of international protocols /</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NOₓ in precipitation</td>
<td>conventions</td>
</tr>
<tr>
<td>Acidification</td>
<td>Use of phosphates (P),</td>
<td>BOD, P, N in rivers</td>
<td>Expenditure on pollution abatement</td>
</tr>
<tr>
<td></td>
<td>Nitrate (N)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eutrophication</td>
<td>Generation of hazardous waste /</td>
<td>Concentration of lead,</td>
<td>% petrol unleaded</td>
</tr>
<tr>
<td></td>
<td>load</td>
<td>cadmium etc. in rivers</td>
<td></td>
</tr>
<tr>
<td>Toxification</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Life Support Indicators</td>
<td>Land use changes</td>
<td>Habitat / NR</td>
<td>Protected areas as % threatened</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oceans</td>
<td>Threatened, extinct species %</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>total</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Special Lands (e.g.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>wetland</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Human Impact Indicators</td>
<td>Burdens of disease (DALYs /</td>
<td>Life expectancy at birth</td>
<td>% NNP spent on health, vaccination</td>
</tr>
<tr>
<td></td>
<td>persons)</td>
<td>Dissolved oxygen, faecal</td>
<td>Access to safe water</td>
</tr>
<tr>
<td></td>
<td></td>
<td>coliform</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Concentration of particulates,</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>SO₂, etc.</td>
<td></td>
</tr>
<tr>
<td>Food Security and</td>
<td>Energy demand</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quality</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Housing / Urban</td>
<td>Population density</td>
<td></td>
<td>% NNP spent on housing</td>
</tr>
<tr>
<td></td>
<td>(persons/km²)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Waste</td>
<td>Generation of industrial,</td>
<td>Accumulation to date</td>
<td>Expenditure on collection and</td>
</tr>
<tr>
<td></td>
<td>municipal waste</td>
<td></td>
<td>treatment, recycling rates</td>
</tr>
<tr>
<td>Natural Disaster</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

† DALYs - Daily Adjustable Life Years
‡ NNP- Net National Product

As with the OECD framework, the World Bank indicators are designed to be used at the policy level, but this time are developed in the context of a view of sustainable development. The four categories are, in principle, consistent with the Ekins and Simon (1998) view that
some aspects of natural capital cannot be substituted – the life support indicators – whilst others, such as non-renewable resources can be substituted with alternatives.

However, if the World Bank view is that sustainable development can be brought about by reducing the pressures on the environmental states indicated through the policy responses indicated, then it is wholly inconsistent with the principles of sustainable development for the mining industry. Expenditure on pollution abatement, waste treatment, and the development of unleaded petrol are not, respectively, going to bring about a sustainable solution to acidification, eutrophication and toxification.

### 1.3.2.2 Key Aggregate Indicators

The World Resources Institute (WRI) (1995) have argued that arrays such as those prepared by the World Bank organise or structure environmental indicators, and lend themselves to integration with social and economic indicators, but they still provide, “An unwieldy amount of information” (Hammond et al 1995, page 13) and suggest further aggregation. The WRI identify four groupings of ‘Key Aggregate Indicators’:

1. Pollution
2. Resource Depletion
3. Ecosystem Risk

The WRI suggest that, “The indicators proposed here can be understood as candidates for the environmental components of sustainability indicators. As such, their interaction with social and economic factors is important” (Hammond et al 1995, ibid.). The methodology outlined by WRI is summarised in Box 2

The WRI framework has strong links with other arguments and frameworks discussed throughout this research. For example, the pollution index is compatible with an analytical framework - discussed later – devised by SETAC. On resource depletion, the WRI argument is consistent with the thesis in Project Document 1 – that sustainable resource use requires the replacement of natural capital with human capital of equal or greater value, rather than simply that harvesting rates do not exceed regeneration rates. Additionally, the indicator required by WRI would express not just the pressure and state concerning resource depletion – i.e. how much extraction (pressure) of scarce resources (state) is taking place – but also the response by society in developing human capital to indicate whether or not the extraction rate is sustainable.

Where the WRI thesis is less strong, however, is in arguing for a distinction between ecosystem risk and human impact / exposure. It is argued here that drinking water pollution, exposure to toxins etc are in fact subsets of the wider aspects of ‘inherent sensitivity’ referred to in the ecosystem risk dimension, rather than a separate indicator grouping.
Box 2 Development of WRI Key Aggregate Indicators

Pollution
For this index the focus is on phenomena that primarily alter the character or health of the Earth's physical or biological systems. Climate change; depletion of the ozone layer; acidification of soils and lakes; eutrophication of water bodies; toxification of soils, water bodies, and ecosystems; and the accumulation of solid wastes all fall into this category.

Each indicator consists of a single graph - showing the course of the environmental pressure over time- one or more policy targets (such as the level consistent with sustainability), and a single percentage, which is the percentage reduction in the pressure reduction required to reach the target.

A composite pollution index can be formed by further aggregation of the indicators. This requires aggregating unlike quantities, so each environmental issue is weighted on the basis of the gap between the long term policy target for sustainability and the current value. The greater the gap, the greater the weighting.

Resource Depletion
The index of resource depletion measures the value of the decline in natural resource stocks in a country relative to the value of investment in human-made capital during the given year. Roughly speaking, the index indicates the degree of departure from sustainable resource use, assuming that the depletion of natural resources is sustainable if their use leads to the creation of other assets of equal value.

Ecosystem Risk
WRI argue that the currently available indicators appropriate to biodiversity - endangered species, amount of wilderness area, protected areas - are either state or response indicators. A pressure indicator is needed. Possible human pressures include destruction of habitats or conversion of land to other uses, overharvesting, introduction of exotic species. However, pressure data alone is not meaningful without a measure of vulnerability. Measures of inherent sensitivity, when combined with pressure data, could help show ecosystem risk.

Human Impact/Exposure
WRI stress that many forms of pollution or resource degradation are important because they directly affect people. They propose that an index be developed based on drinking water pollution, air pollution, environmental disease vectors, contaminated food, inadequate housing, occupational exposures to toxins. They feel that further discussion is needed to establish a consensus on social equity in environmental exposures (should it be correlated to income, or other relevant social groups).

1.3.3 Environmental Indicators not Informed by Sustainable Development
There are two broad types in this category – those designed to be used at the policy level, and those designed to be used at the level of the organisation.

1.3.3.1 OECD Pressure - State - Response
At the policy level, the OECD (1993) first introduced the framework known as 'pressure-state-response' explained in Section 1.3.1.2. On the basis of this framework the OECD drew up a list of environmental indicators to help illustrate trends in the PSR framework. They identified indicators which could be used on the basis of existing knowledge (short term) and also identified potential indicators which would require development in the current knowledge base in order to be useful (medium and long term). On the basis of their assessment, the OECD proposed the indicator framework shown in Table 7.

<table>
<thead>
<tr>
<th>Issues</th>
<th>Indicators of Environmental Pressures</th>
<th>Indicators of Environmental Conditions</th>
<th>Indicators of Societal Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate Change</td>
<td>Emissions of CO2</td>
<td>Atmospheric concentrations of greenhouse gases</td>
<td>Energy intensity</td>
</tr>
<tr>
<td>Stratospheric ozone depletion</td>
<td>Apparent consumption of CFCs</td>
<td>Atmospheric concentration of CFCs</td>
<td>% of population connected to waste water treatment plants</td>
</tr>
<tr>
<td>Eutrophication</td>
<td>Apparent consumption of fertilisers, measured in N, P</td>
<td>BOD, DO, N and P in selected rivers</td>
<td>Expenditure for air pollution abatement</td>
</tr>
<tr>
<td>Acidification</td>
<td>Emissions of SO₂ and NOₓ</td>
<td>Concentrations in acid precipitation (pH, SO₄, NO₃)</td>
<td>Market share of unleaded petrol</td>
</tr>
<tr>
<td>Toxic contamination</td>
<td>Generation of hazardous waste</td>
<td>Concentration of lead, chromium, copper in selected rivers</td>
<td>Protected areas as % of total area</td>
</tr>
<tr>
<td>Urban environmental quality</td>
<td></td>
<td>Concentrations of SO₂, NOₓ particulates in selected cities</td>
<td></td>
</tr>
<tr>
<td>Biological diversity and landscape</td>
<td>Land use changes</td>
<td>Threatened or extinct species as % of known species</td>
<td>Expenditure on waste collection and treatment</td>
</tr>
<tr>
<td>Waste</td>
<td>Generation of municipal, industrial, nuclear, hazardous waste</td>
<td>not applicable</td>
<td>Waste recycling rates (paper and glass)</td>
</tr>
<tr>
<td>Water resources</td>
<td>Intensity of use of water resources</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forest resources</td>
<td></td>
<td>Area, volume and distribution of forests</td>
<td></td>
</tr>
<tr>
<td>Fish resources</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil degradation (desertification and erosion)</td>
<td>Land use changes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>General indicators not attributable to specific issues</td>
<td>Population growth and density GDP growth Industrial and agricultural production Energy supply and structure Road traffic and vehicle stock</td>
<td>not applicable</td>
<td>Pollution abatement and control expenditure Public opinion on the environment</td>
</tr>
</tbody>
</table>

For the OECD, the objectives for their indicator framework are to help the integration of environmental and economic decision making, and to help Member Countries improve their individual and collective performance in environmental management (Group on the State of the Environment 1993, page 4). The resulting indicators, then, are not, ab initio, driven by considerations relating to sustainable development as understood for the mining industry. Just as the framework suggested by Opschoor and Reijnders was limited, so far as its implementation in a sustainable mining industry is concerned, so is the framework suggested by the OECD.

Specifically, the OECD considers that the kind of social responses of interest include the market share of unleaded petrol, and the expenditure on air pollution abatement. A mining sector managing its environmental performance informed by the principles of sustainable development will not find such indicators helpful. An industry or society wishing to maximise the amount of human capital developed through its use of natural capital might find that the most sustainable solution to acidification would be to invest in clean-up technology such as air pollution abatement. But it might equally find that the development of industrial processes or human needs which do not involve acidic by-products in the first place might be the most
sustainable solution. Similarly, for waste – the amount of money spent on waste treatment and collection is not as useful as the development of the capability to avoid generating the waste at all.

Although this illustrates that there may be limitations to using the entire framework as a model for indicating environmental performance in a sustainable mining industry, the specific environmental themes suggested may be useful – since the OECD considers both the state of the environment and the pressures acting upon it.

1.3.3.2 ISO 14031

At the organisational level the International Organisation for Standardisation is developing a system for performance evaluation based on indicators of environmental performance, known as ISO 14031. This system comprises:

- Operational Performance Indicators (covering environmental aspects)
- Management Performance Indicators (measures to evaluate the management system)
- Environmental Condition Indicators (covering environmental impacts) (see International Organisation for Standardisation 1997; Wehrmeyer 1998)

Like the OECD framework, ISO 14031 includes social and economic aspects, but this time is focussed at the level of the firm – so includes indicators such as “research and development funds applied to projects with environmental significance” or “resources applied to support of community environmental programmes” (International Organisation for Standardisation 1997, page 27).

1.3.3.3 Industrial Development of Environmental Performance Indicators

1.3.3.3.1 ICI Environmental Burden Method

Imperial Chemical Industries were one of the first major companies to make a public statement of intent in the use of environmental performance indicators. Launching their ‘Environmental Burden Approach’ (1997) as a technique to rank the potential impacts of their emissions, they state that,

“We believe this method helps improve our environmental management and reporting because it will:

- Provide a more meaningful picture of the potential impact of our emissions from our operations compared with the customary practice of merely reporting the weights of substances discharged
- Help us to identify the most harmful emissions and reduce these first
- Give the public a better understanding of the potential problems associated with the emissions and show how we continue to reduce the potential impact of our wastes” (Clarke et al 1997, page 3).

Such an approach is a step towards the application of life cycle assessment (LCA). LCA itself is described by Fava et al. (1993) as a process to evaluate the resource consumption and...
environmental burdens associated with a product, process or activity, as well as their impacts on the environment. LCA involves the following five stages:

1. Goal Definition
   - define the system under consideration
   - identify the system boundary
   - identify the purpose of the assessment (policy, engineering, economic)

2. Inventory
   - identify and quantify resource requirements
   - identify and quantify environmental emissions

3. Classification
   - assess the contribution of resource requirements to resource depletion
   - assess the contribution of environmental emissions to environmental burdens

4. Valuation
   - assess the relative importance of environmental burdens and resource demands
   - assess the reliability of results and sensitivity to key parameters

5. Improvement
   - use the results of the exercise to identify environmental improvements, use of new technologies, or changes in practice (see Jackson 1996, page 75).

In order to conduct an environmental burden assessment impact categories must be devised against which to assess environmental impact from activities. A useful starting point would be the default list suggested by the CML at Leiden University who have subdivided environmental impacts into the categories shown in Table 8 (Udo de Haes 1996, page 19).

Table 8: Default list of impact categories for life cycle impact analysis, together with the spatial scope of the categories

<table>
<thead>
<tr>
<th>Category</th>
<th>Spatial Scope</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abiotic Resources Depletion and Competition</td>
<td>Global</td>
</tr>
<tr>
<td>Biotic Resources Depletion and Competition</td>
<td>Global</td>
</tr>
<tr>
<td>Land Use</td>
<td>Local</td>
</tr>
<tr>
<td>Global Warming</td>
<td>Global</td>
</tr>
<tr>
<td>Depletion of Stratospheric Ozone</td>
<td>Global</td>
</tr>
<tr>
<td>Human Toxicological Impacts</td>
<td>Global, Regional, Local</td>
</tr>
<tr>
<td>Eco-toxicological Impacts</td>
<td>Global, Regional, Local</td>
</tr>
<tr>
<td>Photo-oxidant Formation</td>
<td>Regional, Local</td>
</tr>
<tr>
<td>Acidification</td>
<td>Regional, Local</td>
</tr>
<tr>
<td>Eutrophication (including BOD and Heat)</td>
<td>Regional, Local</td>
</tr>
<tr>
<td>Odour</td>
<td>Local</td>
</tr>
<tr>
<td>Noise</td>
<td>Local</td>
</tr>
<tr>
<td>Radiation</td>
<td>Regional, Local</td>
</tr>
<tr>
<td>Casualties</td>
<td>Local</td>
</tr>
</tbody>
</table>
The principle of environmental burden assessment, as envisaged by ICI, is to gather data on environmental interventions, and then quantify the potential impact of those interventions against specified environmental impact categories. Quantifying those burdens would require an assessment using environmental classification databases such as that devised by the Centre for Environmental Science at Leiden University (CML) which provides comparative data on the potential impact of different chemicals upon categories such as global warming, acidification, photochemical smog formation, abiotic resource depletion, human toxicity, aquatic toxicity, as examples (see Heijungs et al. 1992).

The purpose of environmental burden assessment, for ICI, is to enable a global organisation to implement a system of communicating environmental issues which are not constrained by local compliance issues, and represent the global activities, rather than reporting group issues on a location by location basis.

In the case of ICI, the categories chosen are acidity (atmospheric acidification and acids to water), global warming, human health effects, ozone depletion, photochemical ozone creation, aquatic oxygen demand, aquatic ecotoxicity (metals and their compounds, other substances) (see Clarke et al. 1997, page 19). They emphasise that one can only assess impacts for each category separately; one cannot and should not aggregate the categories to give an overall burden value, since each uses different reference values and the categories are not commensurable.

Box 3 ICI Environmental Burden Method

ICI use the example of atmospheric acidification to explain how their method operates.

1. Weight of Emission (W)
   Firstly, ICI take the weight, in tonnes, of each of their substance emissions which have the potential to impact upon atmospheric acidification.

2. Potency Factor (PF)
   Secondly, ICI ascribe a potency factor to each emission. Sulphur dioxide is used as the reference substance, with a potency factor 1. Ammonia is given a potency factor of 1.88, or 1.88 tonnes SO₂ equivalent. Nitrogen dioxide gets a potency factor of 0.7, reflecting the view that it has a lower potency, regarding atmospheric acidification potential, than sulphur dioxide.

3. Environmental Burden (EB)
   Thirdly, ICI multiply the weight of emission by the potency factor to give a value for the total environmental burden for atmospheric acidification:

<table>
<thead>
<tr>
<th>Substance</th>
<th>Weight (tonnes)</th>
<th>Potency Factor</th>
<th>Environmental Burden</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonia</td>
<td>20</td>
<td>1.88</td>
<td>37.60</td>
</tr>
<tr>
<td>Hydrogen Chloride</td>
<td>3</td>
<td>0.88</td>
<td>2.64</td>
</tr>
<tr>
<td>Nitrogen Dioxide</td>
<td>4</td>
<td>0.70</td>
<td>2.80</td>
</tr>
<tr>
<td>Sulphur Dioxide</td>
<td>5</td>
<td>1.00</td>
<td>5.00</td>
</tr>
</tbody>
</table>

In this example the total environmental burden to atmospheric acidification is 48.04 units SO₂ equivalent.
1.3.3.3.2 Unilever Environmental Imprint Method

Unilever (1997), like ICI, increasingly recognise that, “As we understand more about our (Unilever’s) environmental impact, it is clear to us that we need to take a broader perspective, and generate a greater determination to seek out new solutions” (Unilever 1997, page 6).

Unilever have taken the environmental burden approach further than ICI, in that they are including economic variables, and are also endeavouring to consider the whole life cycle of their products, back up the supply through the ingredient supply chain and right down to ultimate disposal, in their case (Unilever 1997, ibid.). In the first instance, Unilever reviewed major recognised environmental issues which could be quantified upon which they were confident there was some scientific agreement. They chose eight categories - energy, global warming, acidification, human toxicity (air), photochemical smog, ozone depletion, nutrification, solid waste\(^1\).

Table 9 compares the categories chosen by ICI and Unilever with reference to the default list presented earlier (See Table 8).

**Table 9: Environmental Impact Categories Considered by ICI and Unilever**

<table>
<thead>
<tr>
<th>Category</th>
<th>Included by ICI</th>
<th>Included by Unilever</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abiotic Resources Depletion and Competition</td>
<td>No</td>
<td>Yes (a)</td>
</tr>
<tr>
<td>Biotic Resources Depletion and Competition</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Land Use</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Global Warming</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Depletion of Stratospheric Ozone</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Human Toxicological Impacts</td>
<td>Yes</td>
<td>Yes (b)</td>
</tr>
<tr>
<td>Eco-toxicological Impacts</td>
<td>Yes (c)</td>
<td>No</td>
</tr>
<tr>
<td>Photo-oxidant Formation</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Acidification</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Eutrophication (including BOD and Heat)</td>
<td>Yes (d)</td>
<td>Indirectly (e)</td>
</tr>
<tr>
<td>Odour</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Noise</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Radiation</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Casualties</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

**Notes**

(a) Unilever’s approach uses ‘energy’ as a category, and includes the resources needed to produce energy and the emissions to air produced as a result of energy production in a product life cycle.

(b) In the Unilever approach human toxicity is restricted to airborne toxins.

(c) ICI restrict their eco-toxicological analysis to aquatic systems.

(d) ICI only examine aquatic oxygen demand in this category.

(e) In fact, Unilever prefer to address ‘nutrification’ in their analysis.

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\(^1\) Both Unilever and ICI record solid waste data, although solid waste is not a category in the default list. However, ICI do not ascribe an environmental burden to their waste data.
Unilever collected life cycle data on their products and raw materials and aggregated them, followed by a conversion to potential environmental impacts on a global scale. Once this was done the information was compared with Unilever’s contribution to global GDP, providing an index comparing potential impact with economic value added. Unilever then sub-divided their operations into four business categories: industrial, homecare, personal care, and foods, and repeated the analysis; comparing environmental burden in each theme by each business category with added value provided by each business category.

Unilever conclude from their analysis of this information that,

"In most areas, Unilever’s overall environmental impact is roughly in line with its economic value added. However, we make a disproportionate contribution to the total of photochemical smog and nutrification" (Unilever 1997, page 7).

By breaking the figures down to compare the burdens against added value by business category, Unilever have found that in the case of nutrification, as an example, that while their food businesses and their home-care businesses have similar environmental burdens, the environmental impact relative to economic added value is much greater for homecare than it is for foods (see Unilever 1997, ibid.).

1.3.3.3.3 Storebrand Environmental Value Fund

Storebrand, one of Norway’s leading banks, has developed a methodology to assess the ‘eco-efficiency’ of organisations to help determine which firms to include in their environmental value fund (EVF). Storebrand, like Unilever, have adopted the Business Council for Sustainable Development definition:

"The delivery of competitively priced goods and services that satisfy human needs and bring quality of life, while progressively reducing ecological impacts, and resource intensity throughout the life cycle, to a level at least in line with the earth’s carrying capacity" (Fussler 1996).

Storebrand define an environmental value fund as one which:

- Invests in nearly all manufacturing and service industries
- Has a diversified portfolio
- Incorporates the concept of sustainable development
- Incorporates measures of eco-efficiency
- Holds proactive dialogue with companies
- Has a measurable positive effect on the environment - the EVF’s Sustainability Index (see Joly & Trevet 1997).

Storebrand use nine environmental criteria for eco-efficiency: global warming, ozone depletion, material efficiency, toxic release, energy intensity, water use, environmental liabilities, environmental management quality, product characteristics, aggregated as:

\[
\frac{\text{Eco - Efficency}}{\text{Environmental Impact Added}} = \frac{\text{Value Added}}{\text{Environmental Impact Added}}
\]
Based on the Storebrand analysis, organisations can be characterised as follows:

**Figure 5 Storebrand Evaluation of Shareholder Value and the Environment (from Joly & Trevet 1997)**

The EVF supports investment in organisations which score in the upper right quadrant, usually the upper 30% of performers in each industry sector.

1.3.3.3.4 **Dow Chemical**

Dow Chemical have adopted the eco-efficiency model and incorporated it into their product development system, using the same definition of eco-efficiency as Storebrand and Unilever. They note, however, that, “Eco-efficiency is not absolute. It will evolve as a function of innovation, customer values and economic policy instruments” (Fussier 1996). Dow use what they refer to as the ‘Eco-Innovation Compass’ to help in the evaluation of existing and new products. The compass focuses attention on six dimensions:

1. Mass (raw materials, fuels and utilities consumed in the system during the life-cycle)
2. Energy (during production, use, and disposal)
3. Environmental Quality and Human Health
4. Recyclability
5. Renewable Materials
6. Useful Life and Functionality (Fussier 1996).

In fact, there is very little to distinguish the approaches of Unilever, Storebrand, or Dow – they are all based on eco-efficiency principles. Despite Storebrand referring to 'sustainable
winners’, their approach is based on optimising the financial return from activities which can impact the environment. Sustainable development requires natural capital to be maintained in a steady state where it provides life support functions and that natural capital is either maintained or substituted with human capital of equal or greater value where such substitution is possible (such as through the use of non-renewable resources). Optimising the amount of financial capital produced by the use of given amount of natural capital is not compatible with either perspective.

1.3.3.3.5 Environmental Indicators for Mining

The major environmental effects of mining are summarised by Richards (1996).

Table 10 Environmental Effects From Mineral Extraction Operations (from Richards 1996, page 88)

<table>
<thead>
<tr>
<th>Process</th>
<th>Examples of Environmental Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil stripping and storage</td>
<td>Loss of habitats, agricultural land, archaeological features</td>
</tr>
<tr>
<td></td>
<td>Visual effects</td>
</tr>
<tr>
<td></td>
<td>Dust</td>
</tr>
<tr>
<td></td>
<td>Gases from vehicle exhausts</td>
</tr>
<tr>
<td></td>
<td>Effects on stored soils</td>
</tr>
<tr>
<td></td>
<td>Effects on water courses and aquatic organisms</td>
</tr>
<tr>
<td></td>
<td>Energy consumption effects</td>
</tr>
<tr>
<td>Overburden extraction and storage</td>
<td>Land take for storage mounds</td>
</tr>
<tr>
<td></td>
<td>Visual effects</td>
</tr>
<tr>
<td></td>
<td>Noise</td>
</tr>
<tr>
<td></td>
<td>Dust</td>
</tr>
<tr>
<td></td>
<td>Loss of archaeological features</td>
</tr>
<tr>
<td></td>
<td>Gases from vehicle exhausts</td>
</tr>
<tr>
<td></td>
<td>Energy consumption effects</td>
</tr>
<tr>
<td>Dewatering</td>
<td>Drawdown effects: ecological; impacts on water resources</td>
</tr>
<tr>
<td></td>
<td>Discharge effects: on water courses; aquatic organisms; water supply</td>
</tr>
<tr>
<td></td>
<td>Effects on cessation of pumping; mine-water discharges</td>
</tr>
<tr>
<td>Mineral extraction</td>
<td>Visual effects</td>
</tr>
<tr>
<td></td>
<td>Noise</td>
</tr>
<tr>
<td></td>
<td>Vibration (from blasting)</td>
</tr>
<tr>
<td></td>
<td>Dust</td>
</tr>
<tr>
<td></td>
<td>Loss of geological features</td>
</tr>
<tr>
<td></td>
<td>Gases from vehicle exhausts</td>
</tr>
<tr>
<td></td>
<td>Energy consumption effects</td>
</tr>
<tr>
<td>On-site transport</td>
<td>Visual effects</td>
</tr>
<tr>
<td></td>
<td>Noise</td>
</tr>
<tr>
<td></td>
<td>Dust</td>
</tr>
<tr>
<td></td>
<td>Vibration</td>
</tr>
<tr>
<td></td>
<td>Gases from vehicle exhausts</td>
</tr>
<tr>
<td></td>
<td>Energy consumption effects</td>
</tr>
<tr>
<td>Backfilling</td>
<td>Similar to overburden extraction in reverse</td>
</tr>
<tr>
<td>Restoration</td>
<td>Similar to soil stripping in reverse</td>
</tr>
</tbody>
</table>
Peck (1997) developed a set of operational environmental performance indicators he felt to be most appropriate for the mining and metals industry as follows:

**Table 11 Peck’s Candidate Environmental Performance Indicators (from Peck 1997, page 34)**

<table>
<thead>
<tr>
<th>Candidate EPI</th>
<th>Sub-category</th>
<th>Candidate Expression Form &amp; Units (Absolute or Total)</th>
<th>Candidate Expression Form &amp; Units (Relative)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td></td>
<td>Joules</td>
<td>MJ/ t-material moved</td>
</tr>
<tr>
<td>Water Resources</td>
<td></td>
<td>Litres H₂O total</td>
<td>kl/ t-material moved</td>
</tr>
<tr>
<td>Process Wastes</td>
<td></td>
<td>Litres H₂O renewable</td>
<td></td>
</tr>
<tr>
<td>Air Emissions</td>
<td>Global Warming</td>
<td>Tonnes process wastes</td>
<td>t/ t-material moved</td>
</tr>
<tr>
<td></td>
<td>Acidification (a)</td>
<td>Tonnes H⁺ or SO₂ equivalents (total of all, NOₓ etc.)</td>
<td>g H⁺ or SO₂ equivalents/ t-material moved</td>
</tr>
<tr>
<td></td>
<td>Dust</td>
<td>Tonnes particulates (air)</td>
<td>g particulates/ t-material moved</td>
</tr>
<tr>
<td></td>
<td>Ecotoxicity (b)</td>
<td>Tonnes particulates (air)</td>
<td>g ecotoxic material/ t-material moved</td>
</tr>
<tr>
<td>Effluents</td>
<td>Sediment</td>
<td>Tonnes suspended solids and sediment</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Acidification</td>
<td>Tonnes H⁺ equivalents (water)</td>
<td>g H⁺ equivalents/ t-material moved</td>
</tr>
<tr>
<td></td>
<td>Ecotoxicity</td>
<td>Litres contaminated effluent</td>
<td>g ecotoxic contaminants/ t-material moved</td>
</tr>
<tr>
<td>Ecotoxicity</td>
<td></td>
<td>Tonnes ecotoxic substances emitted in all phases</td>
<td>g ecotoxic material/ t-material moved</td>
</tr>
<tr>
<td>Acidification</td>
<td></td>
<td>Tonnes H⁺ equivalents emitted in all phases</td>
<td>g H⁺ equivalents/ t-material moved</td>
</tr>
<tr>
<td>Physical</td>
<td>Natural Systems</td>
<td>Hectares total disturbed (all land systems to be</td>
<td>Ratio total disturbed to total rehabilitated</td>
</tr>
<tr>
<td>Ecosystem</td>
<td></td>
<td>categorised)</td>
<td></td>
</tr>
<tr>
<td>Change</td>
<td>Degraded land</td>
<td>As above</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Modified</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Agricultural</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Built</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Aquatic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Environmental Incidents</td>
<td>Number of environmental incidents</td>
<td>Number of fines or penalties</td>
<td>Details for all ‘significant' incidents (a threshold for significance should be set and clearly communicated)</td>
</tr>
<tr>
<td>Conversion Factor</td>
<td>Production (d)</td>
<td>Tonnes material moved</td>
<td>t ore/ t-material moved</td>
</tr>
<tr>
<td>Management Effort</td>
<td>Not addressed in this analysis</td>
<td></td>
<td>t product/ t-material moved</td>
</tr>
</tbody>
</table>

Peck makes a number of comments on his table:

1. A separate division for acidification has been identified in the table. Such an expression would require the summation of the aqueous and airborne emissions. However, acidification, per se, may not be the most relevant expression as most weight should be given to ecosystems where the critical acidification load has been exceeded.

2. Ecotoxicity concerns are not of relevance to all operations and are thus commodity group specific. They are listed here for both air and water in recognition of the fact that a breakdown per commodity group can be shown in the chart.

3. Normalised ecotoxicity trends should take account of the commodity group specifically to avoid distortion of trends.
4. Tonnes of material moved is required at all management levels as a conversion factor for different level indicators but is not an EPI per se.

These two tables are useful as they illustrate the issues specific to a mining operation. Issues such as ozone depletion (an important consideration in the chemicals sector) are arguably less directly relevant to a mining operation than land and water use issues, for example. However, there are a number of limitations in some of the proposals which need to be understood and accounted for. These are explored in Section 1.4.
1.4 Discussion on Environmental Indicators

In order to provide a meaningful critique of the indicator frameworks presented a basis for comparison is essential. Each framework has specific objectives in mind, and each is intended to sit at a specific location in the indicator hierarchy. Some identify environmental impacts, whilst others focus on emissions without any basis for impact assessment. Some consider environmental aspects alone, whilst others refer directly to social and economic dimensions, and others still present specific measures for these aspects of performance. It is with this in mind that the assessment of the indicator sets will be made.

1.4.1 Concentration of Data

Figure 6 illustrates how the different indicator frameworks relate in terms of the extent to which the information is aggregated and concentrated.

Figure 6: Hierarchical Concentration of Indicator Frameworks Under Discussion

Peck, for example, concentrates on emissions data. ISO 14031, ICI, SETAC, Unilever etc introduce consideration of environmental conditions also and go further still in terms of concentration of data – relating performance in environmental categories to the potential impact of those emissions. The OECD and the World Bank bring in the Pressure-State-Response framework to concentrate data still further into environmental, social and economic categories. Opschoor and Reijnders and the World Resources Institute take aggregation of the components of the categories of sustainable development (as they see them) to the level of simple indicators which express broad themes such as pollution or risk.

However, it is clear that correlating concentration of data with appropriateness for use at the public, policy, or scientific level (as previously illustrated in Figure 2 and Figure 3 - see this document, pages 14 and 15) is flawed. In fact, increasing selection, rather than concentration, of data appears to be the underlying theme – as illustrated in Figure 7.
For example, global warming is a theme relevant to scientists, policy makers, and the public. ISO 14031, SETAC, OECD, WRI all use similar measures to express this theme, and while there is aggregation towards the level of the public, the key point is that this theme is selected by all sectors. But the social categories discussed by UN CSD cannot be aggregated for public consumption – there is no underlying unifying indicator of social sustainability; rather those options which are required are selected for use at the public level (for example adult literacy rate) while those which may not be required by the public (for example the total fertility rate) might not be selected. But the two cannot be aggregated.

This is of central importance to the development of environmental performance indicators for the mining industry informed by the principles of sustainable development. Indicators which are used at the global level for the mining industry – directed at public consumption and corporate policy making – do not, a priori, exclude those frameworks developed for scientific analysis of primary data. SETAC, for example, insist that their LCA framework is designed as an analytical tool, but the impact categories they develop for the classification of environmental data would be relevant at the policy and public level also (see Udo de Haes 1996).

1.4.2 Alignment with Sustainable Development for Mining

It is argued here that of greater relevance in the assessment of the indicator frameworks is the relationship between the frameworks and the interpretation of sustainable development for mining developed in Project Document 1 (see Vol.1 PD1). The frameworks developed by Unilever, Storebrand, and Dow in the industrial sector all focus on eco-efficiency – useful measures of performance for any organisation, but not indicators of environmental performance informed by sustainable development, which requires the social element to be included also.
The World Resources Institute proposes the framework most closely aligned with the needs of a sustainable mining industry. Its focus is on the three key issues relevant to mining and sustainable development – the pollution arising from mining activities, the transformation of natural capital into human capital through the depletion of non-renewable resources such as fossil fuels and the creation of social and economic welfare, and on the local sensitivity of the receiving environments in which any pollution and resource depletion takes place.

From this analysis of the underlying indicators of performance in pollution and resource depletion, it appears that there is broad consensus on which indicators are relevant and which are not. These are illustrated in Table 12.

Table 12: Extent to which various indicator frameworks agree on the key indicators for environmental performance

<table>
<thead>
<tr>
<th>Theme</th>
<th>SETAC</th>
<th>UNCSD</th>
<th>OECD Short Term Indicators</th>
<th>World Bank</th>
<th>Opschoor and Rijnbergs</th>
<th>ICI</th>
<th>Unilever</th>
<th>Peck</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acidification</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Biological Diversity</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Casualties</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Dust</td>
<td>No</td>
<td>No</td>
<td>No (a)</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Eco-toxicity</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes (c)</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Energy Use</td>
<td>No (d)</td>
<td>No</td>
<td>No</td>
<td>Yes (e)</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Eutrophication</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Greenhouse Effect</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Hazardous Waste</td>
<td>No (f)</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No (g)</td>
<td>Yes</td>
<td>(h)</td>
<td>Yes</td>
</tr>
<tr>
<td>Human Toxicity</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes (k)</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Land Condition Changes</td>
<td>No</td>
<td>Yes</td>
<td>No (l)</td>
<td>Yes</td>
<td>Yes (m)</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Land Use Changes</td>
<td>Yes (n)</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Noise</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Non-renewable resources depletion</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Odour</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Ozone depletion</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Photochemical Ozone Formation</td>
<td>Yes</td>
<td>No</td>
<td>No (p)</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Radioactive Waste</td>
<td>Yes (q)</td>
<td>Yes (r)</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Renewable resources depletion</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Sedimentation</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Water Use</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Notes
(a) Part of 'Urban Environmental Quality' Issue
(b) Although ICI identify this category in 'Future Considerations', it is not included in their Environmental Burden framework
(c) Indirectly – as part of 'Soil Pollution'
(d) Although SETAC deem energy to be an important factor, they do not consider energy all the way up to the system boundary
(e) Indirectly – as part of "Energy Supply and Structure"
(f) In the SETAC framework, only 'solid waste' is considered and, as for energy, is not considered all the way to the system boundary.
(g) ICI monitor hazardous waste, but note that regulatory definitions of the term vary from country to country.

(h) Unilever refer to 'solid waste' – arguing that regulatory regimes differ in classification of the waste.

(i) Indirectly – as part of total ‘Process Wastes’

(j) As ‘Occupational Exposures’ component of ‘Health’.

(k) OECD would like to include Land Condition, but argue that there is, as yet, insufficient data at an international level to include it yet.

(l) Indirectly – as part of ‘Soil Pollution’

(m) SETAC consider ‘land’ as an input into any system, but recognise that this is an all encompassing term that does not adequately reflect the issues associated with land use.

(n) An ‘Urban Environmental Quality’ category exists, but for the OECD, this is limited to SOx, NOx and particulates in the short term.

(o) SETAC consider ‘radiation’ rather than radioactive waste.

(p) The UNCSD identify ‘safe and environmentally sound management of radioactive wastes’ as an important component of a sustainable development indicators framework, but have been unable to determine appropriate indicators for this category.

The extent to which the different indicators themselves are appropriate for the mining sector will be discussed in Section 2 of this document. However, even though there is some consensus over the choice of pollution and resource indicators, whether or not the frameworks of which they are a part will provide a basis for assessing the environmental performance of the mining sector in terms of sustainable development remains a moot point.

**1.4.2.1 Eco-Efficiency is the Wrong Path**

The UN CSD, the World Bank, and the OECD all include a range of indicators of social and economic performance at the policy level, while at the corporate level Unilever, Storebrand, and Dow consider economic indicators of performance to help interpret performance. Indexing environmental burdens against added value remains a convenient measure, and in the context of the entire organisation, eco-efficiency is perhaps a more appropriate measure than Peck’s suggestion of tonnes of material moved as a means of comparison. To be fair to Peck, his system was designed at the level of the operations, rather than the corporation. For the aluminium or coal activities, for example, assessed in isolation from each other, a per tonne measure could allow year on year comparisons to be made within the individual operations. The major difficulty arises when one tries to aggregate the various operations, as has been discussed. Arriving at an appropriate production measure will be critical to the effective utilisation of performance indicators.

The eco-efficiency indicators were never intended to express the contribution an organisation is making to sustainable development, and thus they should not be criticised if they fail to do so. However, a mining organisation attempting to use such indicators as a proxy for environmental performance indicators informed by sustainable development will never actually know whether its environmental performance is compatible with sustainable development. It may well be that an organisation which is highly eco-efficient is more unsustainable than an organisation with low eco-efficiency if that organisation is making a low contribution to other elements of sustainable development. In fact eco-efficiency indicators such as those suggested by Storebrand, Unilever and Dow may lead a mining organisation down the wrong path.
1.4.2.1.1 Operating Environmental Burdens Over Time

A difficult issue specific to mining concerns the temporal aspects of the environmental burdens. The majority of minerals extraction is carried out using open pit rather than underground mining. Although underground mining allows a much higher level of selectivity when choosing which ores to mine, the lower production costs of open pit mining tend to offset this (see Gordon et al 1987, page 40). Gordon et al (1987) suggest that open pit mines are large, roughly conical pits. They explain that, "As mining continues in an open pit and deeper benches are opened, the width of the pit is increased by moving the benches back. As a result, the ratio of ore to overburden removed decreases with time" (Gordon et al 1987, page 41).

This has a fairly obvious implication - that environmental efficiency in an open pit mine may decline with time. As the mine becomes deeper and wider the distances involved in hauling overburden and ore out of the mine increase. The ratio of overburden to ore increases if a mine plan is adopted which follows the ore-body downward. Energy consumption will increase as haul trucks or pit conveyors have to move material greater distances with time. The attendant environmental effects of increased global warming potential, particulates releases, air pollutants release, as examples, will also increase. Taking a supply chain view, if haul trucks have to cover a greater distance, they will use more fuel and wear out more quickly and therefore the environmental burden associated with fuel and haul truck production will also increase proportionally.

Furthermore, there will be other environmental effects such as increased quantities of waste and a greater potential for physical ecosystem change as the size of the pit increases with time. This issue is specific to mining, but is fairly profound from the point of view of target setting if targets are set on a per tonne product produced or on a per tonne material moved basis. Interestingly, looking at these issues at the level of the global mining organisation may be helpful. In a diverse group, with new mines coming on stream continually and others reaching closure, then there is an argument that the organisation can be considered to be in steady state if considered holistically. Relatively high operating environmental costs at the older mines could be offset by the relatively low operating environmental costs at the newer mines.

1.4.2.1.2 Ore-Grade and Environmental Burdens

Just as mine size impacts environmental effects, the grade of ore recovered also has an impact: the lower the ore grade, the higher the ratio of waste to ore. Also, Gordon et al (1987) suggest that the amount of water used in milling ores will increase as ores become leaner (Gordon et al 1987, page 48). They go on to comment that, "Many copper mines and mills are in arid regions, such as northern Chile and Arizona; the provision of an adequate water supply in the face of competing demands for water may become difficult as very low grade ores are milled. The much larger
quantities of water that will be required for milling backstop ore\(^2\) will be an even more serious problem" (Gordon et al 1987, pages 48 to 49).

Thus, from a resource conservation and waste minimisation standpoint, perhaps it is better to process only high grade ores. If the higher grade ores are found at depth and the low grade ores are near the surface, however, then there will have to be some form of trade-off between increasing burden from enlarging the pit and decreasing burden from higher ore grades. Is the application of an aggressive cut-off strategy appropriate in the context of sustainable development. There is a rationale for using only high grade ores, and minimising the environmental effects that will be associated with prolonging the mine life. This will reduce the life expectancy of the mine, but will also reduce the environmental impact of the mine when it is operating.

There are two difficulties with this rationale. The first originates from the interpretation of sustainable development for mining explored in Project Document 1 (see Vol. 1 PD1). In removing just the high grade ore, although the mining organisation is reducing the rate of depletion of the productive base, how useful to future generations will the remaining low grade ore be? Will it be possible to generate an economic return in the future if all the high grade ore has gone? While not minimising current pollution levels, would adopting a strategy which removed both high and low grade ore be more consistent with long term sustainability?

The second difficulty concerns the sustainable development of communities near the mines. Peck's methodology makes no attempt to address social issues, yet without coverage of the issues introduced by the UN CSD's approach, any framework is unbalanced. This issue has been discussed in Project Document 1 (see Vol. 1 PD1, Section 1.4), and it is clear that no assessment of efforts towards sustainable development in mining can be meaningfully measured without a recognition of the importance of issues relating to the local community. In short, eco-efficiency indicators fail to recognise that declining eco-efficiency may still be a less unsustainable situation than improving eco-efficiency in circumstances encountered routinely by the mining sector.

1.4.2.2 The Policy Indicators are too General, Require Data which may not be Available, and Mining Companies won’t be able to Determine Cause and Effect

1.4.2.2.1 Too General

Even though OECD, World Bank and the UNCSD include a wide range of indicators for economic and social elements, there is no guarantee that these will be useful to mining organisations. The work carried out by the OECD, the World Bank, the United Nations and to a certain extent by the WRI, is oriented towards review of national and international themes

\(^2\) Currently the major sources of copper, for example, are sulphide ores, containing ~0.1% Cu or more. Common silicate rocks also contain copper, at concentrations of <0.1% Cu, but due to their composition (all the copper is locked in solid solution in silicates) at least ten times more energy per kg Cu is required for processing. This divide is referred to as the mineralogical barrier. Backstop ore refers
rather than industry or location specific issues. The OECD system proposes indicators that measure environmental pressures, and environmental conditions, and then goes on to assess societal responses. It is against this framework that national governments have been reporting on their progress to the United Nations. This is not intended as a criticism of the OECD work. It is recognised that the core set was developed for the specific objective of assisting the OECD in environmental performance reviews for individual nations. However, this means that the OECD indicators are possibly better suited to evaluations of national performance rather than corporate performance.

Much of the classification into economic, environmental, social or institutional areas is arbitrary, due to the strong inter-relationships involved - consumption of water, pesticides etc. could be classified as economic or environmental (see Gouzee 1996). Clearly, some of the indicator sets are more relevant to mining than others - measures of intensity of natural resource use, lifetime of proven energy reserves, proven mineral reserves, and land use changes, as examples, are very specific to issues directly related to mining. Others can be influenced by mining in developing countries in an indirect manner - environmental protection expenditures, infrastructure expenditure, literacy rates, health care and GDP per capita are examples. Others are much more difficult to influence in a measurable way by mining activities.

1.4.2.2.2 The Necessary Data for the Indicators are Not Always Available.

The second difficulty with the institutional variants concern data availability. When discussing a core set of indicator values, the OECD acknowledged that much of what they feel needs to be measured is limited by information and methodology deficiencies that will only be resolved in the medium to long term. A similar limitation constrains the sustainability indicators - there are many blanks in the matrix as a result. The OECD refer to this issue throughout their report. For the first theme, climate change, alone: the OECD observe that although data on CO₂ emissions are well covered,

"Estimates on methane exist but country coverage is smaller, and there is wide divergence between estimates from different sources. Information on halons is very limited. Significant measurement problems exist with N₂O. ... Measures of energy efficiency are not readily available, data on government R&D expenditure on energy efficiency and alternative energy source are partly available, implicit and explicit tax rates on CO₂ have also been evaluated although coverage is incomplete" (Group on the State of the Environment, pages 21 to 22).

The impact this will have on indicator development within a global mining organisation is indirect rather than direct, however. Data quality within an organisation is controllable, and will depend, largely, on internal systems. However, it would be useful to track progress in a wider context. For example, it may be helpful to identify the relative contribution an organisation makes to the various environmental pressures in the countries where it operates.
It may also be useful to track environmental initiatives by an organisation such as R&D on environmental improvements in the context of national government expenditure trends.

1.4.2.2.3 Determining Cause and Effect is Problematic

A major difficulty in utilising indicators of sustainable development like those proposed by the UN CSD beyond national and international policy levels concerns cause and effect. From the point of view of any organisation investing in any development context - whether in the more developed countries or the less developed countries - it is important to determine the effect of any programmes to assist in bringing about sustainable development. Just as it is important to be able to track the potentially negative consequences on sustainable development of an operation, it is also important to monitor those consequences which could be positive.

Identifying causality in programmes such as life expectancy at birth, net migration rates, adult or juvenile literacy rates, population living below poverty line, potential scientists and engineers per million population, as examples, will be difficult if both company and national government have specific programmes aimed at these areas. In the absence of existing programmes to improve literacy, health care initiatives, drinking water infrastructure, etc., then it becomes easier to track the impact of corporate initiatives in these areas.
1.5 Conclusions

This review of environmental performance indicators offers five findings to take forward into Sections 2 and 3 for the development of the indicator framework for global mining organisations.

1.5.1 Indicators have a Role to Play in Sustainable Mining Organisations

Indicators play an important role in helping communicate progress towards environmental objectives in mining organisations. Used well, they simplify complex data and help actors assess where action is needed to bring about improvement.

1.5.2 Any Indicator Framework must be Understood in the Context of a Hierarchy

Not all indicators provide useful information to all audiences. At the business unit level, for example, data on global warming may be required for different activities and at different locations. At the corporate level, the contribution of the business to global warming may be the important indicator, while at the policy level, the contribution of the mining sector to global warming may be the key issue. At each level, data is concentrated and aggregated according to the needs of the audience. For some issues, however, the important feature of the hierarchy will be selection of information, rather than aggregation. Some data will have a role for local needs, but not be required, even in aggregated form, by policy makers.

1.5.3 How Sustainable Development is Understood and Incorporated into the Indicators makes a Significant Impact on the Indicators which Result.

Those environmental indicators developed with sustainable development in mind differed markedly from those without. Furthermore, the specific interpretation of sustainable development which underpinned the indicators was critical. The steady-state indicators were no more useful than the indicators based on economic progress. As concluded in Project Document 1, sustainable development for mining is based on environmental, economic, and social dimensions, reflecting the role of the industry in helping transform natural capital into human capital where resource extraction takes place, provided that non-substitutable life-support functions provided by natural capital are not compromised. Any framework which either does not recognise this (such as steady-state), or recognises only part of this (such as eco-efficiency), will not adequately reflect environmental performance in mining in the context of sustainable development.

1.5.4 Indicators Can Focus on Environmental Performance and Management Performance.

ISO 14031, Peck, and Storebrand all identify the need for indicators such as ‘environmental management quality’, ‘environmental liabilities’ or ‘environmental incidents’ – identifying that the quality of environmental management will impact on whether environmental performance will improve or deteriorate in the future. In the literature, there was also
agreement that an important quality for an indicator is ease of interpretation (see Group on the State of the Environment 1993; Australian Department of Environment, Sports and Territories 1996; Environment Canada 1991; O'Connor et al 1995; Hammond et al 1995). The information presented must be meaningful to the audience and easy to understand. It is contended that in the cases of these indicators proposed it is not immediately clear how the information will be measured or presented meaningfully.

For example, both the Storebrand EVF and Peck suggest that ‘Environmental Management Quality’ is a suitable environmental performance indicator. It is clear that sound environmental management practices are likely to lead to a greater reduction in environmental pressures than an absence of such practices. However, it is not obvious how environmental management quality could be indicated. The presence of a certified environmental management system (EMS), such as ISO 14001, could indicate sound environmental management practices, but the system itself does not guarantee actual environmental performance, just an improvement from one year to the next. Such an indicator will provide no information on the relative quality of environmental management of two organisations of which either both or neither have a certified EMS.

Storebrand also refer to ‘environmental liabilities’. As with environmental management quality indicators, this would provide background information environmental pressures, but is more appropriate as a financial indicator, since it suggests future costs to the organisation. However, it is not clear how the information needed for such an indicator could be interpreted, unless a specific financial cost of liabilities could be ascribed. Peck’s proposal for an assessment of environmental incidents provides an indication of the quality of environmental management, and a historical trend for comparison - whether incidents and prosecutions are increasing or declining in number or severity. In the case of prosecutions, however, this does not provide any other specific information, since different regulatory regimes apply in different locations. In the case of environmental incidents, Peck correctly specifies that, “A threshold for significance should be set and clearly communicated” (Peck 1997, page 34).

This is not necessarily a reason to discard environmental management indicators out-of-hand. More, it is perhaps a challenge for the longer term. In this project, however, the emphasis will be very much on the ends rather than the means to those ends. While the challenges presented above will not be addressed in this research, the immediate issue of establishing the ends of significance will.

1.5.5 There are Numerous Issues which Depend on Local Circumstances

This was either recognised explicitly or implicitly by a number of the methodologies proposed. SETAC recognised that the various categories they considered as part of their framework were manifested as local, regional or global concerns. ICI similarly recognised that aquatic eco-toxicity, for example, depended on local sensitivity data for its significance and Peck made reference to critical loads in his otherwise emission-based framework. The OECD, World Bank and OECD frameworks could accommodate local and regional concerns by applying their policy frameworks at the local level, but for many of their environmental
categories failed to consider local sensitivity adequately – with the UNCSD framework talking about emissions of sulphur oxides, nitrogen oxides etc without explaining how their significance was to be assessed.

As was shown in the discussion on eco-efficiency, for mining local circumstances are of enormous significance and thus any indicator framework has to take into account local sensitivities. While water use may be of global importance, its significance in the sustainable development of a community depends on how much water is available for use, rather than how much is used.

Thus, there is clearly a place for performance indicators in a sustainable development framework that embraces ecological social and economic dimensions. For organisations as large and diverse as those in the mining industry, with so many different audiences for information, there is a need to find indicators of performance which are representative of reality, but sufficiently aggregated to allow audiences to assess performance meaningfully. There is a need to reconcile the tensions between global and local sensitivities. There is a need for both Group/ Product Group measures of performance, and a potential need for additional measures at the local level based on dialogue with local stakeholders. This approach is consistent with the ‘onion-ring’ philosophy discussed by MERN earlier (see Vol.1 PD1, Section 1.5).

While it is recognised that it will not be possible to address all of these needs in this work, it is suggested that it should be possible to develop aggregated measures of environmental performance in the biophysical dimension informed by the principles of sustainable development for mining which embraces economic, bio-physical and social dimensions at both the local and global level. This will be the focus of the next stages of this work – Sections 2, 3 and 4.
2. Establishing the Methodology for an Environmental Burden for Rio Tinto

2.1 Introduction to the Environmental Burden Phase

2.1.1 Objectives

The objective for this stage of the work is to generate an environmental burden framework for global mining organisations. This requires agreement as to the appropriate measurement categories for mining organisations and an exploration of limitations of currently available knowledge in the assessment of performance in these categories. Then the expressions of aggregate performance for mining organisations in these categories can be developed. Where there are methodological gaps in the analysis of the data then a decision will be taken as to whether the resolution of these methodologies falls within the scope of this work.

It is intended to produce as complete an understanding as possible of the impact global mining operations have upon the global environment. This section concentrates on measures of aggregate environmental performance, rather than relative measures of performance; the latter will be addressed in the subsequent section on development of normalisation factors.

2.1.2 Measurement Categories

Table 12 (see this document, page 37, Table 12: Extent to which various indicator frameworks agree on the key indicators for environmental performance) illustrates the extent to which the indicator frameworks proposed by SETAC (see Udo de Haes 1996), UNCSD (see Gouzee 1996), OECD (see Group on the State of the Environment 1993), the World Bank (see O'Connor et al 1995), Opschoor and Reijnders (1991), ICI (see Clarke et al 1997), Unilever (1997), Peck (1997), agree on the key indicators for environmental performance.

As can be seen, for some categories, such as global warming and acidification, there is broad consensus that they should be included as part of an environmental indicator framework, while for others, such as resources depletion and land use changes, there does not seem to be consensus. Rather than pursuing the most popular measurands, the intention of this section of the work is to establish which are relevant to a global mining organisation attempting to develop indicators of environmental performance informed by the principles of sustainable development for mining.

This objective will be fulfilled by reviewing each category in turn to establish whether there is a need for an indicator for that category in mining, given that some of the frameworks were developed for use by governments rather than corporations. If the need for such an indicator can be found, then an assessment will be made regarding the availability of data within Rio Tinto to fulfil the requirements of such an indicator.
2.2 Casualties and Noise

2.2.1 Casualties and Noise from Global Mining Operations

There is no question that mining operations, like any industrial activity, can have an impact upon the physical safety of its employees and the health of both employees and communities if poorly managed.

2.2.1.1 Casualties

In 1997 the fatality rates for employees and contractors of mining companies in the United States was approximately 12 fatalities per 100 million hours worked, while for the western Australian mining industry, the figure was approximately 8 fatalities per 100 million hours worked (see Rio Tinto 1997a, page 6). The reporting of casualty data is already included in the annual reporting systems of some resources companies. Warhurst (1998) carried out a survey of corporate social responsibility in mining companies. She found that of the 37 mining companies who provided information, only 11 indicated that they regularly audit and report on health and safety performance – which would cover casualties. Of these eleven, five had their headquarters in North America, four in Europe, and two in Australia. These eleven resource companies were mainly either global operators themselves (e.g. Rio Tinto, Anglo-American, WMC, Preussag, Noranda, Inco) or were subsidiaries of global operators (e.g. Witwatersrand).

While casualty rate is a key indicator of performance in mining, and an indicator currently included in the annual reporting systems of many of the global resources enterprises, it is argued here that casualty data is not an indicator of environmental performance in terms of the bio-physical environment, but is an indicator of wider corporate responsibility. This point is certainly open to debate, but for the purposes of this research, it is not considered an appropriate indicator of environmental performance.

2.2.1.2 Noise

In the context of this research, noise is understood to be “Sound that is socially or medically undesirable, i.e. any sound that intrudes, disturbs, or annoys. Very high levels of sound can cause hearing damage” (Porteous 1993, page 246). As O’Cinneade (1997) points out, “In addition to the risks to human health, noise pollution has negative ecological impacts on species sensitive to noise” (O’Cinneade 1997, page 390).

At the human health level, it is argued that noise exposure is certainly an indicator of occupational health, and since mining and ore processing involves the use of explosives, heavy industrial diggers, and the operation of mills and grinders, there is potential for employees, and local communities, to be exposed to unacceptable levels of noise. Although exposure to noise and its effects are felt very much at the local level, it remains a global issue for mining companies. However, as with casualties, it is argued here, that the human health effects of noise exposure are not relevant to environmental performance indicators in particular.
At the species sensitivity level, it is acknowledged that noise could be one of many factors contributing to loss of species in a particular area, and as such should be scrutinised where it is felt to be relevant. But it is suggested that a more useful indicator of environmental performance would be the actual species diversity, rather than the noise levels. On this particular issue, it should be possible to observe the effects of noise, and use them as indicators of environmental performance, rather than focus on just one of the potential causes of that effect.

It is concluded that for a global mining organisation, casualties and noise levels are useful indicators of safety and health performance, but are not appropriate for the development of key environmental performance indicators.
2.3 Eutrophication

2.3.1 Eutrophication from Global Mining Operations

Porteous (1993) defines eutrophication as, “the natural ageing of a lake or land-locked body” (Porteous 1993, page 148). Böckman et al. (1990) explain that eutrophication is due to an increasing abundance of nutrients in water (see Böckman et al 1990, page 155). Mannion (1992) points out that when this process is caused by human intervention, it is referred to as ‘cultural eutrophication’ (see Mannion 1992, page 175).

Böckman et al identify an increase in algae biomass as the primary effect of eutrophication, with a change in relative species abundance also likely. As the frequency of algae blooms increases, the probability of a toxic bloom also rises. The algae consume valuable oxygen and block sunlight from lower strata. Giller et al. (1997) state that “The sources of nutrients that can cause cultural eutrophication are essentially:

- Urban sewage effluent discharge which may be in the form of treated or untreated sewage or;
- Agricultural activities, especially animal wastes and fertilisers which are found particularly in the Western world and the United States” (Giller et al 1997, page 279)

The dominant nutrients in this process are nitrogen and phosphorus, according to Böckman et al. Nichols et al. (1996) argue that eutrophication of terrestrial ecosystems may also be impacted by deposition of atmospheric emissions of NOx in addition to the factors identified by Giller et al.

Mining, then, could potentially contribute to eutrophication in two ways:
1. Through the combustion of fuels leading to releases of NOx which could subsequently be deposited on an area causing eutrophication.
2. Through the production of fertilisers from mined phosphorus.

However, the mining of phosphorus is limited to a small number of operations, and is a commodity specific issue, rather than applying to global mining companies with activities across a broad range of commodities. Lindfors et al (1995) have calculated the maximum eutrophication potentials of various scenarios, expressed in kg PO4 equivalent per kilogram. Phosphorus released to water, for example has a eutrophication potential (EP) of 3.06, nitrogen to water an EP of 0.42. Releases of NOx to air, the possible release in this category relevant to mining, has a maximum EP of 0.13, over 20 times less that of phosphorus to water and over 3 times less that of nitrogen releases to water.

At this time, it is suggested that eutrophication should not be included as a key indicator of environmental performance for mining, as it is likely that global mining companies have a net contribution to this category which is negligible compared to other sources of nutrients, such as fertilisers and sewage.
2.4 Hazardous Waste

2.4.1 Hazardous Waste from Global Mining Operations

According to the United States Resource Conservation and Recovery Act (RCRA), hazardous waste means, "A waste, or combination of wastes, which, because of its quantity, concentration, or physical, chemical or infectious characteristics may cause or significantly contribute to an increase in serious irreversible, or incapacitating reversible illness or pose a substantial present or potential hazard to human health, safety, welfare, or to the environment when improperly treated, stored, transported, used or disposed of, or otherwise managed, however, not to include solid or dissolved materials in irrigation return flows or industrial discharges which are point sources subject to permits under section 402 of the Federal Water Pollution Control Act of 1967 as amended, or source, special nuclear, or by product material as defined by the Atomic Energy Act of 1954" (US Environmental Protection Agency 1999).

There is little doubt that mining can contribute to the generation of wastes which meet this definition. Acid wastes from sulphide processing, gangues containing arsenic, smelter slag, waste oils, waste from electrolytic refining, engine lubricants, just as examples, could all be considered as hazardous waste under definitions such as this.

The difficulty, however, concerns the classification of specific wastes as hazardous and non-hazardous. A number of nations have tried to interpret definitions of hazardous waste through wide-ranging legislation specifying which kinds of wastes specifically must be classed as hazardous. In the United States, for example, the Federal Environmental Protection Agency (EPA) states that the characteristics of hazardous waste are, “Ignitability, corrosivity, reactivity, EP toxicity” in USEPA Definition 40 CFR 260.10. (Riemann 1997, page 697).

However, in the European Union, Directive 91/689/EEC on hazardous waste considers the following properties as relevant, “Explosive, oxidiser, highly flammable, flammable, irritant, harmful, toxic, carcinogenic, corrosive, infectious, teratogenic, mutagenic, water contact liberates toxic gas, source of hazardous substance, ecotoxic” (European Commission 1991)

This is a slightly more prescriptive classification than that used by the USEPA. This is a substantial difficulty concerning the use of hazardous waste as an indicator of environmental performance for global organisations. Individual operations are likely to manage hazardous waste in line with the regulatory regime under which they fall. For US operations, this will be EPA, for European operations, this will be EC DGXI etc. Adding the total values for each operation will give an accurate value of the amount of 'hazardous waste' generated, but it will not provide data which is meaningful or transparent, since wastes from one operation considered as hazardous may not be for another.

A second limitation with the use of hazardous waste as an indicator of environmental performance concerns the relative weighting of different components. One tonne of waste containing material from the treatment of infectious diseases, solvents, and acids, for example, may be considerably more 'hazardous' than one tonne of waste containing fly ash, grease and flue-gas treatment wastes. As Riemann (1997) points out,
"It must be understood that these compounds or wastes or substances that come within the definition change with time as we learn more about their impacts. Additionally, the number of synthetic organic compounds is increasing daily and many of these are considered hazardous" (Riemann 1997, page 696).

Finally, as the United Nations CSD (1996) point out, even though they suggest that hazardous waste might be included in an indicator framework,

"The quantity of the hazardous wastes generated alone may not reflect changes towards a more ‘sustainable’ society. Consideration of the nature of the different kinds of hazardous wastes generated would be a better indicator of sustainable development progress. Data availability and accuracy represents another limitation of this indicator. Finally, the nature of waste itself makes it sometimes difficult to use them as indicators because wastes are often mixed and not produced to specifications" (Waller-Hunter 1996).

For these reasons, it is argued here that hazardous waste is not an appropriate environmental performance indicator for a global mining operation. However, individual sites within such operations may see value in using hazardous waste as a key performance indicator for their particular circumstances. For example, a site whose principle hazardous waste is sulphuric acid, may find it helpful to use a hazardous waste indicator to focus attention on the production of this waste stream.
2.5 Ozone Depletion

2.5.1 Ozone Depletion from Global Mining Operations

Porteous (1993) explains that there is a layer of ozone surrounding the earth, formed by the splitting of molecular oxygen into highly reactive oxygen atoms – which then combine to form ozone (O₃). The energy to break the molecular bonds is supplied by ultraviolet radiation, and an ‘ozone shield’ is formed, with a maximum concentration between 15 and 30 km from the earth’s surface. This shield protects the biosphere below from radiation, and thus reduces the incidence of radiation induced cancer in humans (Porteous 1993, page 273).

Certain gases have the potential to disrupt the ozone shield by reacting with the ozone molecules. Chlorine, for example, will act as a catalyst as follows:

\[
\text{Cl} + \text{O}_3 \rightarrow \text{ClO} + \text{O}_2 \\
\text{ClO} + \text{O} \rightarrow \text{Cl}_2 + \text{O}_2
\]

This chlorine is made available through release of chlorine containing chemicals, and chemicals which can react to increase the levels of chlorine liberated from these chemicals. Such chemicals include chlorofluorocarbons (CFCs) and halons. The use of CFCs has been associated with aerosols, refrigerants, and solvents, (see Kiely 1997, page 361) while halons are used in fire extinction. Different chemicals have different ozone depletion potentials (ODPs) which have been calculated by the World Meteorological Organisation (WMO).

In principle, as an indicator of environmental performance, ozone depletion is particularly relevant, since local releases contribute to a global issue. However, this category is associated with the production and consumption of particular chemicals. The chemicals industry, of which ICI is a part, is rightly concerned with ozone depletion from its releases. For the mining industry, however, direct releases of ozone depleting chemicals will be restricted to very limited releases form refrigerants in office air conditioning systems etc, rather than a significant aspect of production.

For this reason, it is argued that stratospheric ozone depletion is not a key indicator of environmental performance for a global mining organisation.
2.6  Photochemical Ozone Formation

2.6.1  Photochemical Ozone Formation from Global Mining Operations

This indicator was suggested by just three groups – the Society for Environmental Toxicology and Chemistry (SETAC), Unilever, and ICI. Photochemical ozone formation has been associated with local human respiratory conditions and damage to plants. While the depletion of ozone in the upper atmosphere exposes the biosphere to radiation, the formation of ozone in the lower atmosphere can have toxic effects.

The European Environment Agency (1998) describe the theme thus,

"Photochemical ozone formation is caused by degradation of organic compounds (VOCs) in the presence of light and nitrogen oxide. The biological effects of photochemical ozone can be attributed to biochemical effects of reactive ozone compounds. Exposure of plants to ozone may result in damage to the leaf surface, leading to damage of the photosynthetic function, discolouring the leaves, die-back of leaves and finally the whole plant. Exposure of humans to ozone may result in eye irritation, respiratory problems, and chronic damage of the respiratory system” (European Environment Agency 1998).

Volatile organic compounds are associated with the petroleum and petrochemicals sectors, which could suggest why they are appropriate for companies engaged in petroleum and chemicals manufacture and organisations concerned with the chemicals industry. As will be discussed subsequently in Project Document 3 – “Environmental Management in a Global Mining Company” - nitrogen oxide is associated with fossil fuel combustion (see Vol.3 PD3, Section 9.3), so could perhaps be relevant to a wider range of industries than the chemicals sector. However, it is suggested that indirect effects from energy use is insufficient an argument at this time to merit the inclusion of the theme as an indicator of environmental performance.

Thus for some global mining organisations - such as WMC, Rio Tinto, Anglo-American - photochemical ozone depletion will not be a relevant environmental performance indicator, since they have no interests in the petroleum and petrochemicals sectors. Others, such as BHP, BP-Amoco and Shell, will find such an indicator relevant, as they are engaged in both petroleum production and mining. In fact, Broken Hill Proprietary (1999b), BP-Amoco (1999) and Shell UK (1998) do include photochemical oxidant formation / VOC data in their annual environmental reports.
2.7 Radioactive Waste

2.7.1 Radioactive Waste from Global Mining Operations

According to Giller et al. (1997), radioactivity occurs naturally in sea-water, principally from potassium-40. The principle anthropogenic inputs of radioactivity into the oceans are from nuclear weapons testing and liquid wastes from nuclear power stations and fuel reprocessing plants (see Giller et al 1997, page 298). In addition, however, uranium mining activity will produce radioactive wastes. In particular radio-nuclides are released in similar concentrations as in the original ore, predominantly discharged in solid and liquid wastes. According to Ripley et al. (1996), the most important aspect of the long-term control of radiological and chemical pollution from uranium mining is the proper containment of tailings (Ripley et al 1996, page 208).

Ripley et al also state that,

"Uranium mining is unique [compared to other mining activities] in that its purpose is the extraction and concentration of radioactive materials that can cause short-term and long-term damage to the tissues of humans and other organisms... Because waste-rock, tailings, and the waste products of military or nuclear fuel use are radioactive, design and operating decisions will have very long-lasting ramifications" (Ripley et al 1996, page 201).

For mining operations engaged in uranium extraction, then, radioactive waste will be an important indicator of environmental performance. However, at the global level of the mining organisation engaged in the extraction of many minerals, it is suggested that radioactive waste may not be an appropriate performance indicator for the entire organisation.
2.8 Non-renewable Resources Depletion

2.8.1 Non-renewable Resources Depletion for Global Mining Organisations

A non-renewable resource (also referred to as an ‘abiotic’ resource), according to SETAC (1996), is “an object that can be extracted from the environment to serve as an input for the product system, and that is distinguished from a biotic resource by its non-living nature. Examples of resources that are generally considered to be abiotic are mineral ores, fossil fuels, and water” (Udo de Haes 1996, page 32). In the 1996 SETAC work, Finnveden (1996) further classifies abiotic resources into:

- Deposits (e.g. mineral ores) which “are resources that have no, or very limited re-growth possibility within a relevant time horizon (human lifetime(s)), and are therefore depleted when extracted.”
- Funds which “are resources that may, or may not, be depleted. When the funds are harvested, they will decrease temporarily, but since they are intrinsically renewable, they will re-grow if they are not irreversibly damaged”
- Natural Flow Resources which “are continuously flowing resources from which a society can deflect a flow and the use the resource. Although the flow resources can be affected by human activities, they are essentially non-depletable by humans.” (Finnveden 1996, page 40).

For the purposes of this section, the resources under consideration are ‘deposits’. However, water resources will also be considered in a stand-alone section.

According to UNEP (1997),

“A working definition of mining could simply be ‘the extraction of minerals from the earth’...although mining can also be seen as a process that begins with the discovery of mineral deposits and continues through ore extraction and processing to the closure and rehabilitation of worked out sites.” (Anon. 1997e, page 4).

If the raison d’être for mining is to discover and extract non-renewable resources such as minerals, then it seems appropriate to include a measure of any resource depletion in an environmental performance framework.

According to Hodges (1995)

“In the five decades since World War II, the volume of non-fuel minerals consumed has exceeded the sum total extracted from the Earth throughout all of human history” (Hodges 1995, page 1305).

For example, world copper consumption between 1970 and 1997 has increased from around 7.5 million tonnes p.a. to around 13 million tonnes p.a. Over the same period world gold fabrication has increased from just under 1.5 million tonnes to 3.5 million tonnes, primary aluminium consumption has increased from around 10 million tonnes to over 20 million tonnes (see Rio Tinto 1998c; Stockwell et al 1999).

And the trends for many commodities point towards increased consumption in the future, rather than lower. If the world population doubles from 5.7 billion in 1995 to 10 to 12 billion...
in 2035 (see Hodges 1995, page 1305) then it seems entirely possible that demand for commodities will increase in the near term to meet the demands of the growing population for commodity intensive goods (e.g. power lines, houses, water supplies etc.)

The implications of an increasing rate of consumption of non-renewable resources for sustainable development were discussed in some detail in Project Document 1 – “Mining and Sustainable Development”. The debate centred on whether or not economic growth would inevitably lead to the depletion of the earth’s natural resources, or lead to such technological improvements that resource consumption would never become a threat to sustainable development (see Vol.1 PD1, Sections 1.3.3 to 1.3.6).

For mining, non-renewable resource depletion is not in conflict with sustainable development provided that the capital is used to fund human development. Then society is able to decide whether to develop alternatives to those non-renewable resources, or develop more efficient technologies for finding and extracting those non-renewable resources, according to its wishes.

However, whichever viewpoint one takes on non-renewable resource depletion – non-renewable resource depletion remains a critical performance indicator. It either indicates how quickly society is heading for disaster, or to what extent society should be innovating to reduce that depletion.

2.8.1.1 Measures of Reserves

In developing an indicator framework for non-renewable resource extraction, it is necessary to understand the different types of classification for mineral assets. There are four main measures for the reserve bases of the earth: static life, reserves, reserve base, and total world resources.

2.8.1.1.1 Static Life of Identified Reserves.

The static life of a mineral is expressed in years, and expresses the expected lifetime of known global economically recoverable reserves, at current levels of production using existing technology (see Crowson 1997, page ix).

2.8.1.1.2 Reserves

The ‘reserves’ of a mineral are the recoverable materials in the reserve base that can be economically extracted or produced at the time of determination (see Crowson 1997, page viii).

2.8.1.1.3 Reserve Base

The reserve base represents the in-place demonstrated (measured plus indicated) resource from which reserves are estimated, and including those resources that are currently economic (reserves), marginally economic (marginal reserves), and some of those that are currently sub economic (sub-economic reserves) (see Crowson 1997, ibid.).
2.8.1.4 Total World Resources

This value represents the total amount of a mineral that has been estimated to be either available or potentially available. This value is much broader (and speculative) than the value for the reserve base as it includes values for minerals thought to exist in deep sea nodules, for example. Figure 8 illustrates how these different classifications are interrelated.

Figure 8: Mineral Resource Classification System of the US Bureau of Mines and US Geological Survey (based on McKelvey 1973)

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2.8.1.2 Appropriate Measures of Non-renewable Resources

The expression of non-renewable resources in terms of their static life may not be particularly helpful here, since they are expressions based on existing production volumes and techniques. Both of these are dynamic, not static, and for the purposes of an indicator are overly simplistic. Likewise, the use of total world resources as an index may not prove particularly helpful either - the methods used are highly speculative.3

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3 As discussed in Section 1 (see this document Section 1.4.2.1.2) in theory there are enormous resources of copper at very low concentrations in common silicate rocks. The current major sources of copper are sulphide ores, containing ~0.1% Cu or more. Silicate rocks contain copper at concentrations <0.1%Cu. Due to the fact that all the copper is locked in solid solution in silicates, at least ten times more energy per kg Cu would be required to process these silicate rocks. So there are huge potential reserves, but there is a significant mineralogical barrier to overcome before they could be classed as 'economically recoverable'.

Project Document 2 - Development of Key Corporate EPIs for Sustainable Mining Organisations
The two most useful measures, it is suggested here, are reserves and reserve base. The value for the reserves of a mineral will vary from year to year as economic conditions change and production technology changes - improvements will lead to cut-off grades being reduced so that recoverable reserve values increase. Reserve base values will change as a result of exploration activity - as more reserves are identified they are added to the reserve base. These changes are relevant to sustainable development - as the represent the reserves of minerals available to society - with reserves incorporating economic provisions and the reserve base showing the potential reserve available.

Owens and Cowell (1996), ignoring the distinction between marginal reserves and economic reserves and expressing the vertical component of the framework simply as “increasing degree of economic feasibility” (Owens & Cowell 1996, page 15), suggest that environmental considerations should be placed onto a third axis, thus creating what they refer to as ‘A McKelvey Cube’. They argue that,

“An alternative approach [to the McKelvey Box], compatible with certain a priori environmental constraints, would be to make environmental considerations integral to the definition of reserves, in effect introducing a third dimension and transforming the McKelvey Box into a cube. Only that proportion of the resource base which could be extracted without unacceptable environmental consequences would then be included in the reserves category” (Owens & Cowell 1996, page 16).

Whether a box or a cube is preferred, it is argued, depends on whether one takes the view that environmental and social preferences can be integrated directly into the economic feasibility assessment, or whether they cannot, and must instead be seen on a different dimension. Either way, however, the classification of mineral resources is dynamic, driven by social (economic, cultural and technical) factors and physical environmental limits.

According to Hodges (1995) and Crowson (1997), world reserves have been increasing at a faster rate than consumption in the past few decades. Both reproduce Table 13, from the US Bureau of Mines, to illustrate their argument:
Table 13: The Growth of World Reserves of Selected Commodities

<table>
<thead>
<tr>
<th>Decade</th>
<th>Copper</th>
<th>Lead</th>
<th>Zinc</th>
<th>Bauxite</th>
</tr>
</thead>
<tbody>
<tr>
<td>1940s</td>
<td>91</td>
<td>31-45</td>
<td>54-70</td>
<td>1,605</td>
</tr>
<tr>
<td>1950s</td>
<td>124</td>
<td>45-54</td>
<td>77-86</td>
<td>24,164</td>
</tr>
<tr>
<td>1960s</td>
<td>280</td>
<td>86</td>
<td>106</td>
<td>24,164</td>
</tr>
<tr>
<td>1970s</td>
<td>543</td>
<td>157</td>
<td>240</td>
<td>22,700</td>
</tr>
<tr>
<td>1980s</td>
<td>566</td>
<td>120</td>
<td>295</td>
<td>23,200</td>
</tr>
<tr>
<td>1993</td>
<td>590</td>
<td>130</td>
<td>330</td>
<td>28,000</td>
</tr>
</tbody>
</table>

Hodges elaborates,

"Despite an apparent limit to resources, adequate world mineral supplies have been maintained. Major new discoveries in recent decades... have resulted from advances in geologic knowledge, new technologies, and in the case of gold, higher real prices. Technological improvements in mining and metal recovery have enabled massive earth-moving operations, extraction of lower grade ores, and greater efficiencies in production" (Hodges 1995, page 1306)

Crowson highlights the influence of market prices on reserve levels saying that,

"In the first half of the eighties, a decline in prices relative to costs led to reduction in reserves, or hitherto economic ore-bodies became uneconomic. The position was not fully reversed in the second half of the decade. Hence production tended to rise more rapidly than reserves in the 1980s, but not by enough to invalidate the longer term trends" (Crowson 1997, page xvi).

Thus reserves and the reserve base are argued to be the most useful measures of non-renewable resources levels, since they reflect the dynamism of society's demand for mineral non-renewable resources, and, taken together, one can identify whether a commodity is in high demand (where reserves will tend towards the full reserve base) and in relatively low demand (where reserves will tend away from the full reserve base).

Table 14 illustrates the relative sizes of global reserve and reserve bases in a number of commodities⁴. Figures for global reserves are derived from the Minerals Handbook 1996-1997 (Crowson 1997).

---

⁴ Rio Tinto data have been calculated and / or extrapolated from data in Rio Tinto, 1998c, pages 14 to 36.
Table 14: Relative Sizes of Reserves and Reserve Bases for Commodities

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Bauxite</td>
<td>23,000 Mt</td>
<td>28,000 Mt</td>
</tr>
<tr>
<td>Borate (B₂O₃)</td>
<td>161 Mt</td>
<td>630 Mt</td>
</tr>
<tr>
<td>Coal</td>
<td>1,031,611 Bt</td>
<td></td>
</tr>
<tr>
<td>Copper</td>
<td>302 Mt</td>
<td>610 Mt</td>
</tr>
<tr>
<td>Gold</td>
<td>50.9 Kt</td>
<td>70 Kt</td>
</tr>
<tr>
<td>Industrial Diamonds</td>
<td>975 MCarats</td>
<td>1,900 MCarats</td>
</tr>
<tr>
<td>Iron Ore</td>
<td>65 Bt</td>
<td>100 Bt</td>
</tr>
<tr>
<td>Lead</td>
<td>68 Mt</td>
<td>120 Mt</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>5.51 Mt</td>
<td>11.8 Mt</td>
</tr>
<tr>
<td>Nickel</td>
<td>47.38 Mt</td>
<td>110 Mt</td>
</tr>
<tr>
<td>Silver</td>
<td>280 Kt</td>
<td>420 Kt</td>
</tr>
<tr>
<td>Talc</td>
<td>825 - 925 Mt</td>
<td>2000 Mt</td>
</tr>
<tr>
<td>Tin</td>
<td>6.99 Mt</td>
<td>10 Mt</td>
</tr>
<tr>
<td>Titanium (TiO₂)</td>
<td>308.2 Mt (t)</td>
<td>605 Mt (u)</td>
</tr>
<tr>
<td>Uranium</td>
<td>2.8416 Mt (v)</td>
<td>4.6916 Mt (w)</td>
</tr>
<tr>
<td>Zinc</td>
<td>330 Mt</td>
<td>140 Mt</td>
</tr>
</tbody>
</table>

Notes

(t) Global reserves are expressed as 278 Mt of TiO₂ in ilmenite and 30.2 Mt TiO₂ in rutile.
(u) The global reserve base is expressed as 440 Mt of TiO₂ in ilmenite and 165 Mt TiO₂ in rutile.
(v) Reasonably assured reserves available at forward costs up to $80/kg uranium.
(w) Estimate of reasonably assured reserves at forward costs of up to $130/kg uranium. This figure should be treated with caution as it is calculated with less certainty than the value for reserves.

By way of comparison, CML (see Heijungs et al 1992) include reserves values for classification of depletion of the abiotic resources crude oil, natural gas, uranium, cadmium, copper, lead, mercury, nickel, tin, and zinc, derived from the World Resources Institute (1990-1991). Table 15 compares the values presented by CML with those in the Minerals Handbook (1997).

Table 15: Comparison of Reserve Sizes Indicated by World Resource Institute and Reserve Sizes Indicated by Crowson

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Reserves After WRI (1990-1991) (Megatonnes)</th>
<th>Reserves After Crowson (1997) (Megatonnes)</th>
<th>Crowson as % of WRI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uranium</td>
<td>1.67682</td>
<td>2.8416</td>
<td>169.46%</td>
</tr>
<tr>
<td>Copper</td>
<td>350</td>
<td>302</td>
<td>88.29%</td>
</tr>
<tr>
<td>Lead</td>
<td>75</td>
<td>68</td>
<td>90.67%</td>
</tr>
<tr>
<td>Nickel</td>
<td>54</td>
<td>47.38</td>
<td>87.74%</td>
</tr>
<tr>
<td>Tin</td>
<td>4.26</td>
<td>6.99</td>
<td>164.08%</td>
</tr>
<tr>
<td>Zinc</td>
<td>147</td>
<td>330</td>
<td>224.49%</td>
</tr>
</tbody>
</table>

As can be seen, the 1997 Crowson figures for copper, lead and nickel are broadly consistent with those for 1990-1991 from WRI. The lower values could be expected as a result of depletion activities during the intermediate 6 years. However, there is less consistency for uranium, tin and zinc, with Crowson suggesting figures which are at least 50% greater for all three commodities. Given the number of caveats Crowson includes for the determination of
uranium reserves, for example - particularly pricing conditions - it is perhaps unsurprising that
while these values are of the same order of magnitude, they are still considerably different. It
will, however, be useful to note that such deviations between expressed values do exist when
considering uncertainty in any findings from calculations.

However, while depletion rates of reserves can be reduced by increasing the size of reserves
at a greater rate than increases in extraction, and through reducing ore-grade cut-off levels, the
alternative is to reduce extraction rates. Given the almost unfathomable increase in population
anticipated in the next three decades, it seems unlikely that world consumption of
commodities, in general, is going to decline. Thus, to meet this demand while reducing
extraction rates will require substantial recyclate. Increased life-cycle thinking within
operations may move global mining operations in this direction. However, it is difficult to
foresee the extent to which recyclate will be able to meet the demands of the growing
population.

Nonetheless, mineral resource depletion rates, related to reserves, and the reserve base, it is
argued here, provide useful indicators of this component of environmental performance.

2.8.2 Indicators of Resource Depletion

Two key indicators are nominated:

- Mining company [commodity] extraction as % of global [commodity] reserves
- Mining company [commodity] extraction as % of global [commodity] reserve base.
2.9 Water Resources

2.9.1 Water Resource Use from Global Mining Operations

Porteous (1993) describes water thus,

“One of the prime resources for life which must be preserved from contamination for the public water supply. It has many industrial uses: a conveying medium for wastes; a heat-exchange medium; it is used in steam raising and also as a solvent” (Porteous 1993, page 398).

Giller et al. (1997) suggest that water is a renewable resource, naturally recycled in the hydrological cycle. “This recycling renews water resources and potentially provides a continuous supply. With the advent of industrialisation, intensification of agriculture and increasing populations, the demand for water has increased” (Giller et al 1997, page 263). They go on to discuss demand-supply imbalances throughout the world as population and intensive industry are often found in drier parts of countries. Seasonal issues also can put pressure on water resource availability - if rainfall is high during the winter there may be a water surplus, but demand for water is often highest during warm summers when rainfall is low, leading to a deficit (see Giller et al, page 264).

In addition, water abstraction from surface-water regimes may lead to concentration effects for pollutants. For example, if river water demand by industry is high and river water levels drop, then there will be a reduction in the capacity of the river to dilute potential pollutants, leading to potential toxic effects on the water ecosystem. Furthermore, according to Giller et al. (1997), “Engineering based interventions in the hydrological cycle, such as canalisation, damming, diversion of water within and between catchments also have effects on aquatic resources” (Giller et al 1997, ibid.).

Water is used in a variety of ways within the mining industry. In industrial minerals operations, for example, water is used primarily for beneficiation - for transportation of the material through the processing equipment, as well as in the actual treatment. Water is also used extensively to control dust emissions (see Ripley et al 1996, page 274). In coal mining, according to Ripley et al (1996), “Beneficiation uses the greater part of the water required for coal production. The water is used primarily to clean metallurgical coal and, to a lesser extent, to suppress the dust of thermal coal. Most separation processes are carried out in aqueous media” (Ripley et al 1996, page 241).

In iron ore production, according to Ripley et al (1996), “After the ore itself, water is the second most significant input into an iron mill operation” (Ripley et al 1996, page 229) while for copper and gold processing water consumption is especially high during the milling phase, due to its use in flotation systems to concentrate ores (see Ripley et al 1996, pages 29 to 30). Given water’s importance in sustaining life, and given the importance of water in mining processes, it is appropriate to include water resource use in any assessment of environmental burden.
2.9.2 Is Water Use Adequate as an Indicator of Environmental Burden from Global Mining Organisations

As with other indicators under consideration, this information alone is insufficient to be truly representative of the environmental burden at a local level. The stress placed upon local water resources by the mining operation will depend on the scale of the demand relative to local availability. Two operations with similar water demands will potentially place very different stresses if one operates in an area of much lower water availability than the other. It is suggested here that a ‘rough guide’ to availability could be related to climatic conditions. In any given catchment area the hydrological system balances over time, whereby: \[ P - R + E \pm \Delta S \pm \Delta G = 0 \]

where
- \( P \) = precipitation
- \( R \) = stream run-off
- \( E \) = evaporation
- \( \Delta S \) = change in soil moisture status
- \( \Delta G \) = change in groundwater status

This assumes no flow across catchments - which is difficult to verify for subsoil regions (see Kiely 1997, page 150). Over a hydrological year there may be no significant change in \( \Delta S \) or \( \Delta G \), so: \( P - E = R \), so if \( P \) and \( E \) are known, then the stream run-off - the amount of water available for abstraction and the support of surface-water aquatic organisms, can be calculated. This variable may be useful to include as a factor in water extraction values.

For example, at the continental level, the following water balance data is useful:

**Table 16: Continental Water Balance and Ratios of Continental Run-off to All-land Run-off (based on Baumgartner & Reichel 1975)**

<table>
<thead>
<tr>
<th>Continent</th>
<th>Area (10^6 km²)</th>
<th>Precipitation (mm/year)</th>
<th>Evapotranspiration (mm/year)</th>
<th>Run-off (mm/year)</th>
<th>Run-off as % of precipitation</th>
<th>Ratio of run-off to run-off value for all land</th>
</tr>
</thead>
<tbody>
<tr>
<td>Europe</td>
<td>10.0</td>
<td>657</td>
<td>375</td>
<td>282</td>
<td>42.92</td>
<td>1.060:1</td>
</tr>
<tr>
<td>Asia</td>
<td>44.1</td>
<td>696</td>
<td>420</td>
<td>276</td>
<td>39.66</td>
<td>1.038:1</td>
</tr>
<tr>
<td>Africa</td>
<td>29.8</td>
<td>695</td>
<td>562</td>
<td>114</td>
<td>16.40</td>
<td>0.429:1</td>
</tr>
<tr>
<td>Australia</td>
<td>7.6</td>
<td>447</td>
<td>420</td>
<td>27</td>
<td>6.04</td>
<td>0.102:1</td>
</tr>
<tr>
<td>North America</td>
<td>24.1</td>
<td>645</td>
<td>403</td>
<td>242</td>
<td>37.52</td>
<td>0.910:1</td>
</tr>
<tr>
<td>South America</td>
<td>17.9</td>
<td>1564</td>
<td>946</td>
<td>618</td>
<td>39.51</td>
<td>2.323:1</td>
</tr>
<tr>
<td>Antarctica</td>
<td>14.1</td>
<td>169</td>
<td>28</td>
<td>141</td>
<td>83.43</td>
<td>0.530:1</td>
</tr>
<tr>
<td>Total Land</td>
<td>148.9</td>
<td>746</td>
<td>480</td>
<td>286</td>
<td>35.66</td>
<td>1.000:1</td>
</tr>
</tbody>
</table>

Although simplistic, these data illustrate that water resource management in Australia is in general more challenging than in South America, for example. And while run-off represents a similar proportion of rainfall in both Asia and South America, the sheer volumes involved in South America mean that its ratio of run-off to global levels is over double that for Asia.
The practical application of such an analysis would be to use the ratios calculated as modifiers for global mining group data. Thus, surface-water abstraction in areas with a low surface run-off ratio (such as parts of Australia) would be weighted much more heavily than abstraction in those areas with a high surface run-off ratio (such as parts of South America). To be effectively utilised, such a modifier would have to be related back to the watershed from where the operation sources its water.

In the absence of this information, the use of global climate maps, such as those found in common sources, such as ‘The Times Atlas of the World’ (see Bartholomew et al 1990), would provide a starting point for knowledge about precipitation and evapotranspiration rates at a regional level more precisely than the continental data presented here will allow. The following worked example illustrates the intention, using two hypothetical operations which are identical in all ways except location.

Table 17: Hypothetical comparison of weighted fresh water usage for mining operations

<table>
<thead>
<tr>
<th>Operation</th>
<th>Annual abstracted-water demand ('000 cubic metres)</th>
<th>Location (continent)</th>
<th>Ratio of continental run-off to all land run-off</th>
<th>Weighting value (reciprocal of ratio)</th>
<th>Weighted abstracted water demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation X</td>
<td>6,000</td>
<td>Asia</td>
<td>1.038:1</td>
<td>0.963</td>
<td>5,778</td>
</tr>
<tr>
<td>Operation Y</td>
<td>6,500</td>
<td>South America</td>
<td>2.323:1</td>
<td>0.430</td>
<td>2,795</td>
</tr>
</tbody>
</table>

It must be stressed that this table is for illustrative purposes only, but it does highlight the difference made by including weighting values. Operation Y uses slightly more abstracted water than Operation X. However, due to the fact that, in this example, Operation X is located in an area of relatively high water availability, its weighted value is less than half that for Operation Y. This would reflect the greater burden placed on local water resources by Operation Y’s operations than Operation X’s and is a more meaningful measure of water resource use than consumption figures alone.

Such an approach would remain feasible for operations abstracting their water from groundwater reserves. As stated earlier, groundwater reserves are assumed to be in a state of equilibrium over time. However, if an operation abstracts water from groundwater reserves, these reserves will only remain unchanged if they are recharged somehow from precipitation. The UN CSD suggest, “The only approach [to defining water availability] which respects the physical integrity of the water resources is to consider where it is produced internally, that is from precipitation inside the boundaries of the country / area” (Waller-Hunter 1996)

Thus local water availability is understood in the context of sustainable development, with water availability depending on precipitation in the area under consideration. When, considering groundwater, however, it is argued here that the boundaries of the area should be extended to encompass the area in which the precipitation which recharges the groundwater falls, since geological structures may not respect political national boundaries. Only in this way can one ensure that there is consistency in relating water abstraction to water availability.
Refining this ‘rough-guide’ to water availability would require detailed knowledge for each watershed on how much run-off is translated into water supplies. From a sustainable development perspective, the critical issue is not just how much water is used by mining operations in relation to run-off, but how much water is used by mining in relation to the amount of run-off that has been harnessed for use by populations. According to the UN, this will depend on the extent of water resources development (flow regulating reservoirs, inter-basin transfers, groundwater development, system losses) and policy measures (allocation and pricing) (see Waller-Hunter 1996). However, while more complete datasets have been developed by the UN Food and Agriculture Organisation for a limited number of countries (see United Nations Food and Agriculture Organisation 1999) through the Land and Water Development Division’s AQUASTAT initiative5 and the International Commission for Irrigation and Drainage (ICID), “Accurate and complete data are scarce” (Waller-Hunter 1996).

A number of conclusion and recommendations can be made:
1. Water resource use is a relevant indicator of environmental performance in mining
2. It is possible to use site specific weighting to allow a more meaningful assessment of relative stress on water resources, but a number of assumptions are made in the methodology which may require further investigation (e.g. the true level of water availability rather than the potential level).

2.9.3 Indicators of Water Use

Two key indicators are nominated:

- Total Water Abstracted (cubic metres)
- Total Normalised Water Abstracted (cubic metres)

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5 The UN FAO’s AQUASTAT Programme’s objective is to produce rural water use data at country level in a systematic manner. Data thus far cover 53 countries of the African continent, 29 countries of the Near East and 15 countries of the former Soviet Union.
2.10 Energy

2.10.1 Energy Consumption in Global Mining Operations

Electrical energy is frequently supplied by power stations which use a variety of fuels: coal, oil, gas, uranium, water, sunlight, wind, geological heat sources, as examples. There are attendant environmental effects with this, some of which are source specific, but many apply to electrical power generation in general. These will be explored and discussed in detail in Project Document 3 - "Environmental Management in a Global Mining Organisation" (Vol.3 PD3). The key effects are related to resource depletion (see Vol.3 PD3, Section 9.3.1.2.1), atmospheric pollution from energy production and consumption (see Vol.3 PD3, Sections 9.3.1.2.2 and 9.3.3), water and land pollution from energy production (see Vol.3 PD3, Section 9.3.1.2.3).

2.10.1.1 Mining and Energy

Mining uses energy throughout its activities - to power the heavy haul trucks and pit conveyors which move the ore, and to power the crushers, crystallisers, mills, furnaces, or smelters which process the ore. Energy is also required in the transportation systems which move mining products to shipping points and to customers. Some of this energy will be generated on-site by a mining operation while some will be purchased from the energy utilities. Wherever the energy is sourced, there will be environmental effects.

Mining is a relatively large consumer of energy - the US mining industry used 158 TWh of electricity in 1994, 5% of all US electricity consumption that year. The South African mining industry accounted for 25% of national electricity consumption in 1995 (see Industry and Environment Centre 1998). Given the range of environmental issues associated with energy production and consumption, and given its use throughout mining activities, energy is an appropriate category to include in any assessment of environmental burden.

2.10.2 Discussion

A number of global mining companies calculate their energy demand in terms of primary energy - i.e. that energy which is required to meet the energy needs of the operations, rather than just the energy delivered to the sites, or used at the sites. This allows operations to account for the energy required to produce electricity and process fuels, rather than just the electricity metered on site and the contained energy in fuels. Conversely, since a number of larger mining operations have their own power plants, the surplus energy produced and exported onto local and regional grid systems is discounted - as it is a part of a different primary energy 'system'.

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2.10.2.1 Electrical Energy Delivered Electrical Energy System

A difficulty in reviewing energy data is the challenge in accounting for thermal conversion losses and distribution losses. For example, according to Michaelis (1998), the thermal efficiency of European oil fired power stations averages at about 38%, i.e. for every 100 GJ of oil energy input, only 38 GJ of electrical energy will be generated. Statistics from the UK Electricity Industry Association suggest that conventional steam stations have a thermal efficiency of 36.3%, nuclear stations have an efficiency of 35.8% and combined cycle gas turbine stations have an efficiency of 46.9% (see UK Electricity Industry Association 1997).

Furthermore, according to Michaelis, 13.8% of electricity produced is lost in transmission systems due to losses when high voltage electricity is stepped down to lower voltages. Thus, for every 1GJ of energy supplied to a customer from a conventional steam station, 3.196 GJ of fossil fuel energy is actually required to account for thermal losses and transmission losses in the system. Western Mining Company, for example, in their energy reporting, use a ratio of 3:1 to determine how much energy is required to deliver the energy they use to site (see Western Mining Company 1998, page 18).

This illustrates the importance of differentiating between direct and indirect energy use, where direct energy use is associated with the application of energy to processing operations, and indirect energy use is associated with the application of energy to operations to produce electricity. In this way, the underlying performance of an operation remains visible. Some operations purchase their electricity, others produce their own. Those which produce their own will be penalised if system losses are not taken into account for those operations which purchase electricity, but are for those that produce their own.

This is more appropriate in the context of sustainable development, since the emphasis is on the issues to be addressed, rather than the extent to which operational responsibility can be assigned.

2.10.2.2 Distinguishing Between Sources

While it is important to have an indicator of primary energy consumption for an operation, energy is possibly a unique environmental category, since it is not the use of energy, per se, that causes the majority of environmental impacts, it is the nature of the energy produced and used. For example, the environmental impact of energy produced from high sulphur coals will differ from that produced from low sulphur coals, which in turn will differ from that produced from nuclear fission, which in turn will differ from that produced from hydrological sources.

The use of fossil fuels and uranium could lead to resource depletion, the use of fossil fuels could lead to global warming, the use of high sulphur fuels could lead to acidification, the use of nuclear fission could lead to radioactive wastes, while the use of hydrological power could lead to ecosystem damage as a result of damming and river flow disruption. Each fuel source brings about its own concerns. Therefore, as far as an indicator of likely environmental consequences, it is argued that any energy indicator framework should consider whether that energy comes from fossil, nuclear, or renewable energy sources.
2.10.3 Indicators of Energy Use

One key indicator is nominated at this stage:

- Total Primary Energy Required (Pj)

The potential for supporting indicators related to fuel mix and end use is explored in the Case Studies (see this document, Section 4.4.1.2).
2.11 Greenhouse Effect / Global Warming

2.11.1 Global Warming Potential from Global Mining Operations

According to UNEP,

"In the long term, the earth must shed energy into space at the same rate which it absorbs energy from the sun. Solar energy arrives in the form of short wavelength radiation. Some of this radiation is reflected away by the earth’s surface and atmosphere. Most of it, however, passes straight through the atmosphere to warm the earth’s surface. The earth gets rid of this energy (sends it back out into space) in the form of long wavelength, infra-red radiation.” (United Nations Environment Programme 1998).

Some of this outgoing radiation is trapped in the atmosphere by so-called greenhouse gases. For instance, water vapour strongly absorbs radiation with wavelengths ranging from 4 to 7 micrometres, and carbon dioxide absorbs in the range from 13 to 19 micrometres (see Anon. 1998b). Other gases - methane, ozone, CFCs and nitrous oxides are all capable of absorbing in the infrared spectrum and so play a major role in the process. The greenhouse effect exists because the trapped radiation warms the lower part of the atmosphere, which then radiates energy in all directions. Some is re-radiated into space, but some is re-radiated back to the earth’s surface - causing the temperature to rise.

A discussion of the relationship between human activity and the greenhouse effect is included in Project Document 3 – “Environmental Management in a Global Mining Company” (see Vol.3 PD3, Section 9.3.3.6). Specific issues include human-made enhancement of the greenhouse effect (see Vol.3 PD3, Section 9.3.3.6.1.2), carbon dioxide and the global carbon cycle (see Vol.3 PD3, Section 9.3.3.6.1).

Albritton et al (1996) report that the potency (global warming potential – GWP – expressed as tonnes equivalent of carbon dioxide) of the different greenhouse gases will vary over time, relative to carbon dioxide. Some greenhouse gases are relatively short lived, and will therefore have a declining potency over time relative to carbon dioxide. On the other hand, other greenhouse gases persist longer than CO₂ and therefore have a relative potency which increases over time. Table 18 illustrates how the relative GWP values will vary according to the time horizon preferred.

Table 18: Global warming potentials (GWP) given in kg CO₂− eq./kg gas for four selected substances at different time horizons (based on Albritton et al 1996)

<table>
<thead>
<tr>
<th>Substance</th>
<th>Formula</th>
<th>GWP 20 years</th>
<th>GWP 100 years</th>
<th>GWP 500 years</th>
<th>Life time (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon dioxide</td>
<td>CO₂</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>150</td>
</tr>
<tr>
<td>Methane</td>
<td>CH₄</td>
<td>62</td>
<td>25</td>
<td>7.5</td>
<td>10</td>
</tr>
<tr>
<td>Nitrogen dioxide</td>
<td>NO₂</td>
<td>290</td>
<td>320</td>
<td>180</td>
<td>120</td>
</tr>
<tr>
<td>Tetrafluoromethane</td>
<td>CF₄</td>
<td>4,100</td>
<td>6,300</td>
<td>9,800</td>
<td>50,000</td>
</tr>
</tbody>
</table>

Project Document 2 - Development of Key Corporate EPIs for Sustainable Mining Organisations

69
For global mining organisations, the most appropriate of these time horizons will be 100 years. For other industries, the time horizon may be much shorter. Even in the mining sector, for small localised operators the appropriate time horizon may be quite short. But for the global mining organisations, which require economies of scale, a large, long life mine will frequently operate for a century.

Mining leads to direct and indirect emissions of greenhouse gases through its processing operations. Indirect sources of greenhouse gases are largely attributable to electricity purchased from utilities, while direct sources of greenhouse gases from mining operations include fossil fuel combustion and process emissions. The main greenhouse gases associated with fossil fuel combustion in mining are carbon dioxide ($CO_2$) and methane ($CH_4$), while processes such as aluminium smelting can lead to the release of perfluorinated carbon compounds ($CF_4$ and $C_2F_6$)\(^7\) (see Rio Tinto 1998b, page 14). Given the potential of mining activities to contribute to global warming, and given the seriousness of the consequences of climate change, it is appropriate to include global warming in any assessment of environmental burden.

2.11.2 Discussion

2.11.2.1 On-Site and Off-Site Emissions

A number of large mining companies consider ‘upstream’ greenhouse gas arisings, just as they do for energy. BHP, for example, state that, “When we buy electricity, we include emissions associated with its generation in our inventory of emissions” (Broken Hill Proprietary 1998). According to Rio Tinto, only 45% of the greenhouse gas arisings associated with their operations themselves (as opposed to downstream uses of their products) actually take place on site. The remaining 55% arises in the production of purchased electricity for the Group (see Rio Tinto 1998b, page 14). As with energy, it is suggested that the most appropriate indicator would cover the primary system – i.e. greenhouse gas arisings associated with mine operations whether they occur on-site or not, but discounting those associated with on-site electrical production subsequently ‘exported’ into another primary system to avoid double counting at the global level.

A recent global initiative to standardise global warming reporting is the UNEP Insurance Industry Initiative (UNEP III) for the Development of A Corporate Global Warming Indicator (1998) (see Thomas & Tennant 1998). This initiative, authored by Thomas and Tennant from the investment company NPI, provides a methodology for corporations to measure the greenhouse gas arisings associated with their operations using the structure outlined in Figure 9.

\(^7\) PFCs are generated in the aluminium smelter reduction process when the cells do not operate at their optimal efficiency.
Figure 9: NPI Global Warming Indicator Framework

As can be seen, there is no distinction between off-site and on-site emissions, and the operational divisions are in terms of energy related and process related emissions. The NPI categorises energy related emissions as static (non-mobile), i.e. electrical power stations, and fuel refining; and mobile, i.e. automotive. In addition, the NPI takes a further step, that of normalising the value according to corporate turnover, added value, number of employees etc, to allow inter and intra-industry comparison. This theme will be explored in greater depth in Section 3 of this document (see Section 3 - The Use of Normalisation Factors for Expressing Relative Unitary Environmental Performance Trends).

It is argued that the use of ‘process’ and ‘mobile’ are arbitrary divisions. It is suggested that the ‘process’ category be exploded to cover the various stages of the processing operations. It is suggested that this would be a more useful approach, since for mine operations the use of mobile systems such as shovels and haul trucks are associated with the actual mineral extraction activity predominantly, rather than with subsequent beneficiation and smelting, for example.

Accordingly, it is suggested that the following two themes would be the most appropriate:
1. Greenhouse gas arisings associated with the production and delivery of energy - to include off-site electricity production and delivery plus on-site electricity production and delivery (which includes the off-site refining of fossil fuels used on-site to produce electricity)
2. Greenhouse arisings in operations associated with the activities themselves.

This thesis will be explored further in Section 4 of this document (see Section 4 - Case Study of Environmental Performance Indicators in Practice in the Global Mining Industry).

Nonetheless, at this stage it can be concluded that:
- Greenhouse Gas Emissions is a useful measure of environmental performance in global mining organisations
• Methodological advances are being made by international organisations which may provide external support for the methodology suggested here.

2.11.3 Indicators of Greenhouse Gas Emissions

One key indicator is nominated:

- Absolute Global Warming Potential (MT CO₂ equivalent)
2.12 Acidification

2.12.1 Acidification from Global Mining Operations

According to the European Environment Agency (1998), "Acidification is caused by releases of protons in the terrestrial or aquatic ecosystems" (European Environment Agency 1998). Substances are considered to have an acidification effect if they result in either the supply or release of hydrogen ions (H+) in the environment or the leaching of the corresponding anions from the concerned system (see Hauschild & Wenzel 1997).

Organisms can be affected by acidification either directly by physiological stress or indirectly by such changes as food supply, habitat provision and predation. According to Giller et al (1997), "As expected, the ecosystem response to acidification is very complex, indicating the complexity of both ecological and pollutant processes" (Giller et al 1997, page 286). Acidification issues apply to acidic releases to soil, to water and to the atmosphere.

2.12.1.1 Soil Acidification

The capacity of some soils to ‘absorb’ and retain cations increases as pH increases. Generally heavy metal mobility increases as soil pH decreases (see Magette & Carton 1997, pages 426 to 427). Thus acidification of soils increases the movement of toxic materials in the soil, and also contributes to the leaching of valuable minerals down through the soil profile, limiting the availability of nutrients to plants. These include calcium - removed from both soil and plant leaves - aluminium - liberated into aquifers - and magnesium. Aluminium leaching has consequences if leached as it is poisonous to all life forms, with fish suffering the highest exposure.

2.12.1.2 Aquatic Acidification

In the case of aquatic acidification,

"Typically acid waters have significantly reduced diversity [of macroinvertebrates]...
The acidity affects the fish in many ways, principally through gill and blood physiology (impaired ion regulatory and acid-base status), reproductive physiology, developmental effects and demineralisation, metal accumulation and changes in behaviour" (Kiely 1997, pages 286 to 287).

2.12.1.3 Atmospheric Acidification

Atmospheric acidification is discussed as part of Project Document 3 – “Environmental Management in a Global Mining Company” (see Vol.3 PD3, Section 9.3.3). Specifically, sulphurous oxides (see Vol.3 PD3 Section 9.3.3.3), and acid rain and its effects (see Vol.3 PD3, Sections 9.3.3.5 and 9.3.3.5.1) were discussed.
2.12.1.4 **Mining and Acidification**

A number of mining activities have the potential to contribute to acidification of the various media. A common problem derives from the mining and processing of sulphide ores. A phenomenon known as acid drainage - essentially the production of a metal hydroxide precipitate and sulphuric acid when a metal sulphide combines with oxygen and water - can occur, resulting in the leaching of metals and reduced pH of water that comes into contact with the oxidised surfaces.

Atmospheric releases can arise from both point and fugitive emissions of sulphurous oxides. Electricity generation for mining activities will produce a significant quantity of sulphur dioxide, but in addition, processing of sulphide ores (which are a major source of copper, nickel, lead, and zinc) will lead to considerable levels of sulphur dioxide releases to atmosphere. Atmospheric emissions of substances leading to acidification can be transported great distances. Much of Canada's acid deposition is from the United States (see Henry & Heinke 1989) and a study by Tang et al. (1987) indicated that Inco's Sudbury Smelter in Canada contributed up to 45% of the sulphur fallout from dry deposition and 12% of the fallout from wet deposition, in an area up to 500km from Sudbury (see Tang et al 1987, page 100). Given the use of sulphide ores in global mining operations, and given the indirect effects of energy production on acidification, it is appropriate to include acidification in any assessment of environmental burden.

2.12.2 Translating acidic emissions data, or acidification potential into actual impact

One of the most challenging aspects of this evaluation remains the difficulty in using 'acidification potential' information at site level. Nichols et al (1996) concluded during a SETAC workshop to discuss key challenges in Life Cycle Analysis that,

"The most significant problem when assessing this impact group [i.e. acidification] is the very significant differences in the effect of acidification on the receiving environment. This can vary between no effect when the buffering capacity and dilution is high e.g. the sea, to very significant when buffering is low as it is in many forested areas" (Nichols et al 1996, page 68).

Nichols et al (1996) go on to suggest that a way of overcoming this challenge would be to use 'spatially differentiated characterisation factors' - the use of maps illustrating the particular sensitivity of different areas to acid deposition in conjunction with information on regional deposition and emission of acidifying substances. They use the following expression:

\[ \text{Acidification from site (As)} = Q \times \sum_i \text{AP}_i \times m_i \]

(see Nichols et al 1996, ibid.)

Where

- \( \text{AP} \) = acidification potential (in SO₂ equiv. or mol H⁺)
- \( m \) = emission at site
- \( i \) = the compound(s) under consideration
- \( Q \) = Percentage from region of the emission falling on sensitive areas
The total acidification potential from global mining operations would be equal to the sum of the acidification potentials for each of the sites. Maps that would allow soil chemistry, precipitation and land usage to be used to indicate the likely sensitivity threshold of the soil for acid deposition are reported to exist for Europe (see Nichols et al 1996, page 68; Stanners & Bourdeau 1995, pages 49 to 50), but for global operations to be able to incorporate such an approach into any indicator framework will require substantially more information than is currently available. Developments of the kind suggested by Nichols et al, however, would improve the level of confidence in an assessment of likely acidification associated with global mining activities and would make comparison between operations more meaningful.

A number of conclusions and recommendations can be made:

- Acidification is a useful measure of environmental performance in global mining organisations
- Methodological advances outside the scope of this study may provide useful techniques to better incorporate site specific issues in the framework, which at present can only consider potential to cause acidification in general terms.

### 2.12.3 Indicators of Acidification

Three key indicators are nominated:

- Total Atmospheric Acidification Potential (tonnes SO₂ equivalent or hydrogen ion – H⁺ - equivalent)
- Total hectares soil exceeding critical acid load from deposition
- Total cubic metres water exceeding critical acid load from deposition / drainage
2.13 Toxicity

2.13.1 Toxicity from Global Mining Operations

Giller et al (1997) describes toxic pollutants as

“Compounds which directly affect an organism’s health. ... Toxic pollutants include a range of compounds from heavy metals, polychlorinated biphenyls (PCBs) and dioxins to radioactive ions” (Giller et al 1997, page 256).

Their toxicity depends on a number of factors, including concentration, chemical form, and persistence in nature. Porteous (1993) identifies three main mechanisms by which fauna such as humans can be affected by toxic pollutants:

1. They influence enzymatic action, for example, combining with the enzyme so that it cannot function;
2. They can combine chemically with the constituents of cells, as for example, carbon monoxide combining with blood haemoglobin so that oxygen transport to the brain is affected;
3. Secondary action because of their presence. Hay fever is brought about by pollen and the system reacts to produce histamine.

The factors of importance are the concentration of the pollutants, the length of exposure, the age of the animal / person, the activity - whether slight or heavy exertions - and the health of exposed person / population (see Porteous 1993, page 365).

Processes such as bio-accumulation - the natural process where organisms selectively absorb and store trace element micronutrients - are relevant to toxic metals as organisms can absorb toxins as they are similar to micronutrients. Many toxins that are dilute in the environment can reach dangerous levels inside cells and tissues through bio-accumulation (see Giller et al 1997, page 256). Also bio-magnification - whereby a toxic compound is not readily excreted from an organism but instead is stored and then passed up the food chain, being accumulated and concentrated towards levels which will only become toxic at the upper levels of the food chain - is relevant.

A number of metals and their compounds have been classified as toxic; including arsenic, cadmium, lead, copper, mercury and zinc, as have other substances that can be associated with mining such as cyanide. Arsenic (a metalloid and common minor constituent of many metal ores - especially copper, iron, zinc, silver and gold) is toxic to plants as well as animals (see Ripley et al 1996, page 156). Cadmium, a rare element found in association with zinc, is highly toxic to plants and animals and is readily absorbed from the environment. In addition, cadmium is highly toxic to humans; it is easily ingested, and acts synergistically with other toxic metals (see Ripley et al 1996, page 157).
Lead has toxic effects as a systemic agent affecting the brain. Porteous (1993) observes that, "It has been suggested that it is associated with mental retardation and hyperactivity in infants" (Porteous 1993, page 222), with Whitelegg (1988) adding that lead accumulates in persons who are exposed. Copper ions (Cu^{2+}) are toxic to most forms of life. According to Porteous (1993), "0.5 parts per million is lethal to many algae, most fish succumb to a few parts per million. In higher animals, brain damage is a characteristic feature of copper poisoning" (Porteous 1993, page 80).

According to Riemann (1997), "Mercury is highly toxic, causing damage to the central nervous system and kidney malfunction. It bio-accumulates and has been responsible for high mortality in birds" (Riemann 1997, page 700). Cleary and Thornton (1994), reporting on the environmental impact of gold mining in the Brazilian Amazon, note that the processing of mercury-gold amalgam can release elemental mercury which can then be methylated in aquatic systems, partly through microbial action, and hence bio-magnified. Zinc is a micronutrient at low concentrations, essential for growth. However, at elevated concentrations it has toxic effects, with symptoms of zinc toxicity in plants including chlorotic leaves with green veins, white dwarfed forms, dead areas on leaf tips, and stunted roots (see Ripley et al 1996, page 92).

Potassium cyanide is used to dissolve gold from crushed rock, and sodium cyanide can be used in the iron and steel industry. According to Porteous (1993), "Like the other cyanides, it [i.e. sodium cyanide] is extremely toxic if swallowed, breathed in as a dust or gas, or absorbed via eyes or mouth" (Porteous 1993, page 85) Given the use in global mining organisations of ores and processing technologies which have the potential to release material of a potentially ecotoxic nature, and given the effects of ecotoxicity, it is appropriate to include ecotoxicity in any assessment of environmental burden.

2.13.2 Discussion

As with acidification, mining activities can have toxic effects on both terrestrial and aquatic ecosystems. Materials with the potential to cause toxic effects can be found in atmospheric and liquid waste streams – thus terrestrial systems can receive doses of toxic material from atmospheric deposition and aquatic systems can receive doses of toxic material from atmospheric deposition and direct effluent discharges. In addition exchange between the two media can occur at the interface between the water table and soil, for example.

The actual toxic effect of discharges will depend on a variety of factors discussed earlier which can be divided into ‘dose’ effects – i.e. sources of material and their flow into the ecosystem, and ‘response’ effects – i.e. the sensitivity of the receiving environment to that dose. As Ripley et al. (1996) point out,

"In aquatic ecosystems, element concentrations are relatively easily measured in solution. Responses of aquatic ecosystems to supplies of nutrients tend to be rapid because of the short reproductive cycles of plankton" (Ripley et al 1996, page 59).

In terrestrial systems, by inference, it is more difficult to observe the levels and effects of potentially toxic materials. An additional level of uncertainty is imposed on the assessment of toxic effects arising from mining operations on terrestrial environments. While levels of
different materials can be monitored for aquatic and atmospheric point sources alike, there is far greater certainty over the fate of aquatic discharges – which go directly into the aquatic environment – than atmospheric discharges which may, or may not, fall upon a particular area of land. Figure 10 illustrates some of the numerous factors which will influence the dose of atmospheric discharges on terrestrial receptors.

Figure 10: The movement of atmospheric residuals from source to receptor showing the main factors affecting the emission, transport and uptake (from Ripley et al 1996, page 81)

Thus, the European Environment Agency (EEA) (1998) state that, “Criteria already exist for assessing bio-degradation, bio-accumulation and aquatic effects whereas no formalised criteria have been developed for terrestrial toxicity” (European Environment Agency 1998).

The theoretical effect score for ecotoxicity expressed by the EEA is as follows:

$$ S_{i}^{nm} = E_{i}^{m} \cdot F_{i}^{nm} \cdot M_{i}^{n} $$

Where:

- $S$ = the ecotoxicological effect score
- $i$ = the substance emitted to an initial medium
- $n$ = the initial medium (air, water, soil or food chain)
- $m$ = the compartment to which the substance is transferred to from the initial medium
- $E$ = the effect factor for the substance
- $F$ = the fate and exposure factor for the substance
- $M$ = the emission of the substance

Thus, if the substance under consideration were 50kg of lead, emitted into air and subsequently transferred to soil through deposition, then the formula would look like this:

$$ S_{\text{lead, air to soil}} = E_{\text{lead, soil}} \cdot F_{\text{lead, air, soil}} \cdot 50kg_{\text{lead, air}} $$
Or 'the effect score for 50 kg lead to air and then soil equals the effect factor of lead to soil multiplied by the fate and exposure factor for lead going to air and then soil multiplied by 50 kg of lead to air.'

As can be seen, this score does not have an absolute value. The values for E and F must be determined on a comparative basis – so that if lead has five times the effect of zinc, but half that of mercury, when deposited on land from air emissions, then we would see, for example that:

\[
\begin{align*}
E_{\text{lead, soil}} &= 1 \times (E_{\text{lead, soil, eq.}}) \\
E_{\text{zinc, soil}} &= 0.5 \times (E_{\text{lead, soil, eq.}}) \\
E_{\text{mercury, soil}} &= 2 \times (E_{\text{lead, soil, eq.}})
\end{align*}
\]

Heijungs et al (1992) have developed effect scores for ecotoxicity in the terrestrial and aquatic environment. These are shown for seven substances in Table 19.

**Table 19: CML Classification Factors for the Effect Scores Terrestrial and Aquatic Ecotoxicity (based on Heijungs et al 1992).**

<table>
<thead>
<tr>
<th>Metal</th>
<th>Terrestrial Ecotoxicity (relative to Chromium)</th>
<th>Potential</th>
<th>Aquatic Ecotoxicity Potential (relative to Chromium)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsenic</td>
<td>8.6</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>Cadmium</td>
<td>31</td>
<td>200</td>
<td></td>
</tr>
<tr>
<td>Chromium</td>
<td>1</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>Copper</td>
<td>1.8</td>
<td>2.0</td>
<td></td>
</tr>
<tr>
<td>Lead</td>
<td>1</td>
<td>2.0</td>
<td></td>
</tr>
<tr>
<td>Mercury</td>
<td>69</td>
<td>500</td>
<td></td>
</tr>
<tr>
<td>Nickel</td>
<td>4</td>
<td>0.33</td>
<td></td>
</tr>
<tr>
<td>Zinc</td>
<td>6.2</td>
<td>0.38</td>
<td></td>
</tr>
</tbody>
</table>

While this kind of analysis is helpful in illustrating the importance of potency factors, it does not necessarily take account of local conditions very well. One of the key parameters relating to toxicity discussed earlier is the concentration of materials discharged, with higher concentrations of potentially toxic materials being more likely to cause toxic effects.

But, again, the effect that these discharges will actually have depends very much on the sensitivity of the receiving environment, so knowledge of the concentration of releases is only useful if there is some understanding of the likely impact of that level of concentration. The use of Environmental Quality Standards may be helpful here. According to Ripley et al (1996),

"Guidelines defining air and water quality standards ... are related directly to the effects and impacts of the pollutants on people, other animals, plants, agricultural output, and so on. Some plant and animal species are far more sensitive than others to certain pollutants, requiring more stringent standards in areas in which they are found. In addition, consideration must be given to interactive effects (synergism) between different pollutants, and to the processes of bio-accumulation and bio-magnification."
Standards are generally set differently for aquatic ecosystems, for terrestrial sites, and for air quality” (Ripley et al 1996, page 134).

So, if environmental quality standards (EQSs) exist for the waters and soils receiving discharges from global mining operations, then there is a genuine possibility of developing an indicator which reflects global issues at the local level. ICI have attempted to utilise this approach for their operations in Europe, where there are EQSs for a number of substances in the aquatic environment. Where ICI were unable to identify EQSs, they utilised proposals from regulatory authorities in the first instance and their own toxicological information as a default (see Clarke et al 1997, pages 16 to 17).

To convert an EQS into some measure of potency of different materials in an aquatic environment with a given EQS, ICI have used reciprocals of the EQS, and then divided by the factor for copper to give an equivalence factor, as shown:

**Table 20: Potential Aquatic Ecotoxicity Factors Based on ICI’s EQS Derived Approach**

<table>
<thead>
<tr>
<th>Substance</th>
<th>European EQS (µg/l)</th>
<th>Reciprocal of EQS</th>
<th>Reciprocal of EQS divided by Reciprocal of Copper EQS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsenic</td>
<td>25</td>
<td>0.04</td>
<td>0.2</td>
</tr>
<tr>
<td>Cadmium</td>
<td>2.5</td>
<td>0.4</td>
<td>2.0</td>
</tr>
<tr>
<td>Chromium</td>
<td>15</td>
<td>0.067</td>
<td>0.33</td>
</tr>
<tr>
<td>Copper</td>
<td>5</td>
<td>0.2</td>
<td>1.0</td>
</tr>
<tr>
<td>Lead</td>
<td>25</td>
<td>0.04</td>
<td>0.2</td>
</tr>
<tr>
<td>Mercury</td>
<td>0.3</td>
<td>3.333</td>
<td>16.67</td>
</tr>
<tr>
<td>Nickel</td>
<td>30</td>
<td>0.033</td>
<td>0.17</td>
</tr>
<tr>
<td>Zinc</td>
<td>40</td>
<td>0.025</td>
<td>0.125</td>
</tr>
<tr>
<td>Cyanide</td>
<td>0.5</td>
<td>2.0</td>
<td>10.0</td>
</tr>
</tbody>
</table>

This approach takes a critical step further forward than the one from CML, which proposed generic potency factors. If location specific EQS data can be identified, then different potency factors for specific operations can be included into a calculation which will be able to express Group performance and individual performance in terms of releases to the aquatic environment, which are potentially toxic, relative to an index material.

This information would allow different operations within the same commodity groups and the commodity groups themselves to compare their performance in the knowledge that areas with more strict EQSs will find their emissions weighted more heavily than those with less strict EQSs. Providing the EQSs adequately reflect the likely sensitivity of receiving waters, this should be a useful measure of environmental performance in global mining operations. Nonetheless, knowledge of dispersion factors for atmospheric emissions will still be required to carry out such an exercise for soils.

As can be seen, this indicator category depends on knowledge of effect and fate factors for specific locations, together with knowledge of dispersion – so that for a given unit of emissions, one can identify where it has been received, and then derive a value for its likely ecotoxicological effect. The extent to which this is possible for global mining operations will be tested in Section 4 - Case Study of Environmental Performance Indicators in Practice in
A number of conclusions can be made:
1. Ecotoxicity potential is a relevant indicator of environmental performance in mining.
2. For a satisfactory indicator to be developed, data for aquatic and atmospheric releases of potentially toxic materials, the exposure of receiving environments to those releases, and the sensitivity of receiving environments to those releases are necessary for a complete analysis.
3. Site specific ecosystem sensitivity factors are helpful, and the use of EQSs may provide a useful starting point in this regard.

2.13.3 Indicators of Ecotoxicity
Two key indicators are nominated:
• Total Aquatic Ecotoxicity Potential (tonnes copper equivalent)
• Total Terrestrial Ecotoxicity Potential (tonnes copper equivalent)
2.14 Land Use Change

2.14.1 Land Use Change from Global Mining Operations

The use of land is perhaps one of the key issues related to the impact of mining and its environment. Mining leads to the use of land in a variety of ways: the mine itself, the processing facilities, the roads and infrastructure required for the mine. Firstly there is the mine itself. Surface mines disturb a substantial amount of land due to the nature of the mining process, as Figure 11 illustrates. The proportion of waste rock to ore is very high for a number of minerals and materials, and as the slope walls must be not be so steep they are unstable, open pits increase land use with increasing depth in proportion to the square of depth.

Figure 11: Cross-section of open-pit mine

Not all ore-bodies are configured as shown in Figure 11. Coal is often found as a seam, rather than a body, and therefore open-cast coal mining pursues a seam horizontally, rather than horizontally and vertically. For underground mines, while there is clearly no surface disturbance associated with a pit, the waste rock beneath the surface must go somewhere, so spoil heaps of waste rock consume considerable amounts of land, just as they do for surface mines.

In addition to the pit and spoil heaps, mines often process material on-site, requiring space not only for the operating facilities, but also for the storage of process water and process waste. As Barbour (1994) explains,
"The end product of the milling process [for non-ferrous metals] is the concentrate of the desired metal or metals, together with a slurry containing the discarded process water, unwanted gangue, and the reagents, frothers, collectors etc. added during the flotation stage" (Barbour 1994, page 8).

The exact nature of these wastes will vary from mine to mine, but they are generally stored in surface impoundments known as tailings facilities (see Barbour 1994, ibid.). These facilities require significant amounts of land at a mine facility.

The use of land for mining can have profound effects on the eco-system. As Ripley et al. (1996) observe,

"While the actual area disturbed by mining may be small relative to the surrounding area or relative to that disturbed by other industries (such as forestry, for example), the impact of mining is, in some ways, more profound. Mining represents a disturbance that is often - evolutionarily speaking - a new experience. When this is the case, the damage can last longer than many human life spans" (Ripley et al 1996, page 114).

This will be explored further in Section 2.15 on 'Biodiversity'. However, it is clear that the disturbance of land on a substantial scale represents a significant environmental aspect associated with mining and mining-related activities. Two factors are critical if the lasting impact from land disturbance associated with mining is to be minimised:

1. That the amount of land disturbed by the mining is kept to an absolute minimum through careful planning;

2. That land which is disturbed must be reclaimed, restored, or rehabilitated, according to the wishes of the local community and their elected regulatory representatives (see also Lima & Watherm 1999; Australian Environmental Protection Agency 1995).

Minimising land use may require an operation to switch from surface mining to underground mining as the mine moves deeper over time, to avoid the exponential effect of pit growth becoming unacceptable. There should be an economic driver for this also — eventually the haul distances involved in deep open-pit mining increase production costs to a point where the ore becomes sub-economic. Both points require sensible mine planning.

As Ripley et al (1996) stress,

"Reclamation is now considered an essential element of resource management. It is no longer regarded by either practitioners or regulators as a matter to be dealt with at the end of operations. Rather, it is an ongoing activity throughout the life of the operation to which any mining company... must be committed. Even in those situations where actual reclamation work cannot be started until the close of operations, current activities can generally be carried out in such a way as to accomplish final closure more efficiently and effectively" (Ripley et al 1996, page 113).

It should be emphasised that final closure may not necessarily mean that the land has been restored to a condition identical to those pre-mining. A community may determine that the
reclamation programme embarked upon by the mining operation may represent an opportunity to convert the land from one socially productive land-use to another. In Wyoming and Colorado, USA, for example, Kennecott Energy Company, is working to reclaim land as its coal operations progress along the coal seam in the Powder River Basin. In that area community consultation and co-operation with the Department of Surface Mines has determined that the optimum post-mining land-use for some of the land will be as cattle-ranching land, rather than to restore all the land to its pre-mining state, which was not appropriate for ranching (Green 1998).

To do this requires that topsoil is removed and stored separately from the underlying waste rock, so that it can be used again to provide a topsoil once the mine operations progress along the seam. The land behind the seam is then reclaimed, the topsoil restored, and then a seed mix added which promotes grasses which are appropriate for ranching and are compatible with the existing eco-system. This process, referred to as 'contemporaneous reclamation' is done in consultation with local communities and regulators to ensure that the reclamation work is carried out to the standards demanded by the operations, the communities of which they are a part, and the regulators.

In other areas, Kennecott Energy is reclaiming to a condition which is as close to that pre-mining as possible, ensuring that there are rocky outcrops to provide shelter for smaller mammals, wetland areas for wildfowl, and that the overall topography is as close as possible to the pre-mining landscape. In some areas, Kennecott Energy is reclaiming to within sixty feet of the mining operations as they progress, ensuring that reclamation activities are timely. In order to establish the extent to which mining activities are disturbing, and then reclaiming land, data related to these activities is required. Specific themes might include:

1. The amount of land disturbed by the operation
2. The ‘land-use’ prior to mining, e.g. forestry, agricultural, recreational, etc.
3. The ‘land-use’ desired after mining by stakeholders, e.g. forestry, agricultural, recreational etc.
4. Progress towards achieving the desired post-mining land-use (net changes over the year etc.)

To be fully useful, baseline data for land uses prior to mining and a body of data covering a number of years will be needed to demonstrate both progress and land use-changes.

2.14.2 Discussion

2.14.2.1 Lack of Institutional Direct

Land-use is one of the most challenging themes to address appropriately in this work. It is clear that land-use is an important area for consideration, especially for a mining organisation with activities which can have potentially significant land requirements while it is operating which much be reclaimed successfully. The OECD (1993) argue that, in addition to the physical threat to landscape presented by human activities such as some agricultural practices,
infrastructure projects, wetland drainage, forestry and mining, "Landscape can be seen as a part of environmental quality as such, important to humans for ethical, aesthetic and cultural reasons. Thus, degradation of landscape entails both a loss of naturalness and historic cultural values" (Group on the State of the Environment 1993, page 29).

However, the OECD (1993) go on to report that, "So far, no internationally agreed definition of landscape exists and no attempt has been made to develop landscape indicators in this report," (Group on the State of the Environment 1993, ibid.) limiting their suggestions for environmental pressure indicators on landscape to 'Habitat alteration and conversion of land from its natural state' and 'Land use changes', with the latter measurable in the short term, but the former only viable in the longer term, in the opinion of the OECD.

The UN Commission on Sustainable Development (UNCSD) (1996) adopt a similarly Spartan approach to land related indicators. In their framework for indicators of sustainable development, the UNCSD suggest simply that a 'driving force' indicator of 'land use change' to be complemented by a 'state indicator' of 'land condition change' (see Gouzee 1996).

2.14.2.2 Establishing a Framework for Mining Industry

Land use and land use change are the two core themes in the work of the UNCSD and the OECD. However, it is suggested that they are too simplistic to allow underlying performance to allow meaningful targets to be set. Bob Green at Kennecott Energy has suggested an alternative approach which allows progress to be tracked more meaningfully. Green (1998) suggests that a meaningful measure of performance would be, “The proportion of ‘acreage available for reclamation’ reclaimed each year, based on a 3 year rolling average” (Green 1998). Table 21 illustrates how the acreage available for reclamation is defined.

Table 21: Features Included and Excluded from Kennecott Energy Definition of ‘Acreage Available for Reclamation’

<table>
<thead>
<tr>
<th>Features of an operation to be included in ‘acreage available for reclamation’</th>
<th>Features of an operation to be excluded from ‘acreage available for reclamation’</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zone from the near-pit edge of the backfill or spoil ridges to the furthest edge of reclaimed land</td>
<td>Facilities such as buildings, support areas and load-outs</td>
</tr>
<tr>
<td>Previously reclaimed lands</td>
<td>Transportation routes such as roads, long-term ramps and rail lines</td>
</tr>
<tr>
<td>Lands in interim phases of backfill and grading</td>
<td>Stockpiles for topsoil, overburden, and scoria</td>
</tr>
</tbody>
</table>

The argument for excluding features such as buildings, roadways, and stockpiles is that they only become available towards the end of the working life of the mine. Until that time they are fixed features. The mine itself, however, is a variable feature, which can contribute to net changes in land use depending on whether the rate of reclamation exceeds the rate of extra disturbance or not. Focusing on the variable features of reclamation provides a much clearer picture of underlying performance, it is argued here.
In addition, it is suggested that intermediate indicators may support the overall reclamation total value. For example, there are three processes which can be identified in reclamation:

1. Backfill and Grading
2. Temporary Reclamation (where backfill and grading has been followed by topsoil addition in preparation for seeding)
3. Permanent Reclamation (the final condition, where the land has been reclaimed to its final target land-use condition)

To achieve the final phase – permanent reclamation – requires stakeholder involvement in the planning and verification stages as outlined earlier. An area of land can only be defined as achieving permanence when it is accepted as being in that state by stakeholders, using pre-agreed conditions. If long term trends are to be identified and targets set, then progress towards the first two stages will provide an indication of the capacity to advance towards the final stage subsequently. If an operation has established a target to increase its permanent reclamation acreage, an objective which may take a number of years to deliver due to the time scales involved in flora and fauna development, interim indicators will provide information to show progress towards this objective.

A number of conclusions and recommendations can be made:
1. Land-use is a relevant indicator of environmental performance in mining
2. The principles established by international agencies can be improved to allow mining companies to express their performance in this area more meaningfully - particularly through the use of 'acreage-available for reclamation' data and the use of interim reclamation indicators.

### 2.14.3 Indicators of Land Use Change

Four key indicators are nominated:

- Total Area Disturbed (hectares)
- Area Available for Reclamation (hectares)
- Area of Permanent Reclamation (hectares, % of total area disturbed, % of area available for reclamation)
- Land Use of Permanent Reclamation (% of permanent reclamation) (to native, forestry, agricultural, recreational or other)
2.15 Biodiversity

2.15.1 Biodiversity in Global Mining Operations

2.15.1.1 Biodiversity Under Threat

The OECD (1993) define biological diversity (biodiversity) as,

"The variability among living organisms from all sources including terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species and of ecosystems. An ecosystem is a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit" (Group on the State of the Environment 1993, page 29).

The World Bank (1995) reports a number of threats to wildlife survival:

Figure 12: Threats to the survival of mammals and birds world-wide (based on O’Conner et al 1995)

The World Resources Institute (1997) concurs, commenting that,

"Many of the world’s species are gravely threatened. Various projections suggest that from 1975 to 2015 between 1 and 11 percent of the world’s species per decade will be committed to extinction. The causes include introductions of non-indigenous species, habitat destruction, hunting and deliberate extermination" (World Resources Institute 1997).

Flora are also under threat. The World Resources Institute report that there are approximately 270,000 known species of flowering plants in the world, a number of which fall into the
‘threatened species’ category (see World Resources Institute 1997). In tropical countries like South Africa, for example, which has a relatively high plant species diversity, 4.1% of species were ‘threatened’ in 1993. In the more heavily developed countries like the USA and Japan, the percentage of flowering plant species threatened increases to 11.3% and 14.9% respectively in 1993 (see World Resources Institute 1993).

Clift and Fairclough (1994) have identified five key reasons to safeguard biological diversity:
1. Maintaining the largest number of species, and the largest possible number of varieties within species, provides important genetic resources for human development (food medicines, pest resistant crops);
2. The role of various species in the regulation of local, regional and global ecological systems is sometimes imperfectly understood, but crucial;
3. Safeguarding individual species, and their habitats, is as important as safeguarding works of art and beautiful buildings;
4. The beauty and power of nature have provided spiritual inspiration for human beings down the ages, with echoes in many major religions of the world today;
5. Human beings have no right, ethically, to determine the destiny of other species (Clift & Fairclough 1994, page 18).

Thus, with the importance of biological diversity identified, and with the awareness that biological diversity is under pressure, it is clear that biodiversity is an important environmental issue. If a causal relationship between mining and biodiversity can be demonstrated, then this issue will merit inclusion in Group measures of environmental performance.

2.15.1.2 Mining and Biodiversity

As Figure 12 illustrated, the greatest threats to mammals and birds, world-wide, come from loss of habitat. Thus, the issue of biodiversity is closely linked to the issue of land use and landscape. In fact, the OECD (1993) address the two subjects together in their core set of indicators (Group on the State of the Environment 1993). As has been demonstrated in Section 2.14 on Land Use Change, mining operations do present a threat to landscape which can be addressed through well planned rehabilitation programmes, which use seed banks to re-colonise rehabilitated soil, and incorporate rock shelters, for example, to provide refuges which encourage the re-colonisation of the area by mammals, and trees to provide refuges for birds.

However, while flora can be stored in seed form and managed through nurseries to prepare for replanting to restore biological diversity to an area once mining has progressed, fauna present a far greater challenge since they cannot be ‘stored’ while mining is carried out. Instead,

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8 WRI define threatened species as those which are either endangered, vulnerable, rare, out of danger or indeterminate (known to be either endangered, vulnerable or rare) or insufficiently known (suspected but not definitely known to belong to one of the previous categories).

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attention must also be focussed on surrounding ‘native’ areas to ensure that there is a strong population which can re-colonise an area as part of the rehabilitation process.

In addition to the potential threat to biodiversity posed by land use in mining, the industrial processes may also present threats to the biological diversity in an area. Marine species may be threatened, for example, by any aqueous discharges of a toxic nature. In the industrialised world, in particular, freshwater fish may be threatened. In the USA, for example, 174 of the 822 known species of freshwater fish present in that country are considered threatened (i.e. 21.2%) (see World Resources Institute 1997).

Given the importance of biological diversity as an environmental issue, and given the potential of mining to have an adverse effect upon biological diversity, it is appropriate to include biodiversity as an indicator of environmental performance in the mining industry.

2.15.2 Discussion

There is considerable difference between acknowledgement of biological diversity as an important issue and the ability to gather and interpret meaningful information related to it. The United Nations Convention on Biological Diversity's Subsidiary Body on Scientific, Technical and Technological Advice (1997) recently commented that,

"Figures on biodiversity statistics have no meaning without being placed into context. For example, saying that there are currently a thousand dolphins in a particular sea area has very limited usefulness without an idea of the original population, the size of the sea, the nature of current threats etc. The type of reference and baseline determines the category of meaning (i.e. the so called ‘policy signal’)” (Subsidiary Body on Scientific, Technical and Technological Advice 1997, page 12).

They suggest it is important to know not just whether 1000 dolphins is a high or a low number, but whether it provides any useful information at all. The UN CBD acknowledge that, “Establishing indicators is neither an easy nor an entirely objective task, and sometimes value judgements have to be made” (Subsidiary Body on Scientific, Technical and Technological Advice 1997, page 4). Nonetheless, they have an important role to play –

“They summarise data on complex and sometimes conflicting environmental issues to indicate the overall status and trends of biodiversity.... They can be used to assess performance and to signal key issues to be addressed through policy interventions and other actions” (Subsidiary Body on Scientific, Technical and Technological Advice 1997, page 11).

It is important to establish at the outset what the objectives of any biodiversity indicators within a mining company are going to be. For example, the objective may not be to increase the level of species diversity indefinitely – indeed it may be counterproductive to do so. Also, it may not be the objective to identify spatial variations in diversity – it could be argued that the level of diversity in an area is not important compared with another area (how meaningful is it to compare diversity in a desert with that in a rainforest?)
It is suggested here that the objective, from a mining company's point of view, is to establish the relative impact upon biological diversity each of their operations is having on their local environment over time – as a means of monitoring progress and identifying opportunities for action.

The experience of Richards Bay Minerals (RBM) in addressing this challenge may be helpful in illustrating how this could be done meaningfully. Richards Bay Minerals, a joint venture between Rio Tinto (50%) and Billiton (50%), have been mining sand dunes for selected minerals (mainly titanium, rutile and zircon) north of Richards Bay in KwaZulu – Natal, South Africa, since 1978 (see Van Aarde & Smitt, 1997). The environmental management programme developed at Richards Bay, in partnership with the landowner, the KwaZulu-Natal Government, is to establish an indigenous coastal dune forest on one third of the area mined and to re-vegetate the remaining two thirds of the area with beef-wood (an exotic non-invasive member of the oak family) for the development of a local charcoal industry. This will represent a change from the pre-mining land use, where only 20% was indigenous coastal dune forests, with 60% exotic plantations and 20% disturbed grasslands (Van Aarde & Smitt 1997).

Van Aarde and Smitt (1997) have documented the process of developing meaningful measures of ecological conditions in this area. Pursuing the theme discussed in Section 2.14.1 (Land Use Change from Global Mining Operations), namely that mining represents a disturbance to an ecosystem that is often - evolutionarily speaking – a new experience for a particular zone, they have monitored the process of recovery in those areas affected by mining.

They suggest that it is possible to use directional changes in the occurrence and abundance of species in an area to monitor the recovery of ecosystems, which results from local colonisation and extinction of species in the area – associated with the principles of ecological succession. The extent to which biological communities are able to cope with the disturbance associated with mining can be indicated by a number of variables over time:

1. Changes in species composition;
2. Changes in species density;
3. Changes in species richness;
4. Changes in species diversity

They conclude that,

"When disturbances are followed by rehabilitation efforts, these variables and comparisons thereof with those of pre-disturbed or undisturbed areas, may serve as indicators of the success of a rehabilitation programme. Should rehabilitation be associated with ecological succession, we can expect directional and definable trends as communities develop from pioneer to mature stages of succession" (Van Aarde & Smitt 1997, page 6).

Box 4 summarises the principles of ecological succession:
Box 4: Principles of Ecological Succession

The organisms found in any community at any specific place and time will be a selection from those which can tolerate the prevailing environmental conditions. The organisms which exist can modify their environment, e.g. increasing humus content, affecting micro-climates, giving shelter, shade, changing drainage. As these changes occur they create different conditions in which new species may be able to survive. Therefore the species structure will change through time.

The very first plants to colonise an area must be able to tolerate difficult conditions, e.g. lack of nutrients, too much or little water, salt etc. They are fast growing. Such organisms are called ‘pioneer species’. Within a short time other organisms may be able to tolerate the environment because of the changes brought about by the pioneers. This may be a second stage community. These ‘secondary’ organisms will produce changes and later a next stage of organisms may develop. Each change by its existence creates conditions which are more favourable for more complex and demanding communities.

If a succession is unhindered, the final ‘climax’ community should result. In the case of plants, for example, the climax vegetation is thought to develop if a naturally well drained surface is left completely undisturbed for a long time, with no human activity, climatic change or other changes. A whole sequence of plant communities are established one after another until ultimately a community persists, unchanged, indefinitely. This stable vegetation – the climax vegetation – is in equilibrium with the environment and capable of self perpetuation.

By applying these principles, RBM have established that they can expect to see the relative densities of pioneer species declining with an increase in habitat regeneration age, complemented by an increase in the relative densities of secondary species as the ecological succession process allows pioneers to colonise the area and then give way to secondary species as the changes they bring about allow the development of a more complex eco-system (see Van Aarde & Smitt 1997, page 31).

This point is critical to the development of meaningful indicators of biodiversity in an area. It is absolutely essential to understand whether the area under consideration is at an early stage of development, an advanced stage of development, or is approaching the more gradual evolution associated with climax conditions (which nonetheless continue to develop over time), compared to its surroundings. Without this knowledge any assessment of biodiversity is meaningless. It must be known whether the desired temporal change in the relative density of a species in an area is an increase, a decrease, or no change.

With this in mind RBM have established a baseline of their surroundings covering herbs and woody plants, millipedes, beetles, birds, mammals, and reptiles, which has allowed them to categorise the ‘natural’ condition of the coastal dune area at different habitat ages, to assess whether their progress in rehabilitating mined areas is compatible with the natural processes. They have carried out work to establish temporal comparisons of species composition, relative densities of primary and secondary species, species richness and a similarity index of the herbaceous layer, woody plant, beetle, millipede, bird and small mammal communities of rehabilitating areas of known age with those of abutting mining areas.

2.15.2.1 Developing Meaningful Indicators of Biodiversity

Clearly, biodiversity is one of the most complex environmental issues facing mining companies. Firstly, to understand whether temporal changes in any species are favourable or
adverse, one must know whether it tends towards pioneer characteristics or secondary. Secondly, one must be able to compare a range of species in different categories – a decline in pioneer species may be acceptable if these are being succeeded by secondary species, unacceptable if not.

Thirdly, it is insufficient to have one indicator species for a global mining company; in fact it is not sufficient to have one indicator species for any individual operation. The former is the case because while the health of a particular species may indicate ecosystem health at one location, it may not at another (in addition to the issue about the choice of indicator species – primary or secondary etc). The latter is the case because the health of a bird species, for example, may present no indication as to the health of mammals (unless one can clearly demonstrate the exact nature of the holistic relationships of a particular ecosystem).

Nonetheless, it is also clear that it should be possible to identify areas where progress can be expressed more simply than using inventories for over 130 plant species, 87 bird species, 25 mammal species and 19 reptile species (the number of identified species at Richards Bay – see Rio Tinto 1998b, page 9). Van Aarde et al. (1996) have produced data for two themes for the coastal dunes. The first (Figure 13) is relative densities of secondary species of different groups (as % of all species), where secondary species were defined as those occurring in non-mined mature forests excluding pioneer species. The second (Figure 14) is the number of species in each category. Both sets of data were collected during the summer months and reported in 1996.
Figure 13: Relative Densities for Secondary Species (as % of all species) during summer months in rehabilitating and non-mined forests on the coast of KwaZulu-Natal

![Graph showing relative densities of various species over time.]

Figure 14: Number of species recorded during summer months in rehabilitating and non-mined forests on the coast of KwaZulu-Natal

![Graph showing the number of species recorded over time.]

The values in the mature stands in non-mined areas represent the target conditions in terms of relative species density and number of species. The charts illustrate how progress towards these targets is being made with time. In the case of millipedes, for example, species density in the rehabilitating areas matched that in the non-mined areas within about 10 years and has...
maintained the relative density required. In terms of number of species, however, there are still two species missing after 30 years which are present in the mature stands.

It is suggested that these two expressions may provide useful data on biodiversity at the operations in a mining organisation such as Rio Tinto. Two caveats must be considered, however:

1. They must be used at an individual site level to track year on year progress. More than any other indicator, perhaps, the real value in this indicator is likely to be realised when applied in a temporal context, rather than a spatial one. Absolute numerical comparisons on millipede populations between Richards Bay Minerals in eastern South Africa (where annual precipitation approaches 1,200mm per year) and BHP’s Western Australian iron ore operations (where annual precipitation is in the 200 to 300 mm range) may not be meaningful.

2. A considerable amount of baseline data is needed to illustrate progress in the most complete fashion. It is possible that a number of global mining operations simply do not have information at the same level of detail demonstrated by RBM.

2.15.3 Indicators of Biological Diversity

Two key indicators are nominated:

- Relative Densities for Secondary Species (as % of all species) in impacted and non-impacted areas
- Number of species recorded in impacted areas relative to those in mature areas of target land conditions
2.16 Suspended Solids

2.16.1 Suspended Solid Release from Global Mining Operations

Suspended solids in water systems, according to Kiely (1997), "Increase turbidity and over time settle out on the bottom, increasing the nutrient, metal and toxic levels of settled sediments. It can also cause a sediment oxygen demand (SOD)" (Kiely 1997, page 304). This will reduce oxygen availability for aquatic life. According to Cairns and Atkinson (1994), "Sediment run-off into streams and increased suspended solids have been identified as 'the most destructive features' in surface mined areas with widespread surface disturbance and / or disturbance in steep terrain. The primary cause is removal of vegetative cover... Sediment loss from mined watersheds can exceed that for non-mined watersheds by a factor of 1000" (Cairns & Atkinson 1994, page 113).

Hill and Grim (1975) explain that sediment reduces light penetration and alters temperature in streams, reduces fish production as food organisms are buried and spawning grounds are filled, and can choke streams and increase potential for flooding (see Hill & Grim 1975, page 290). Porteous (1993) suggests that sediment is also a source of secondary contamination as "Sediments act as sinks for pesticides and can contain concentrations as much as 800 times that of water in the case of dieldrin. ... They allow the bottom feeders (e.g. invertebrates) to accumulate the pollutants at much greater concentrations than water analysis would indicate, thereby contaminating the food chain" (Porteous 1993, page 332).

Given the large number of surface mines in many global mining operations, then, it is appropriate to include suspended solids in any assessment of environmental burden. Useful as total suspended solid data is, it must be used in conjunction with knowledge of the local ecosystems, to determine a better understanding of likely effects. Large quantities of suspended solids would suggest an increase in sedimentation, but concentration data will indicate the likely effects on ecosystems. For example, United Nations Food and Agriculture Organisation guidelines, indicate the probable effects of suspended sediment on fisheries:

Table 22: UN FAO Guidelines on the relationship between suspended sediment levels and effects on fisheries.

<table>
<thead>
<tr>
<th>Suspended Sediment Level</th>
<th>Effect on Fisheries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 25 mg⁻¹⁻¹</td>
<td>no harmful effects</td>
</tr>
<tr>
<td>25 to 80 mg⁻¹⁻¹</td>
<td>small decreases in numbers and growth rates</td>
</tr>
<tr>
<td>80 to 400 mg⁻¹⁻¹</td>
<td>good fishery cannot be supported</td>
</tr>
<tr>
<td>Greater than 400 mg⁻¹⁻¹</td>
<td>Few or no fish</td>
</tr>
</tbody>
</table>

A number of conclusions can be drawn.
1. Suspended solid emissions remain a relevant indicator of environmental performance in mining
2. Concentration of suspended solids is important information to be used in conjunction with quantities released. In this way, progress can be measured more meaningfully, since reductions in concentrations could be caused by increased dilution, rather than an actual reduction in releases.

2.16.2 Indicators of Suspended Solids

One key indicator is nominated:

- Gross weight of suspended solids in aqueous discharges
2.17 Dust

2.17.1 The Need for an Indicator of Dust Emissions from Global Mining Operations

Releases of dust, also referred to as airborne particulate matter, are solids suspended in air as a result of the disintegration of matter. Porteous (1993) states that “Dust is normally taken as between 1 and 76μm in diameter” (see Porteous 1993, page 109). Kiely (1997) suggests that “Particulate matter, either of natural or anthropogenic form, is undesirable as it impedes lung efficiency in humans and animals. Particulate matter also interferes with plant growth when deposited on their leaves, it impedes photosynthesis by shielding sunlight from the plant and it interferes with the balance of CO₂ between the plant and the atmosphere. Some particulates are toxic” (Kiely 1997, pages 101 to 102).

Ripley et al (1996) suggest that the spread of chemically reactive particulate matter to the atmosphere and hydrosphere tends to be fairly local, but observe that, “These effects broaden out to the regional scale in the case of very large open-pit operations or closely spaced facilities such as gravel pits ... air quality effects are likely to be the greatest in the case of surface mines” (Ripley et al 1996, page 21). Given the large number of surface mines in many global mining operations, it is appropriate to include particulate matter in any assessment of environmental burden.

2.17.2 Discussion

According to Kiely, “Because of their very small size, [particulates] remain in the atmosphere for long periods and can travel great distances” (Kiely 1997, page 101). Assessing the environmental burden caused by an individual mining operation at the global level will not be straightforward, in the same way that assessing the effects from atmospheric transportation of toxic material, discussed in Section 2.13, is difficult. Ripley et al (1996) explain that there are various sources of particulate emissions: the action of wind on disturbed land and stockpiles of ore and waste, machinery movement and exhaust, and while some smaller particulates will travel long distances, “The extraction stage primarily produces larger particles with limited dispersion, which have major effects on mine workers and, occasionally, on local residents” (Ripley et al 1996, page 23).

In addition, according to Ripley et al (1996), “Particulate emissions would seem to be the most serious problem associated with the mining of industrial minerals” (Ripley et al, page 293) and “The particulate emissions [from extraction of sulphide ores such as copper] are relatively minor compared with those from mining iron ore and the releases from other industries” (Ripley et al 1996, page 160).

Table 23 illustrates how mining will contribute to the generation of coarse particulate matter – from blasting and mining operations in particular – and fine particulate matter – from combustion processes and refineries in particular.
Table 23 Particulate matter size (based on Kiely 1997, page 346)

<table>
<thead>
<tr>
<th>Group description</th>
<th>Composition</th>
<th>WHO</th>
<th>USEPA (PM-10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse</td>
<td>Dust, earth, crust matter</td>
<td>&gt; 2.5 μm</td>
<td>≥ 10 μm</td>
</tr>
<tr>
<td>Fine</td>
<td>Aerosols, combustion particles, re-condensed organic and metal vapours (primary and secondary pollutants)</td>
<td>&lt; 2.5 μm</td>
<td>&lt; 10 μm</td>
</tr>
</tbody>
</table>

This particulate matter will arise from ‘point sources’ – such as stacks – and ‘area’ or ‘fugitive’ sources – such as open pits, haul routes, tailings, stockpiles etc. On the basis of the impact particulate matter can have and the potential for global mining operations to liberate this matter, it is argued that particulate emissions remain a relevant indicator of environmental performance in mining.

### 2.17.3 Indicators of Dust Emissions

One key indicator is nominated:

- Total (Point + Fugitive Source) Particulate Matter Released from Operations (tonnes)
### 2.18 Summary

Table 24 provides a summary of the key indicator expressions nominated through this phase of the project.

**Table 24 Summary of Key Physical Environmental Performance Indicators for Global Mining Organisations**

<table>
<thead>
<tr>
<th>Category</th>
<th>Primary Indicator</th>
<th>Spatial Scope</th>
<th>Location of Discussion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-Renewable Resources</td>
<td>Mining company [commodity] extraction as % of global [commodity] reserves</td>
<td>Global</td>
<td>2.8</td>
</tr>
<tr>
<td>Depletion</td>
<td>Mining company [commodity] extraction as % of global [commodity] reserve base</td>
<td>Global</td>
<td>2.8</td>
</tr>
<tr>
<td>Energy</td>
<td>Primary Energy Required</td>
<td>Global</td>
<td>2.10</td>
</tr>
<tr>
<td>Global Warming</td>
<td>Absolute Global Warming Potential</td>
<td>Global</td>
<td>2.11</td>
</tr>
<tr>
<td>Acidification</td>
<td>Total Atmospheric Acidification Potential</td>
<td>Global</td>
<td>2.12</td>
</tr>
<tr>
<td></td>
<td>Total hectares soil exceeding critical acid load from deposition</td>
<td>Local – Regional</td>
<td>2.12</td>
</tr>
<tr>
<td></td>
<td>Total cubic metres water exceeding critical acid load from deposition / drainage</td>
<td>Local – Regional</td>
<td>2.12</td>
</tr>
<tr>
<td>Water Use</td>
<td>Total Water Abstracted</td>
<td>Local – Regional</td>
<td>2.9</td>
</tr>
<tr>
<td></td>
<td>Total Normalised Water Abstracted</td>
<td>Global</td>
<td>2.9</td>
</tr>
<tr>
<td>Ecotoxicity</td>
<td>Total Aquatic Ecotoxicity Potential</td>
<td>Local</td>
<td>2.13</td>
</tr>
<tr>
<td></td>
<td>Total Terrestrial Ecotoxicity Potential</td>
<td>Local</td>
<td>2.13</td>
</tr>
<tr>
<td>Land Use</td>
<td>Total Area Disturbed</td>
<td>Local</td>
<td>2.14</td>
</tr>
<tr>
<td></td>
<td>Area of Permanent Reclamation</td>
<td>Local</td>
<td>2.14</td>
</tr>
<tr>
<td></td>
<td>Land Use of Permanent Reclamation</td>
<td>Local</td>
<td>2.14</td>
</tr>
<tr>
<td>Biological Diversity</td>
<td>Relative Densities for Secondary Species (as % all species) in impacted and non-impacted areas</td>
<td>Local</td>
<td>2.15</td>
</tr>
<tr>
<td></td>
<td>Number of species recorded in impacted areas relative to those in mature areas of target land conditions</td>
<td>Local</td>
<td>2.15</td>
</tr>
<tr>
<td>Sedimentation</td>
<td>Gross weight of suspended solids in aqueous discharges</td>
<td>Local</td>
<td>2.16</td>
</tr>
<tr>
<td>Dust</td>
<td>Total particulate matter released from operations</td>
<td>Local</td>
<td>2.17</td>
</tr>
</tbody>
</table>

These are the indicators which sit at the apex of any particular environmental theme. So, for example, the key indicator of global warming performance is the total for the global mining organisation. This is derived through the successive ‘rolling up’ of data from individual activities, operations, business units and product groups to provide a number for the organisation. This is clearly more appropriate for some indicators than for others.

As the third column in Table 24 suggests, the different environmental themes must be considered in the context of the spatial scope within which their effects are felt. While global warming, energy use and normalised water use express global issues of environmental concern (in that local activities impact at the global level), others are restricted to local consequences. In the case of dust emissions for example, while this is an indicator relevant...
throughout the mining sector, appropriate to mining, processing and distribution operations alike, the effects are always local. Improvement or deterioration in performance at one operation will not necessarily offset those at another — and so while it is technically feasible to generate an aggregate value — total amount of dust emissions — this value is not as transparent as an aggregate value for greenhouse gas emissions.

Returning to the indicator pyramid structures discussed in Section 2 (see this document, Figures 1, 2, 3, 6 and 7 on pages 13, 14, 15, 35, and 36 respectively), here it can be seen that global warming indicators will be selected and aggregated upwards throughout the organisation, but acid load indicators, dust indicators, etc will be selected by all operations, but will not be aggregated for the global organisation.

Nonetheless, it has been demonstrated that the potential exists to develop indicators of environmental performance for a global mining organisation which reflect the potential contribution to biophysical themes made by the organisation over time. It should be emphasised at this stage that on the basis of these indicators, past performance will be no indicator of future performance. Management indicators, such as implementation of environmental policies, management systems, closure plans, emergency plans, ‘greenhouse challenge’ plans etc. will provide some indication of whether or not environmental performance is likely to improve or deteriorate in the future.

The methodology presented illustrates how site data can be used in conjunction with ‘background’ information on environmental quality standards, water availability, and energy supply to develop a set of meaningful indicators of environmental performance for each of the operations. These can be aggregated to allow different regional and commodity related groupings to be evaluated for significant themes.

It should be remembered, however, that these will be no more than indicators of performance. Issues such as aquatic and terrestrial acidification can only be fully assessed if the critical loading level of the receiving media are known. The use of environmental quality standards, for example, will provide a better indicator than emissions data alone, and is more appropriate than generic modifications for acidification, but is still less accurate than indicators determined using a full understanding of critical loading would be.
3. The Use of Normalisation Factors for Expressing Relative Unitary Environmental Performance Trends

3.1 The Need for Normalisation factors

With the environmental burden methodology design phase complete, attention turns to the challenge of enabling the data to be used on a unit basis. While the burden methodology will allow the total contribution made towards the different environmental themes to be determined for individual sites, for product groups and for entire global mining organisations, the extent to which different operations can compare their performances with other operations and with their own operations over time is limited.

If production at an operation increases, and its contribution to the various environmental themes increases, does this mean that environmental performance is getting worse at the operation under consideration? In absolute terms the answer would be ‘yes’ but this could mask an underlying improvement in performance per unit contribution by the site. Similarly, how can a large open pit mine compare its performance with a small one. While in absolute terms its environmental performance is likely to be worse, it could well be that its performance per unit contributed is better.

This is not to argue against using aggregate indicators also. For example, if one considers an indicator of acidification to be concerned with critical loads, then it will be important to know whether the total emissions will cause this critical load to be exceeded, not how efficiently the mine is operating. However, when comparisons are to be made between organisations in the same sector, and between sectors, then some basis for assessment is needed. Which operation is more compatible with the principles of sustainable development – a large operation that contributes to social and economic development on a large scale, but with large emissions of carbon dioxide, or a small operation that makes a smaller contribution to local development, but similarly makes a smaller impost upon the global climate?

Having argued in Project Document 1 (see Vol.1 PD1) against definitions of sustainable development that focus exclusively upon natural capital – which would insist that the smaller operation, a priori, would be more compatible with sustainable development – the emphasis of this section will be to understand how comparisons between organisations and sectors can be made through the use of normalisation factors. The work undertaken thus far has considered those indicators of performance which can be utilised throughout a global mining organisation wherever possible. This means that they must be appropriate to the mining, processing, shipping and administration operations in each of the commodity groups.

Working with National Provident Institution and The United Nations Environment Programme, Thomas and Tennant (1998) faced the issue of normalisation in work on the development of global warming indicators for corporations. They contend that,

“The most common form of normalised measure is one that relates an environmental measure (e.g. aggregated emissions and energy usage) to a measure of business
activity (e.g. production, value added, or turnover). Normalised measures are critical in the production of environmental indicators since they screen out noise from factors such as changing levels of output and focus on the critical relationships. They also allow industry comparisons to be made.” (Thomas & Tennant 1998, page 18)

Thomas and Tennant identify three possible ways in which corporate performance can be normalised:

**Table 25: UNEP/ NPI suggested normalisation factors developed for a corporate global warming indicator**

<table>
<thead>
<tr>
<th>Normalisation Factor</th>
<th>Definition</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turnover</td>
<td>Total value of goods and services sold by the company to third parties in the normal course of trade</td>
<td>Readily available: obligatory requirement for annual accounts.</td>
</tr>
<tr>
<td>Added Value</td>
<td>Turnover minus direct cost of production</td>
<td>Isolates contribution of organisation to GDP and thus avoids double counting</td>
</tr>
<tr>
<td>Employees</td>
<td>Number of employees under contract and directly employed by a company</td>
<td>Readily available and can be applied to industry sectors where added value and unit turnover could have limited value (e.g. banking sector.)</td>
</tr>
</tbody>
</table>

The World Business Council for Sustainable Development – WBCSD – (see Lehni 1998a; Lehni 1998b) is exploring techniques to normalise performance along themes like energy use, materials use, greenhouse gas emissions, ozone depleting substances. Originally favouring ‘eco-efficiency’ measures, discussed in Section 2 (see this document, Sections 1.3.3.3.2 to 1.3.3.3.4), WBCSD has identified a number of financial and functional value indicators with which to normalise performance. These are illustrated in Table 26.

**Table 26 WBCSD cross-comparable indicators as at November 1998 (see Lehni, 1998b)**

<table>
<thead>
<tr>
<th>Environmental Indicators of Product / Service</th>
<th>Financial and Functional Value Indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Definition harmonised within WBCSD members</td>
<td>Definition harmonised within WBCSD members</td>
</tr>
<tr>
<td>Total amount of energy use</td>
<td>Unit of product (mass / amount / quantity)</td>
</tr>
<tr>
<td>Total amount of materials use</td>
<td>Number of employees</td>
</tr>
<tr>
<td>Greenhouse gas emissions</td>
<td>Sales / Turnover</td>
</tr>
<tr>
<td>Ozone depleting substances emissions</td>
<td></td>
</tr>
<tr>
<td>SO2 and NOx emissions</td>
<td></td>
</tr>
<tr>
<td>Nitrification emissions</td>
<td></td>
</tr>
<tr>
<td>Definition not yet harmonised across WBCSD members</td>
<td></td>
</tr>
<tr>
<td>Net water consumption</td>
<td>Total cost of operation</td>
</tr>
<tr>
<td>Area of land used</td>
<td>Value added</td>
</tr>
<tr>
<td>Volatile organic compound emissions</td>
<td>Gross margin</td>
</tr>
<tr>
<td>Persistent organic pollutant emissions</td>
<td>Profit / Earnings / Income</td>
</tr>
<tr>
<td>Priority heavy metals emissions</td>
<td>Space</td>
</tr>
</tbody>
</table>

Like Thomas and Tennant, WBCSD favour those normalisation factors which are easily reconciled with data already available to organisations. While it is useful to work with metrics which are straightforward to assemble, it is just as important to develop metrics which are meaningful. As was discussed in Project Document 1 (see Vol.1 PD1, Section 1.3.9), for example, the use of GDP, an easily assembled metric, is no basis for meaningful assessment.
of whether a society is moving in a sustainable direction. Whether or not the metrics suggested by WBCSD and Thomas and Tennant are similarly flawed will be explored in this section.  

There is, nonetheless, a need for unitary normalisation factors. The objective for this phase of the work is to identify exactly how to define the unitary normalisation factors for performance comparison. The work of Behmanesh et al (1993) highlights just how significant the implications of using different bases for normalisation are. They discuss approaches to normalising levels of pollution to take account of levels of industrial activity. The objective of such an approach is to help overcome the difficulty when assessing progress in pollution prevention introduced by changes in levels of industrial activity. Behmanesh et al. argue that, “Measures of pollution, normalised to levels of industrial activity (i.e., emissions/production), would enable decision makers to track emissions over time and identify facilities that are making great, little, or no progress in pollution prevention, despite changes in economic conditions.” (Behmanesh et al 1993, page 161)  

The pollution data they use is that reported through the Toxic Release Inventory (TRI) and they assess the ranking of various industries, such as chemical and allied products, primary metal industries, paper and allied products, as examples, in terms of their total release of TRI class materials. They then calculate six ratios:  
1. Total release / Total no. of employees  
2. Total release / Payroll  
3. Total release / Number of production employees  
4. Total release / Wages of production employees  
5. Total release / Value added by manufacturer  
6. Total release / Value of shipments.  

The findings of the study included, for example, that although the petroleum and coal products industry\textsuperscript{10} had only the ninth highest total emissions, they had the third highest ratio of emissions over value added among the twenty three industries in the study. Conversely, when the total toxic releases inventory (TRI) tonnage for the transportation equipment industry (the industry with the fifth highest aggregate emissions in the manufacturing sector in 1987) were normalised, Behmanesh et al found that the industry had the rankings for different normalisation factors illustrated in Table 27.

\textsuperscript{9} For a further critique of the specific approach to eco-efficiency proposed by WBCSD, see Vol. 4 IP2 – Feedback on the WBCSD Eco-Efficiency Report – a document prepared for WBCSD on behalf of Rio Tinto outlining specific issues for mining companies such as Rio Tinto in implementing the WBCSD framework.  
\textsuperscript{10} This refers to both extraction and subsequent processing.
Table 27 Ranking of the Transportation Equipment Industry Based on Different Environmental Indices Using 1987 Toxic Release Inventory Data (Relative to Other Industries in the Manufacturing Sector)

<table>
<thead>
<tr>
<th>Factor</th>
<th>Rank (1-22)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total TRI</td>
<td>5</td>
</tr>
<tr>
<td>TRI/ No. of employees</td>
<td>8</td>
</tr>
<tr>
<td>TRI/ No. of production employees</td>
<td>7</td>
</tr>
<tr>
<td>TRI/ Payroll</td>
<td>12</td>
</tr>
<tr>
<td>TRI/ Wages of production employees</td>
<td>11</td>
</tr>
<tr>
<td>TRI/ Value added by manufacturer</td>
<td>11</td>
</tr>
<tr>
<td>TRI/ Value of shipments</td>
<td>13</td>
</tr>
</tbody>
</table>

Depending on the factor used, the transportation equipment industry is either a relatively highly pollution intensive part of the manufacturing sector or a relatively moderately pollution intensive part of the sector. Whether the factors which should be used for mining should be production based, e.g. ‘environmental burden per tonne of material moved’ or ‘environmental burden per tonne of product shipped’, human resources based, e.g. ‘environmental burden per employee’, ‘environmental burden per production employee’, or ‘environmental burden per person-year worked’, financial based, e.g. ‘environmental burden per dollar revenue’, ‘environmental burden per dollar invested’ ‘environmental burden per dollar value added’ or whether there are other bases for developing indicators will be explored in this phase of the work.
3.2 Parameters of Sustainable Development

In Project Document 1 the underlying rationale for mining was determined as sustainable development, and the parameters upon which this should be considered were 'economic', 'social' and 'biophysical'. To be compatible with sustainable development, mining operations must work with their communities for progress along these three interwoven dimensions, as shown in the MERN Stakeholder Index (see also Vol.1 PD1, Section 1.5):

Figure 15: The MERN Stakeholder Index (from Warhurst, 1998)

This will be explored as a basis for developing relevant unitary normalisation factors. The United Nations Commission on Sustainable Development - UN CSD - (see Gouzee, 1996) developed indicators of sustainable development in terms of four variables - social, economic, environmental, and institutional. A starting point may be to re-examine their framework to evaluate its usefulness to mining organisations working towards sustainable development.11

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11 The full listing of tables is in Section 1 - Review of Environmental Performance Measures Development (see this document, Tables 2 to 5, pages 19 to 21)

Project Document 2 - Development of Key Corporate EPIs for Sustainable Mining Organisations

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Table 28: UN CSD Categories and Themes for Indicators of Sustainable Development

<table>
<thead>
<tr>
<th>Social Categories</th>
<th>Economic Categories</th>
<th>Environmental Categories</th>
<th>Institutional Categories</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combating poverty</td>
<td>International co-operation to accelerate sustainable development</td>
<td>Water</td>
<td>Integrating environment and development in decision making</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1. Protection of the quality and supply of freshwater resources</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Protection of the oceans, seas and coastal areas</td>
<td></td>
</tr>
<tr>
<td>Demographic dynamics and sustainability</td>
<td>Changing consumption patterns</td>
<td>Land</td>
<td>Science for sustainable development</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1. Integrated approach to the planning and management of land resources</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Managing fragile ecosystems</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. Promoting sustainable agriculture and rural development</td>
<td></td>
</tr>
<tr>
<td>Promoting education, public awareness and training (including gender issues)</td>
<td>Financial resources and mechanisms</td>
<td>Other natural resources</td>
<td>National mechanisms and international co-operation for capacity building in developing countries</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1. Combating deforestation</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Conservation of biological diversity</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. Environmentally sound management of biotechnology</td>
<td></td>
</tr>
<tr>
<td>Protecting and promoting human health</td>
<td>Transfer of environmentally sound technology, co-operation and capacity building</td>
<td>Atmosphere</td>
<td>International institutional arrangements</td>
</tr>
<tr>
<td>Promoting sustainable human settlement development (including traffic and transport)</td>
<td></td>
<td>Waste</td>
<td>International legal instruments and mechanisms</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Information for decision making</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Strengthening the role of major groups</td>
</tr>
</tbody>
</table>

The themes suggested by the UN CSD are closely linked to the principles of sustainable development discussed in Project Document 1 (see Vol.1 PD1) and the environmental burden categories discussed in Section 2 (see this document, Sections 2.2 to 2.17, pages 47 to 98). For example, combating poverty, international co-operation, integrating environment and development in decision making, all are in line with the core arguments in Project Document 1 – namely that sustainable development requires more than just maintaining the stock of natural capital intact and that economic growth is not a basis for sustainable development but that combating poverty is (provided that the objective is to increase the capacity of a community to develop along a sustainable path, rather than simply raise living standards).
The themes are a useful reference point for organisations wishing to play their part in sustainable community development. However, these indicators are aimed at government and policy makers rather than individual actors within the wider framework. To elaborate, the principle difficulty lies with establishing causality - if the number of children reaching grade 5 of primary education is rising, for example, can this be an indicator of improving performance by the mining organisation? It is unlikely that this question can be answered satisfactorily, since the amount of knowledge required of other factors which could contribute is great, and it would be very difficult to establish cause and effect for each factor. Instead, perhaps, it is better to identify themes where the organisation should make a contribution and attempt to identify how it is best positioned to contribute in those areas.

The objective of developing performance indicators for the mining industry, however, is to identify unitary normalisation factors which are meaningful throughout the organisations in the sector, and across the sector itself. With this in mind, then, it is important to identify whether any of the indicators suggested by the UN CSD lend themselves to this task. The principles of the environmental category themes are already incorporated in the performance measures themselves discussed in Section 2.
3.3 Economic Categories

Throughout the discussion in much of the literature on sustainable development and mining considerable emphasis was placed on the role of the industry in providing the economic wherewithal to developing communities to improve their capacity to pursue a sustainable path. As was discussed in Project Document 1 (see Vol.1 PD1, Section 1.3.9.1), there is a theoretical argument that increasing per capita income ultimately leads to demand for environmental quality exceeding demand for the goods and services which are associated with pollution (see Kuznets, 1934 and 1973).

The UK Government (see Department of Environment Transport and the Regions 1998) insists that economic growth is an indicator of sustainable development, while the UN Economic and Social Council (see Committee on Natural Resources, 1996) has argued that industry has an important role to play in community development by encouraging the economy to be competitive, creating employment opportunities to provide sustained increases in household income and social development and to promote the efficient use of resources. The UN Commission on Sustainable Development consider economic themes such as consumption patterns, financial resources and mechanisms, technology transfer and capacity building, and international co-operation to accelerate sustainable development. Specific indicators include per capita GDP, sum of exports and imports as % of GDP, share of natural resource intensive industries in manufacturing value added, total overseas direct aid given or received as a % of GDP, foreign direct investment, as examples.

Thus, regardless of whether economic growth in itself will lead to sustainable development, the argument that economic conditions are an important component of sustainable development is sound. Although the measurands established by the UN might provide useful information to government, the challenge for a mining organisation would be to establish causality. As objectives, these measurands provide useful guidance, but none of these options, in themselves, provides an indicator of economic progress that would be useful for an organisation.

The objective for this section is to establish whether an economic normalisation factor can be identified which is meaningful to an organisation.

3.3.1 Contribution to GDP

If the central economic measures at the policy level, globally, relate to Gross Domestic Product (see Vaze 1998), and several of the United Nations CSD’s indicators of sustainable development require GDP, then from the point of view of a sector (such as mining) or a firm, can contribution to GDP represent the key economic normalisation factor for environmental performance.

Unilever (see Unilever, 1997), when developing their overall business impact assessment (OBIA) approach discussed in Section 1 (see this document, Section 1.3.3.3.2), considered contribution to GDP in their framework. Their view was that economic scaling of environmental themes would be the most appropriate way to assess the relative contribution.
made by their operations. Firstly, they calculated the dollar value of the net proceeds of sales ($NPS) for their operations and scaled their environmental contributions according to the $NPS for each group. Then they tried to carry out a similar exercise for the global economy, to identify whether their impacts per $ contribution were greater or lower than that for the global economy (see Unilever, 1997, page 45).

The objective for this was to establish where the environmental impacts for a given product or process were disproportionate to their economic value – as a basis for targeting products and processes for improvement. This framework was described in a document entitled ‘Sustainability – Unilever’s Approach’, but was not intended to be used to suggest whether Unilever’s activities were in line with sustainable development principles or not.

While the revenues generated by mining operations can be used to improve per capita GDP, reduce reliance on overseas direct aid, improve the value of exports as a % of GDP, enhance foreign direct investments, improve investment share in GDP (all economic indicators of sustainable development, according to the UN CSD), for examples, it is argued that contribution to GDP will not be a useful normalisation measure for environmental performance for mining companies.

The implicit assumption in using GDP is that an increase in GDP is a desirable phenomenon in the context of sustainable development, and that if organisations contribute to GDP growth, then they are making a contribution to sustainable development. However, as was discussed in Project Document 1, contribution to GDP is not an acceptable economic factor in relation to sustainable development because it is ‘additive’ – incorporating both expenditure on education programmes and defensive expenditure on pollution abatement, emergency services, contaminated land clean up etc in to a total of domestic product (see Vol.1 PD1, Section 1.3.9.2). The more a country has to spend on cleaning up toxic waste, the higher its gross domestic product will be. Thus GDP is rejected as an economic normalisation factor.

3.3.2 Expressions of Environmental Performance Used by Mining Companies

The Financial Times Mining Yearbook for 1999 (Brown, 1998) provides, amongst other information, three-year financial and operating summaries for 650 international companies engaged in exploration for and production of metals and minerals. The key financial indicators included for the companies listed include turnover, net income, cash flow, capital employed and stockholder’s funds. Each provides, in whole or in part, an indication of the financial contribution made by the company. The intention is to assess the extent to which these indicators are helpful to a mining company in the context of sustainable development.

3.3.2.1 Turnover and Revenue

The most fundamental expression of financial performance for an organisation is turnover, or revenue. Turnover is the total value of goods and services sold by the company to third parties in the normal course of trade (see Thomas & Tennant 1998, page 18), nominated by NPI as a potential normalisation factor because it is readily available for most companies. Turnover is a financial factor proposed by the WBCSD (the only financial factor whose definition is
'harmonised within WBCSD members' — see Lehni, 1998b), and was also investigated (as 'value of shipments') by Behmanesh et al. The higher the turnover an operation has, the higher the tax benefit paid to the government, in an area which can be used to invest in community development and in regional planning to develop non-resource-intensive industries which can endure after the mine has closed, so, in principle, there may be some correlation between turnover and sustainable development.

However, turnover suffers from similar limitations to GDP, which takes little account of the financial costs to society, or the company, associated with producing those revenues. In the development of the index of sustainable economic welfare for the United Kingdom, Jackson et al. (1997) calculate the total economic welfare of a country by deducting 'costs' such as expenditure on pollution control, the costs of water pollution, the costs of air pollution, noise pollution, the cost to the society of the loss of natural habitats and depletion of natural resources, the costs of climate change and ozone depletion.

The principle of calculating an ISEW is, though, more robust than the actual methodology used for each component, since it is by no means a straightforward exercise to calculate the cost of acidification, for example. Nonetheless, it does illustrate the importance of deducting 'costs' from benefits when looking at economic indicators. On this basis, then, turnover is rejected as an appropriate normalising factor for environmental performance — since it is a flawed objective. Turnover maximising activities may not be compatible with sustainable development, if the costs of those activities are not accounted for.

3.3.2.2 Net Income and Net Earnings

The key indicator used by mining companies for their environmental performance is 'net income' or 'net earnings'. This is calculated as follows:

Net income = \((\text{Profit on ordinary activities before taxation} - \text{taxation}) - \text{equity attributable to outside shareholders}\)

Where 'profit on ordinary activities before taxation' = \((\text{Group turnover} - ((\text{Share of associates turnover} - \text{operating costs}) + \text{share of associates' profit}) + (\text{profit on ordinary activities before interest} - \text{net interest payable}))\)

The benefit of using net income as an indicator, as opposed to turnover, is that, as for ISEW, it deducts the costs borne by the company from the total flow of turnover. As was discussed in Project Document 1, penalties incurred for pollution will be deducted from net income in the company accounts (see Vol.1 PD1, Sections 1.3.8 and 1.3.9). Provided that royalties paid to stakeholders, taxation to the government and penalties for pollution accurately reflect the cost to society of the loss of the natural resource being mined, and the impost of having a mining operation in place to remove that natural resource, then net income is an accurate reflection of the performance of the organisation. However, as was shown in Project Document 1, Kopp and Smith (1989) demonstrated that there is rarely consensus on what these values should be (see Vol.1 PD1, Section 1.3.9.4.2). Thus there is no certainty that the income flows generated by the mining company will, in fact, compensate fully for any damages caused. Nonetheless, net income provides a step forward from turnover as a financial indicator, since it explicitly deducts those costs which can be quantified from any revenue streams.
3.3.3 Net Present Value

3.3.3.1 Cost of Capital

However, even though net income is a progression from turnover as an indicator, it still does not fully represent the financial ‘contribution’ made by the mining operation in a society pursuing the principles of sustainable development. After all, a society does have choices on how to invest its capital, and financial sustainability depends on the value of the cash flows generated by an activity being equal to or greater than the value of the capital invested.

In the wider sense of sustainable development, as understood for the mining industry, one can argue that sustainable development requires the rate of financial return from the use of natural capital to be maximised, and the rate of social return from the investment of this finance in human capital to be similarly maximised. This understanding will lead to entirely different choices about investments than those informed solely by an objective to maximise financial returns. As an objective, maximising financial returns pays no regard to the efficiency with which natural capital is used, and pays no regard to the efficiency (or lack of efficiency) with which society converts this into human capital.

As a starting point, though, society needs to know the return on its investment, not just the flow of funds arising from the project once that investment has been made. Some involved in the appraisal of mining projects from an investor’s perspective are beginning to take the financial element of this into account. For example, Mining Journal (1999), observing an apparent fixation with operating cash costs when discussing mine performance, contend that, “The copper mining industry (and the same charge could be levelled at other sectors) has not served the interests of shareholders because it has not provided returns that cover the cost of its capital. .. Projects [are] becoming ever more capital-intensive, as mining companies have sought to reduce unit costs through economies of scale” (Anon. 1999a, page 47)

One financial measurement system, which considers the lifetime of an investment, is the Net-Present-Value (NPV) approach. According to Lumby (1991), “The NPV investment appraisal method works on the simple, but fundamental, principle that an investment is worthwhile undertaking if the money got out of the investment is at least equal to - if not greater than - the money put in.” (Lumby, 1991, page 59)

Box 5 The NPV Decision Rule (see Lumby, 1991, page 63)

In general terms, NPV can be expressed as 

$$\sum_{t=0}^{n} \frac{A_t}{(1+r)^t}$$

Here $A_t$ is the project’s cash flow (either positive or negative) in time $t$ ($t$ takes on values from year 0 to year $n$, where $n$ represents the point in time when the project comes to the end of its life) and $r$ is the annual rate of discount or the time value of money (which is here assumed to remain constant over the life of the project). All other things being equal, if the expression has a zero or positive value, the company should invest in the project; if it has a negative value, it should not invest.
From the standpoint of mine planning, this objective means that in order to maximise NPV, a mine must aim to,

"Maximise the value of the entire reserve, considering both the present value of mining a reserve block with the discounted benefit of mining it at some time in the future. This often leads to higher processed grades in the early life of the mining operation, then gradually reducing it towards the break-even grade at the end of the mine life. As a consequence of maximising the project value, the mine life is often reduced as a declining cut-off grade policy is applied." (King, 1998)

3.3.3.2 The Discount Rate

NPV calculations work on the principle that one always has a choice in how to invest money. Therefore, "The opportunity discount rate is the rate of interest or return the decision maker could earn in his or her best alternative use of the funds at the same level of risk." (Douglas 1987, page 10) The discount rate can have a very powerful influence on investment decisions. For example, at a discount rate of 10%, the present values of $5,000 now, $20,000 in ten years, and $100,000 in 25 years are $5,000, $7,710 and $9,230 respectively. All things being equal, an investor would chose to receive $100,000 dollars in 25 years time. However, at a discount rate of 15%, the present values of these alternatives would be $5,000, $4,944 and $3,040 respectively instead.

From the point of view of mining operations informed by the principles of sustainable development, this is critical. King (1998) shows that the inclusion of future decommissioning costs into the mine planning NPV calculation extends the life of the mine and increases the NPV. As King observes, however,

"The schedule that would theoretically maximise the NPV would be to not mine the last block of material unless the discounted closure cost was less than the value of the last increment of resource. This may be likened to maintaining a nominal mining capacity to avoid incurring the closing costs." (King, 1998, page 4)

Herein lies the fundamental flaw in using NPV in any attempt to normalise environmental burdens – the discount rate. Holmes (1998) argues that, "When monetary streams are subjected to discounting, even very large costs and benefits far in the future (say, 30-50 years) barely affect the NPV... This is one limitation, especially when far-in-the-future values are still important." Manipulations of discount rates and mine plans to optimise NPV may be misleading and dangerous. The loss of natural resources to future generations and the social and environmental costs of mine closure will be no less real because their present value is marginal. It is not known how this dilemma can be overcome at this stage – it would appear to merit a research programme in its own right.

3.3.4 Economic Value Added

The need for the incorporation of the cost of capital remains. If part of mining's justification for its presence is that the financial returns will allow a society to invest in projects such as schools and hospitals, then it would be unfortunate if society could earn the same financial
return on capital in a bank and not have to worry about any environmental degradation. After all there would be a compelling case to ‘cut out the middle person’ (i.e. the mining project) if this was so.

If society uses NPV calculations to inform their investment decisions before the start of the mining project — to look at the lifetime of the mine — then a tool is also needed which looks at the economic contribution from the mine on an ongoing basis. This is more naturally consistent with the development of normalised measures of performance which can be used on an ongoing basis, responding to changes in environmental performance.

A technique to generate this information is known as ‘economic value added’, or EVA™. EVA was defined by Stewart (1990) as shown in Table 29

### Table 29: Terms and Expressions for Economic Value Added

<table>
<thead>
<tr>
<th>Term</th>
<th>Expression</th>
</tr>
</thead>
<tbody>
<tr>
<td>EVA or Economic Value Added</td>
<td>Net Operating Profit After Taxes (NOPAT) – Cost of Capital * Capital Employed</td>
</tr>
<tr>
<td>Capital Employed</td>
<td>Total balance Sheet – non interest bearing debt at the beginning of the year/project</td>
</tr>
<tr>
<td>Cost of Capital</td>
<td>Cost of Equity * Proportion of Equity from Capital + Cost of Debt * Proportion of Debt from Capital * (1-tax rate)</td>
</tr>
</tbody>
</table>

According to Keen (1996), “Discounted cash flow is very close to economic value added, with the discount rate being the cost of capital.”

### 3.3.4.1 Value Added and Environmental Accounts

The UK Office of National Statistics (ONS) has taken an approach based on economic value added. (see Vaze, 1998) In their UK Environmental Accounts (UKENA) programme, the ONS aims

“To provide a systematic and comprehensive account of the pressures placed by the economy on the environment. The accounts use standard national accounts classifications to reveal environmental impacts by different industries. This disaggregation enables environmental data to be seen and analysed alongside economic data from the national accounts” (Vaze, P., Balchin, S., 1998, page 7).

The UKENA project identified three routes to arrive at the gross domestic product in an economy:

1. The total income earned from the production of goods and services
2. The total expenditure on all finished goods and services, work in progress, and stocks, less the cost of imports
3. The sum of value added by activities that produce goods and services (See Vaze, P., Balchin, S., 1998, page 12).

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12 Economic Value Added, EVA, is a trademark of the American consulting firm, Stern Stewart & Co.
The mining industry as provider of resources for goods and services, will find the third route, value added, the most appropriate.

Value added is defined by the ONS as "The contribution of an industry to gross domestic product. It consists of profits, wages and rent on land and buildings. It is measured at factor cost, that is after the payment of taxes on expenditure and subsidies" (Vaze, P., Balchin, S., 1998, page 12).

3.3.5 Discussion on Economic Normalisation Factors

Of the possible economic measures considered thus far, value added is the most appropriate to the mining industry relating to sustainable development. As stated earlier, high profits suggest the operation is efficient and society places considerable economic value on its products - suggesting the operation is likely to be economically sustainable. The inclusion of wages is critical, since wages paid to members of the local community directly benefit the community, whereas taxation and purchasing of goods and services will only provide a benefit if the revenues therefrom are channelled to the local community.

Value added must be calculated with reference to the cost of capital, but still represents the least flawed economic normalisation factor, rather than the most compelling one. It does not allow the full economic cost to society of the environmental performance it will be normalising to be calculated. For example, if the calculated economic value added of a mining project is $10,000,000 per year, and the rate of greenhouse gas production by that operation is 10,000 tonnes CO₂e per year, then a normalised expression of environmental performance could be $1,000 value added per tonne of CO₂e. But, unless the cost of 1 tonne of CO₂e is incorporated into the calculation for added value, it is not entirely clear how meaningful that expression is.

Even if such costs could be calculated, if they are subjected to discounting factors, then they appear to be negligible when considered in present value terms. By way of mitigation however, it should be noted that some mining companies are well aware of the distorting effects of discounting future costs. Rio Tinto (1999a) in its Annual Report, states that for its close down and restoration costs,

"These costs include dismantling and demolition of infrastructure, removal of residual materials and remediation of disturbed areas. Costs are provided for over the life of each operation on a units of production basis. Provisions are estimated on the basis of current prices and are not discounted. Changes in estimates are recognised in the profit and loss account over the remaining life of the operation." (Rio Tinto 1999a, page 98)

3.3.5.1 ISEW as an Economic Normalisation Factor

This is an improvement on the phenomenon described by King (to extend the mine life to reduce the discounted present value of the costs). However, an improved basis for establishing the 'true' costs of a mining project – in the form of pollution, rehabilitation and resource loss – is needed in the longer term to make economic normalisation more

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meaningful. Jackson et al’s work on ISEW illustrates the kind of issues which would need to be included in such an assessment. Thus, the economic normalising factor for environmental performance most consistent with sustainable development principles would be contribution to sustainable economic welfare.

This would require data not only on revenue streams from mining ventures, but would also demand cost data on the following which may arise directly as a result of mining operations (see Jackson et al, 1997):
- Water pollution costs
- Air pollution costs
- Noise pollution costs
- Costs of loss of natural habitats
- Cost of loss of farmlands
- Cost of depletion of non-renewables (e.g. fossil fuels, industrial minerals)
- Costs of climate change
- Defensive expenditures on health

In the case of water pollution, as an example, three data streams would be required:
1. Total discharges of polluting substances
2. Sensitivity of receiving waters to those discharges
3. Cost to society of water pollution attributable to mining operations

As Kopp and Smith (1989) showed, however, consensus on the costs of pollution from mining projects is difficult to achieve. Progress, nonetheless, is being made in some of these themes. Jackson et al (1997) discuss exactly how the costs of climate change could be incorporated into such an assessment. They observe that,

“A variety of estimates exist of the marginal social cost of carbon emissions in the 1990s, ranging from a little over $5 per tonne to more than $120 per tonne of carbon (based on the 1996 report by the Intergovernmental Panel on Climate Control (IPCC)).” (Jackson et al 1997)

This marginal cost varies with time, as the marginal cost rises as overall levels increase.

It is not suggested that values with a variation of an order of magnitude represents a definitive step forward on normalisation, and it is stressed that the marginal social costs for other issues, such as pollution of water-courses, will vary from location to location, since, unlike global warming, many of the issues under consideration are local in nature rather than global. While progress is being made, however, it is clear that while contribution to ISEW is the most meaningful economic normalisation factor for environmental performance in the context of sustainable development, there is as yet insufficient consensus on costs to implement it fully.

In the meantime, then, economic value added is the economic expression most closely aligned with the principles of sustainable development outlined in Project Document 1. It is, however, a proxy for ISEW, and mining companies must play their part in determining the costs associated with their activities at the local level with as much conviction as they strive to quantify the benefits that their activities bring.
3.4 Social Categories.

It should be emphasised once again that economic considerations alone do not move a mining operation and its community along a sustainable path. Wicker-Miurin (1999) argues that, "Discounted cash flow or the NPV of future earnings, no matter how accurately measured in terms of economic value added or return on economic capital, seem increasingly inadequate as measures of the value a company can and should deliver to its investors and to its other stakeholders. As a stand-alone measure of performance, purely financial shareholder value seems to me to be morally bankrupt." (Wicker-Miurin, 1999, page 1)

Social considerations are equally important. To revisit the concerns of Friends of the Earth (1999) (see Vol.1 PD1, Section 1.3.9.4.1), a rise in economic value added will only be compatible with sustainable development if it:

1. Translates into jobs;
2. Is matched by the spread of democracy;
3. Celebrates cultural identity;
4. Does not despoil the environment;
5. Allows the benefits to be distributed throughout society.

The UN have identified a number of social themes relating to sustainable development, related to poverty alleviation, demographics, education, health, and human settlement. Specific indicators include unemployment rates, measures of poverty, migration rates, fertility rates, number of children reaching grade 5 of primary education, adult literacy rate, % of population with access to safe drinking water, life expectancy, infrastructure expenditure per capita, just as examples.

The World Bank’s ‘World Development Report 1998/1999’ (World Bank, 1998) provides extensive data on the relative performance against these indicators of world economies. However, it is clear that these measures are designed for government policy-making rather than industrial strategy. As in the case of economic indicators of sustainable development, it is suggested here that these themes and indicators should provide guidance only to the mining company, as causality is difficult to demonstrate.

There is little question of the importance of social factors in sustainable development, but there is a challenge in identifying an index which is meaningful across global mining organisations with interests in a wide range of commodities. The International Council for Metals and the Environment (ICME) includes the following objective in its statement on community responsibility:

"Contribute to and participate in the social, economic and institutional development of the communities where operations are located and mitigate adverse effects in these communities to the greatest practical extent." (International Council for Metals and the Environment, 1996)

Is there an index which reflects engagement towards this objective?
3.4.1 Financial Investment in Community Programmes

The provision of financial resources will play an important part in community development, for example through investment in infrastructure programmes to build roads, hospitals, schools, and housing where the local communities of an operation feel that the assistance of a mining company in this way will help develop a sustainable future.

However, it is not clear that a financial measure is the most appropriate method of measuring engagement in community development. One of the key messages emerging from the work of the United Nations Economic and Social Council’s Committee on Natural Resources (1996, 1998a and 1998b), from the Commission on Sustainable Development (1998) and from the experiences of multinational organisations such as Shell UK (1998), Western Mining Company (1998), and Rio Tinto (1997b) is that the transfer of knowledge through education programmes to build capacity in the local community is a fundamental driving force for sustainable community development. The emphasis is on knowledge transfer rather than money transfer.

An example of this can be found at Weipa, in Cape York, Queensland, where the Australian mining company Comalco has operated since the late 1950s. Howitt (1992) provides a review of relations between Comalco and the native Napranum community over a thirty year period, in particular the control and use of funds earmarked for community programmes through the Weipa Aboriginal Society (WAS), jointly financed by Comalco and the Queensland and Australian Governments. Howitt observes that,

"There have always been Aboriginal people on the WAS Executive Committee, but the original operation was extremely paternalistic and failed to meet Aboriginal expectations of compensation and justice in relation to mining." (Howitt, 1992, page 230)

Howitt goes on to find, however, that,

"Despite its paternalistic beginnings, however, the contact between the Aboriginal leadership and senior company management in the operations of WAS seems to have provided a means of achieving unpredicted but enormously valuable outcomes... Both the funds and the projects have increasingly come under Aboriginal control in the 1980s .. [and] the emphasis of WAS expenditure in the 1980s changed from infrastructure development to ‘training and development of people’."(Howitt, 1992, pages 230 to 231)

3.4.2 Knowledge for Development

The World Bank (1998) describes the importance of knowledge in development in these terms,

"Poor countries - and poor people - differ from rich ones not only because they have less capital but because they have less knowledge. Knowledge is often costly to create and that is why much of it is created in industrial countries. ... Knowledge about how to treat a simple ailment like diarrhoea has existed for centuries - but millions of children continue to die from it because their parents do not know how to save them."
The World Bank identifies ‘knowledge gaps’ (i.e. technical know-how - e.g. nutrition, birth control, software engineering and accountancy) and ‘information gaps’ (e.g. public disclosure of information about job availability, educational opportunities, obtaining a loan) as being the critical challenges for communities to overcome if they are to develop. Box 6 illustrates the critical steps to take to overcome these gaps:

**Box 6: World Bank Strategies for Acquiring Knowledge for Development (see World Bank, 1998)**

**Narrowing Knowledge Gaps:**
- Acquiring knowledge: tapping and adapting knowledge available elsewhere in the world as well as creating knowledge locally through research and development, and building on indigenous knowledge
- Absorbing knowledge: ensuring universal basic education, with special emphasis on extending education to girls and other traditionally disadvantaged groups; creating opportunities for lifelong learning; and supporting tertiary education, especially in science and engineering
- Communicating knowledge: taking advantage of new information and communications technology and ensuring that the poor have access.

**Narrowing Information Gaps:**
- Processing the economy’s financial information: by ensuring transparency through effective accounting and disclosure, and by designing regulatory approaches that work in information-scarce settings
- Increasing our knowledge of the environment: conducting research to provide the underpinnings for effective environmental policies, and by disseminating information to create incentives for pollution reduction and responsible stewardship.
- Addressing information problems that hurt the poor: taking the time to learn about their needs and concerns, so that society can offer them useful information and assist them in devising ways to reduce their isolation from markets and to improve their access to formal institutions.

The last point in the checklist introduces what is argued here to be the global constant in community programmes - time.

### 3.4.3 Investing Human Resources and Time in Community Programmes

While financial support for community programmes is critical, the key to sharing knowledge, whether it is in a developed country or not, is time. Training programmes do not require just money, per se; they require the time of individuals willing to share their expertise with an audience which is willing to invest its time in listening to what the trainer has to say or show. Physical resources to help with the training are vital, but it is argued here that it is the time the engaged group invests which is likely to affect the success or otherwise of an initiative, it is argued here.

When the indicators suggested by the UN CSD regarding social development are revisited, it can be seen that improvements in education, public awareness, training, human health protection and human health promotion all rely on individuals and groups providing time to those who can benefit from their expertise to make their own communities more sustainable. While it is acknowledged that financial provision of support for community programmes is
important, it is argued here that the most appropriate index of social sustainable development for this work will be the amount of time an operation invests in community programmes, rather than simply the amount of money it spends to address its community responsibilities.
3.5 Physical Categories

Economic and social normalisation factors may be insufficient on their own, however, to fully reflect the relative environmental performance of a mining company in particular. This is especially the case in the mining industry for global operators whose core business relates to a small number of commodities. Using the example of aluminium, Figure 16 and Figure 17 illustrate the performance of two of the world's largest aluminium producers – Aluminium Canada (Alcan) and the Aluminium Company of America (Alcoa) - over the last five years (see Alcan 1999; Alcoa 1999).

Figure 16 Alcoa Financial and Production Performance, 1994 to 1998

The figures demonstrate the relative performance of the companies on total costs (including taxes), sold production, and prices. These three factors are the main drivers of net income for the mining operations: (Income = (Production * Price) – Costs). As the figures show, however, the income performance for Alcan and Alcoa over the past five years has been very
heavily influenced by the price of aluminium on the London Metals Exchange (LME), with cost reductions and production increases rarely able to offset the effect of price falls, and vice-versa.

As Figure 18 shows, the price of aluminium has fluctuated considerably over the past eleven years, from a peak of US$2,306 per tonne in 1988 to a trough of US$1,161 in 1993 – a price decline of almost 50%.

Figure 18 Average 3-month LME Price of Aluminium, 1988 to 1998 (see London Metals Exchange, 1999)

For a mining company to determine its management effort on the basis of financial performance - driven to a great extent by wildly fluctuating factors which are largely outside the mining company's control - would be counter-productive. For example, both Alcan and Alcoa's net income rose between 1993 and 1995, buoyed by rising aluminium prices. All other things being equal, their relative environmental performance would have appeared to improve without any intervention by the organisation. Conversely, declining earnings would give declining relative performance.

Clearly there are ways in which mining organisations can influence prices – since they are governed by forces of supply and demand – such as shutting down mines or starting up additional capacity. However, these are both costly options\(^{13}\) and usually mining companies will work to a large extent within prevailing price conditions. So, a mining company managing its environmental performance with the principles of sustainable development in mind will seek an additional, non-financial, normalisation factor to use in conjunction with economic value added and social investment.

\(^{13}\) Phelps Dodge's decision in the summer of 1999 to reduce copper output by 68,000tpa was anticipated by the company to require, post tax, US$61 million of funds.
Both the WBCSD and Behmanesh et al considered that production measures would be a useful factor against which to normalise environmental performance. Behmanesh et al considered a variety of factors relating to numbers of employees and salaries of employees. In fact, four of their six factors were related to either numbers of employees in different functions or their wages. Behmanesh et al’s study was carried out in the United States, where the wages / payroll of an organisation would be a consistent measure across the organisations under review. For global organisations, however, such a measure would be misleading, since it would be distorted by high wage levels in operations in developed countries compared to ‘relatively’ low wages in operations in developing nations. The use of quotation marks is deliberate – since although the wages paid to the local workforce in developing nations may be lower than those in developed nations, the buying power in the local market-place of those wages may be greater. Due to this lack of transparency, wages are rejected as a useful normalisation factor.

The actual of number of workers, however, is unaffected by global variations in wage rates. However, whether or not it is a useful basis for normalisation is dependant on the scruples of the organisation using the indicators. An organisation whose relative environmental performance in water use, for example, is declining – expressed as cubic metres of water abstracted per worker – has a number of options to improve its relative performance. These include reducing the amount of water usage in the production process, installing recycle and recovery systems to allow water to be recirculated – this might require a water treatment facility if the process requires water of a given quality – or increasing the number of workers.

The lowest cost option may be to simply hire more workers, particularly in activities that can utilise low paid workers. Beyond providing an income to a larger proportion of the local community, it is difficult to see how this course of action could be considered consistent with the principles of sustainable development. For this reason this normalisation factor is rejected.

The WBCSD propose that the most appropriate form of production-related normalisation of environmental performance should be a measure of physical production. They propose that “Unit of product (mass / amount / quantity)” is the most appropriate form, while “Space” is under discussion (see Lehni, 1998b). The merit of these kind of factors, when considering environmental performance, is clear. Of the production related themes considered thus far, there is the most clear relationship between these factors and environmental performance. Increasing physical production is likely to have a direct and causal relationship with energy use, water use, land use etc. In fact, for mining land-use is considered as an environmental theme in its own right, rather than as a normalising factor. The challenge for mining, in particular, is to identify the kind of physical production measure that is the most meaningful across the global mining industry. A number of options will be considered.

3.5.1 Per Tonne Product Milled or Produced

The challenge of comparison of different operations of different sizes has been encountered and addressed to a greater or lesser extent by some global mining organisations. Broken Hill Proprietary (1999b), for example, discusses its environmental performance data, for the most
part, in terms of absolute totals of emissions, for the Group and for product groups. The one exception for BHP is greenhouse gases, which the company reports on a product group basis in terms of ‘greenhouse intensity’ – i.e. tonnes of CO₂e per tonne of product. BHP also has a group expression for greenhouse intensity which ‘is calculated by weighting the greenhouse intensities of 13 of our main products according to the proportion of total greenhouse emissions that each product represents’ (Broken Hill Proprietary 1999b).

Rio Tinto (1998b and 1997a) also expresses most of its performance on an aggregate basis, as well as providing data for each operation and each product group. For specific issues, such as sulphur dioxide emissions from copper smelters, or fluoride emissions from aluminium smelters, Rio Tinto also reports performance for specific commodities on an emissions per tonne of product (for copper) and per tonne of aluminium basis. Western Mining Company has used ‘tonnes of ore milled’ as its physical production index (see Western Mining Company, 1998) to allow it to address underlying performance as well as total performance as production levels change. While there is some merit in this for a group such as WMC, whose operations are dominated by products such as nickel, gold and copper, for which milled product is a useful measure of production, it is not clear whether this approach would have merit for other global mining organisations.

At the level of the operation a physical measure must be identified which remains meaningful across the global organisation. Unit material ‘produced’ by operations, it is suggested here, does not reflect the level of physical activity at the site level. The following table, based on data reproduced in UNEP’s Industry and Environment Journal (see Anon., 1997e) illustrates the wide variation in ore grades, and associated waste levels in typical minerals, as Table 30:

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Average grade (%)</th>
<th>Ore (million tonnes)</th>
<th>Waste (million tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper</td>
<td>0.91</td>
<td>1,000</td>
<td>990</td>
</tr>
<tr>
<td>Gold</td>
<td>0.00033</td>
<td>620</td>
<td>620</td>
</tr>
<tr>
<td>Iron</td>
<td>40.0</td>
<td>906</td>
<td>540</td>
</tr>
<tr>
<td>Phosphate</td>
<td>9.3</td>
<td>160</td>
<td>140</td>
</tr>
<tr>
<td>Potash</td>
<td>17.0</td>
<td>160</td>
<td>130</td>
</tr>
<tr>
<td>Lead</td>
<td>2.5</td>
<td>35</td>
<td>130</td>
</tr>
<tr>
<td>Aluminium/ bauxite</td>
<td>23.0</td>
<td>109</td>
<td>84</td>
</tr>
<tr>
<td>Nickel</td>
<td>2.5</td>
<td>38</td>
<td>37</td>
</tr>
<tr>
<td>Tin</td>
<td>1.0</td>
<td>22</td>
<td>21</td>
</tr>
<tr>
<td>Manganese</td>
<td>30.0</td>
<td>22</td>
<td>16</td>
</tr>
<tr>
<td>Tungsten</td>
<td>0.25</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Chromium / chromite</td>
<td>30.0</td>
<td>13</td>
<td>9</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td><strong>3,200</strong></td>
<td><strong>2,700</strong></td>
</tr>
</tbody>
</table>

Waste figures do not include overburden. Totals do not add due to rounding.

---

Taking the ‘per tonne product milled’ approach of WMC, or the per tonne product approach, could be completely counterproductive if applied at either the commodity group level or at the group level. At the group level this is because, as the table illustrates so clearly, low grade ores such as gold and copper require enormous amounts of material to be moved to produce 1 tonne of product compared with high grade ores such as iron and aluminium, and it would therefore be impossible to compare their efficiencies on these terms.

BHP’s approach for greenhouse gases, as interpreted here, is an interesting one. An overall group intensity appears to be based on weighting the intensity for specific commodities according to their overall share of the total burden and adding these values to provide a group intensity.

This could be expressed as follows:

$$W_{op} = \left( \frac{G_{op}}{P_{op}} \right) \times \left( \frac{G_{op}}{\sum G_{all\text{ ops}}} \right) = \left( \frac{G_{op}}{P_{op}} \right) \times \frac{\sum G_{all\text{ ops}}}{\sum G_{all\text{ ops}}}$$

where

- $W_{op}$ = Weighted Greenhouse Gas intensity
- $G_{op}$ = Greenhouse Gas emissions at operation under consideration
- $P_{op}$ = Proportion of $\sum G_{all\text{ ops}}$ emitted at operation under consideration

$\sum G_{all\text{ ops}}$ = Sum of Greenhouse Gas emissions for all operations

A hypothetical example, given in Table 31, would illustrate the process:

**Table 31: Hypothetical example of weighted greenhouse intensity framework**

<table>
<thead>
<tr>
<th>Operation</th>
<th>Production (tonnes)</th>
<th>CO$_2$e (tonnes)</th>
<th>CO$_2$e intensity (tonne CO$_2$e per tonne)</th>
<th>% of total CO$_2$e</th>
<th>Weighted intensity (tonne CO$_2$e per tonne product)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (industrial minerals)</td>
<td>1,000,000</td>
<td>500,000</td>
<td>0.5</td>
<td>3.45</td>
<td>0.01725</td>
</tr>
<tr>
<td>B (copper)</td>
<td>500,000</td>
<td>4,000,000</td>
<td>8.0</td>
<td>27.59</td>
<td>2.2072</td>
</tr>
<tr>
<td>C (aluminium)</td>
<td>2,000,000</td>
<td>10,000,000</td>
<td>5.0</td>
<td>68.96</td>
<td>3.448</td>
</tr>
<tr>
<td>Group</td>
<td>3,500,000</td>
<td>14,500,000</td>
<td>13.5</td>
<td>100</td>
<td>5.67</td>
</tr>
</tbody>
</table>

The greenhouse intensity for the group, calculated simply by adding up greenhouse gas emissions and dividing by the sum of production, would be 4.14tCO$_2$e/tonne production. But, as has been seen in a multi-commodity business, it is simply not meaningful to generate a sum of production value. The approach which appears to be advocated by BHP, that of weighting values to give a relative value for the group (5.67 in this example) which can then be compared on a temporal basis with performance in other years, could be helpful if applied at the Group level in a global mining organisation.

However, regardless of the approach taken for normalising physical aspects of performance on per tonne production basis, whether at the level of the group or at the commodity level, there remains a danger that operations could seek to improve the appearance of their environmental performance through the selective mining of only the highest grade ores – i.e. those which yield the highest amount of product from the minimum amount of material disturbance.
As has been discussed earlier, to take a selective high grade ore approach reduces the life of the mine, and leaves a large amount of ore which becomes uneconomic to mine which could have been economic if blended with higher grade ores during operation. This will reduce the time the mine is able to provide employment and technology transfer to the surrounding community, and reduces the amount of time a sustainable society has to establish itself before the mine closes. Therefore, the per tonne product approach to physical categorisation is suggested to be inappropriate.

3.5.2 Per Tonne Material Moved

An alternative to this approach may be the ‘per tonne material moved’ approach. This considers the amount of material an operation must handle in its operations. There are a number of advantages to this approach. Firstly, it negates the incentive to operations to reject low ore grades as the amount of energy required to move material relative to the amount of ore yielded is reduced. It is possible that instead this could provide an incentive to operations to move more material to make their relative efficiency appear to improve, but since this is likely to lead to a corresponding increase in energy demand, land disturbance, etc., it is unlikely that such a course of action would be pursued.

Secondly, this approach is more accessible to a wider spectrum of operations. Distribution functions, for example, handle large volumes of material, but it is not clear whether they necessarily ‘produce’ material per se. In the case of Borax, a subsidiary of Rio Tinto, for example, some sites in the Group (Boron, Tincalayu, Sijes, Porvenir) are mining activities, but Boron, an open pit mine, has to move a lot more material to produce a ton of product than Porvenir, where deposits are much closer to the surface. Other sites within Borax (Rotterdam, Valencia [Spain]) are more focused on distribution, while others (Coudekerque, Wilmington, Nules, Campo Quijano) are focused on processing and shipping product. The common ground for these three types of activity is material handling.

3.5.3 The Need to Avoid Double Counting

When the activities of these operations are aggregated, however, a note of caution is required regarding double counting. While the waste rock at the mines will only be handled at the mine site, other material related to product may be handled at more than one facility. For example, refined mineral from Boron could be sent to Wilmingon for processing and then to Rotterdam for distribution into European markets. The same material could be counted three times as different operations handle it.

Lipsey (1983) uses the case of bread in national income accounting to illustrate how double-counting causes distortions;

“Suppose we took the value of all farmers’ outputs of wheat and added to it the value of all flour mills’ outputs of flour, plus the value of the outputs of bakeries, plus the value of the sales of bread by all retail shops. The resulting total would be much larger than the value of the final product – bread – produced by the economy.”

(Lipsey, 1983, page 510)
The argument holds for physical production. If one company mines iron ore; sells it to another firm for smelting into steel; who then sells the steel to a household products manufacturer; who sells the products to a wholesaler; who sells them to a retailer; who sells them to a consumer, how much iron ore has been used, and what is the environmental impact per tonne of iron ore? Table 32 provides a simple hypothetical example to illustrate the point.

Table 32: Hypothetical example of the effect of double counting in cumulative and unit iron ore requirements and environmental impact

<table>
<thead>
<tr>
<th>Stage of Production</th>
<th>Iron required</th>
<th>Cumulative iron ore mined</th>
<th>Environmental impact added by stage of production</th>
<th>Cumulative environmental impact</th>
<th>Environmental impact per unit mined iron ore used in stage of production</th>
<th>Cumulative environmental impact per unit mined iron ore</th>
<th>Environmental impact per unit mined iron ore</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mining</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Smelting</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>10</td>
<td>1.25</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>3</td>
<td>5</td>
<td>5</td>
<td>15</td>
<td>1.66</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Wholesaling</td>
<td>2</td>
<td>5</td>
<td>5</td>
<td>20</td>
<td>2.5</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Retailing</td>
<td>2</td>
<td>5</td>
<td>5</td>
<td>25</td>
<td>2.5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Consumption</td>
<td>2</td>
<td>5</td>
<td>5</td>
<td>30</td>
<td>2.5</td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>

Here it can be seen that even though the sum of iron ore requirements is 18 units, in fact only five units of iron ore are required. However, for environmental impact, each stage does ‘add’ impact and therefore the final impact per unit is 6; 30 units of impact for 5 units of iron ore. There may be additional stages – including the transportation of material from one stage of production to the next. Where mining operations embrace more than one stage of production, they must ensure that they consider the total environmental impact in terms of the true total production measure without double counting.

A suggested solution to this challenge is to remember when rolling data up that the value for material moved for a business unit should reflect the total amount of material handled (this is likely to be equal to the amount of material handled at the mines within a business unit) and avoid double counting, as the arguments against ‘per tonne product’ are strong enough to reject it as an alternative. Therefore it is suggested that, for the purposes of Group-wide measures of performance in global mining organisations, per tonne material handled is the most appropriate measure of physical activity.
3.6 Discussion

What has become clear from the review of approaches to normalisation is that while there is merit in having indicators such as global warming normalised against solely financial criteria, indicators informed by the principles of sustainable development in the mining industry will require a far broader scope to normalisation. The UK Department of Environment, Transport and the Regions (DETR) launched a consultation paper in 1998 called ‘Sustainability Counts’, which sets out 13 headline indicators of sustainable development in the United Kingdom. The following figure illustrates the categories identified by DETR as being of headline significance in the sustainable development debate, together with the inter-relationships between them.

Figure 19: DETR headline sustainable development indicators and the links between them (based on Department of Environment Transport and the Regions 1998)

It is clear from Figure 19 that the principles of sustainable development require consideration of a whole host of themes, with economic growth having a strong causal effect on other categories, and health strongly affected by changes in a number of other categories. Different actors will attach a different level of significance to each. Some may argue that, in the long term, climate change is the critical indicator, since ultimately, this could make our environment uninhabitable. Others may prefer to think of economic growth as the most important, since it is this growth which pays for education, social investment, health infrastructure and other social progress without which development may not be sustainable.
While such a discussion may be purely academic it is important to emphasise the importance of value judgements in the process of developing indicators and normalisation factors. As noted in Section 3.1 earlier, Thomas and Tennant (1998) working with UNEP and the insurance industry, focussed on normalisation factors related, in one way or another, to finance. The mining industry, which understands sustainable development in terms of the use of physical assets to develop both financial and human or social capital, must focus instead on the amount of effort it expends in its wider sphere of relationships to sustainable development. As was concluded in Project Document 1, the mining industry and its stakeholders must be in a position to establish:

1. That improvements in economic and social conditions do not undermine those ecological functions which are non-substitutable;
2. That improvements in economic conditions are achieved without undermining social conditions;
3. That improvements in economic and social conditions which require the use of non-renewable resources deliver the means to substitute that natural capital with human capital;

if they intend to manage their operations in a manner consistent with the principles of sustainable development for mining (see Vol.1 PD1, Section 1.3.9.4.3).

With these principles in mind, the key indicators of environmental performance outlined in Table 33 and Table 34 are proposed for use at the corporate level of the global mining organisation. They are not sustainable development indicators. They focus on the environmental aspects of performance informed by the principles established in Project Document 1 and reiterated above. The indicators which are appropriate for aggregation to the global level are outlined in Table 33, while those indicators which are relevant throughout global mining organisations but where aggregation is only appropriate to the local or regional level are outlined in Table 34.

Table 33 Normalised key environmental performance indicators for issues with global effects for global mining companies

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Normalised Against Economic Criteria</th>
<th>Indicator Normalised Against Social Criteria</th>
<th>Indicator Normalised Against Physical Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mining company [commodity] extraction as % of global [commodity] reserves per US$m value added</td>
<td>Mining company [commodity] extraction as % of global [commodity] reserves per 1000 person-hours invested in community programmes</td>
<td>Mining company [commodity] extraction as % of global [commodity] reserves per Kt material moved</td>
<td></td>
</tr>
<tr>
<td>Mining company [commodity] extraction as % of global [commodity] reserve base per US$m value added</td>
<td>Mining company [commodity] extraction as % of global [commodity] reserve base per 1000 person-hours invested in community programmes</td>
<td>Mining company [commodity] extraction as % of global [commodity] reserve base per Kt material moved</td>
<td></td>
</tr>
<tr>
<td>Primary Energy Required (Gj) per US$m value added</td>
<td>Primary Energy Required per 1000 person-hours invested in community programmes</td>
<td>Primary Energy Required per Kt material moved</td>
<td></td>
</tr>
<tr>
<td>Absolute Global Warming Potential (MTCO2e) per US$m value added</td>
<td>Absolute Global Warming Potential per 1000 person-hours invested in community programmes</td>
<td>Absolute Global Warming Potential per Kt material moved</td>
<td></td>
</tr>
<tr>
<td>Total Atmospheric Acidification Potential per US$m value added</td>
<td>Total Atmospheric Acidification Potential per 1000 person-hours invested in community programmes</td>
<td>Total Atmospheric Acidification Potential per Kt material moved</td>
<td></td>
</tr>
<tr>
<td>Total Normalised Water Abstracted per US$m value added</td>
<td>Total Normalised Water Abstracted per 1000 person-hours invested in community programmes</td>
<td>Total Normalised Water Abstracted per Kt material moved</td>
<td></td>
</tr>
</tbody>
</table>
### Table 34 Normalised key environmental performance indicators for issues with regional / local effects for global mining companies

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Normalised Against Economic Criteria</th>
<th>Indicator</th>
<th>Normalised Against Social Criteria</th>
<th>Indicator</th>
<th>Normalised Against Physical Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total hectares soil exceeding critical acid load from deposition per US$m value added</td>
<td>Total hectares soil exceeding critical acid load from deposition per 1000 person-hours invested in community programmes</td>
<td>Total hectares soil exceeding critical acid load from deposition per Kt material moved</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total cubic metres water exceeding critical acid load from deposition / drainage per US$m value added</td>
<td>Total cubic metres water exceeding critical acid load from deposition / drainage per 1000 person-hours invested in community programmes</td>
<td>Total cubic metres water exceeding critical acid load from deposition / drainage per Kt material moved</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Water Abstracted per US$m value added</td>
<td>Total Water Abstracted per 1000 person-hours invested in community programmes</td>
<td>Total Water Abstracted per Kt material moved</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Aquatic Ecotoxicity Potential per US$m value added</td>
<td>Total Aquatic Ecotoxicity Potential per 1000 person-hours invested in community programmes</td>
<td>Total Aquatic Ecotoxicity Potential per Kt material moved</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Terrestrial Ecotoxicity Potential per US$m value added</td>
<td>Total Terrestrial Ecotoxicity Potential per 1000 person-hours invested in community programmes</td>
<td>Total Terrestrial Ecotoxicity Potential per Kt material moved</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Area Disturbed per US$m value added</td>
<td>Total Area Disturbed per 1000 person-hours invested in community programmes</td>
<td>Total Area Disturbed per Kt material moved</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area of Permanent Reclamation per US$m value added</td>
<td>Area of Permanent Reclamation per 1000 person-hours invested in community programmes</td>
<td>Area of Permanent Reclamation per Kt material moved</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Land Use of Permanent Reclamation per US$m value added</td>
<td>Land Use of Permanent Reclamation per 1000 person-hours invested in community programmes</td>
<td>Land Use of Permanent Reclamation per Kt material moved</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relative Densities for Secondary Species (as % all species) in impacted and non-impacted areas per US$m value added</td>
<td>Relative Densities for Secondary Species (as % all species) in impacted and non-impacted areas per 1000 person-hours invested in community programmes</td>
<td>Relative Densities for Secondary Species (as % all species) in impacted and non-impacted areas per Kt material moved</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of species recorded in impacted areas relative to those in mature areas of target land conditions per US$m value added</td>
<td>Number of species recorded in impacted areas relative to those in mature areas of target land conditions per 1000 person-hours invested in community programmes</td>
<td>Number of species recorded in impacted areas relative to those in mature areas of target land conditions per Kt material moved</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gross weight of suspended solids in aqueous discharges per US$m value added</td>
<td>Gross weight of suspended solids in aqueous discharges per 1000 person-hours invested in community programmes</td>
<td>Gross weight of suspended solids in aqueous discharges per Kt material moved</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total particulate matter released from operations per US$m value added</td>
<td>Total particulate matter released from operations per 1000 person-hours invested in community programmes</td>
<td>Total particulate matter released from operations per Kt material moved</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### 3.6.1 A Hypothetical Example of How Normalisation Factors Could Work in Practice

The following example illustrates how these normalisation factors might be used to express performance. The perspective used is that of Group management of environment within a global mining organisation. The expressions preferred by other stakeholders may be entirely different, however.
Engineering Doctorate in Environmental Technology, Sustainable Development and the Global Mining Industry  
P.W. Argust, Rio Tinto / Borax

3.6.1.1 Hypothetical Indicator Information

Table 35 illustrates the information required on the basis of the discussions in this section and Section 2. These are the values that sit at the top of the information pyramid discussed in Section 2 (see this document: Section 1, Figures 1, 2, 3, 6, and 7, pages 13, 14, 15, 35, and 36). Beneath these values a significant amount of supporting data will exist.

Table 35: Hypothetical Data Set for Group Indicators

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Primary Energy Required (GJ)</td>
<td>105.0</td>
<td>110.0</td>
<td>120.0</td>
<td>100.0</td>
</tr>
<tr>
<td>Absolute Global warming potential [GWP] (MT CO2 equivalent)</td>
<td>100.0</td>
<td>105.0</td>
<td>110.0</td>
<td>105.0</td>
</tr>
<tr>
<td>Total Atmospheric Acidification Potential [AAP] (H+ ions)</td>
<td>95.0</td>
<td>80.0</td>
<td>75.0</td>
<td>75.0</td>
</tr>
<tr>
<td>Terrestrial Critical Acidification Load Exceedence (hectares)</td>
<td>450.0</td>
<td>200.0</td>
<td>100.0</td>
<td>10.0</td>
</tr>
<tr>
<td>Aquatic Critical Acidification Load Exceedence (Mebic metres)</td>
<td>20.0</td>
<td>25.0</td>
<td>30.0</td>
<td>25.0</td>
</tr>
<tr>
<td>Total Water Abstraction (cubic metres)</td>
<td>95.0</td>
<td>100.0</td>
<td>105.0</td>
<td>105.0</td>
</tr>
<tr>
<td>Normalised Water Abstraction (cubic metres, related to local availability)</td>
<td>110.0</td>
<td>110.0</td>
<td>120.0</td>
<td>125.0</td>
</tr>
<tr>
<td>Total Aquatic Ecotoxicity Potential (tonnes copper equiv. related to EQS)</td>
<td>80.0</td>
<td>110.0</td>
<td>100.0</td>
<td>90.0</td>
</tr>
<tr>
<td>Total Land Disturbed (ha)</td>
<td>150.0</td>
<td>160.0</td>
<td>150.0</td>
<td>145.0</td>
</tr>
<tr>
<td>Area Available for Reclamation (ha)</td>
<td>70.0</td>
<td>70.0</td>
<td>80.0</td>
<td>90.0</td>
</tr>
<tr>
<td>Area of Permanent Reclamation (ha)</td>
<td>40.0</td>
<td>45.0</td>
<td>50.0</td>
<td>55.0</td>
</tr>
<tr>
<td>Area of Permanent Reclamation as % of Area Available for Reclamation</td>
<td>57.1</td>
<td>64.3</td>
<td>62.5</td>
<td>61.1</td>
</tr>
<tr>
<td>% of Permanent reclamation to Native</td>
<td>80.0</td>
<td>75.0</td>
<td>80.0</td>
<td>90.0</td>
</tr>
<tr>
<td>% of Permanent reclamation to Forestry</td>
<td>10.0</td>
<td>15.0</td>
<td>10.0</td>
<td>5.0</td>
</tr>
<tr>
<td>% of Permanent reclamation to Agricultural</td>
<td>5.0</td>
<td>5.0</td>
<td>10.0</td>
<td>0.0</td>
</tr>
<tr>
<td>% of Permanent reclamation to Recreational</td>
<td>5.0</td>
<td>5.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>% of Permanent reclamation to Other</td>
<td>0.0</td>
<td>5.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Relative Densities for Secondary Species (as % of all species) in impacted and non impacted areas</td>
<td>5.0</td>
<td>10.0</td>
<td>10.0</td>
<td>10.0</td>
</tr>
<tr>
<td>Number of species recorded in impacted areas relative to those in mature areas of the site</td>
<td>5.0</td>
<td>5.0</td>
<td>10.0</td>
<td>15.0</td>
</tr>
<tr>
<td>Gross weight of suspended solids (tonnes) in aqueous discharges</td>
<td>120</td>
<td>130</td>
<td>95</td>
<td>100</td>
</tr>
<tr>
<td>Total Particulates (tonnes)</td>
<td>100.0</td>
<td>110.0</td>
<td>120.0</td>
<td>100.0</td>
</tr>
<tr>
<td>Material Extracted (tonnes)</td>
<td>150.0</td>
<td>170.0</td>
<td>180.0</td>
<td>180.0</td>
</tr>
<tr>
<td>Material Extracted as % of Global Reserves</td>
<td>4.0</td>
<td>5.0</td>
<td>6.0</td>
<td>7.0</td>
</tr>
<tr>
<td>Tonnes Material Moved</td>
<td>100.0</td>
<td>110.0</td>
<td>120.0</td>
<td>120.0</td>
</tr>
<tr>
<td>S Value Added</td>
<td>100.0</td>
<td>100.0</td>
<td>140.0</td>
<td>170.0</td>
</tr>
<tr>
<td>Man Hours on Community Programs</td>
<td>90.0</td>
<td>110.0</td>
<td>80.0</td>
<td>70.0</td>
</tr>
</tbody>
</table>

It should be stressed that the data used are fictional and are intended solely for illustrative purposes.

3.6.1.2 Indicator Trends

In this example, just 3 indicator trends will be considered – energy, land and water use - to provide an overview of how the indicators could be used. Energy use, land use and water use may have merit as appropriate direct indicators of environmental performance across global mining companies for two reasons. Firstly, all of a global mining company’s operations - whether they are mine facilities, processing facilities, distribution facilities, or administration facilities - require power, space, and water.

Secondly, the environmental burden methodology section illustrated that water, energy and land use are all significant aspects of environmental performance for mining activities. The mining industry is a large consumer of electricity - in the USA in 1994, the mining industry...
consumed 5% of total US electricity consumption; in South Africa in 1995 the proportion was approximately 25% (see Industry and Environment Centre, 1998). Mining involves the movement of large quantities of rock, much of which contains very low concentrations of ore, and water is used in large quantities. Nonetheless, other indicators might have greater significance to stakeholders than those discussed here for the purposes of illustrating this example. Figure 20 illustrates how trends in the three themes can be illustrated:

Figure 20: Hypothetical Trends in Headline Indicators

![Graph showing headline indicator trends from 1996 to 1999.](image)

3.6.1.3 Underlying Indicators

Stakeholders interested in the water data, for example, might wish to see how the water consumption pattern has changed. This could be demonstrated using the indicator data gathered.

Figure 21: Underlying Indicators of Performance in Hypothetical Water Consumption

Figure 21 illustrates the underlying performance in water consumption. Although the total

![Graph showing water consumption trends from 1996 to 1999.](image)
water use has increased slightly over the period, the proportion of this derived from water abstraction has fallen, showing the increased use of recycled and impounded water, reducing the strain on surface and groundwater sources of water. However, the weighted water abstraction value has risen, suggesting that reduced water abstraction in relatively water abundant areas, such as Asia, has been offset by increased water abstraction of water in relatively water scarce areas, such as Australia.

3.6.1.4 Using Normalisation Factors

Alternatively, if a stakeholder were interested in performance in relative terms, then the total water consumption headline, which showed a slight decline in overall water consumption over the period, could be expressed as follows, using the normalisation factors proposed:

Figure 22: Using the Normalisation factors to Express Trends in Hypothetical Environmental Performance

Figure 22 illustrates that although water consumption per unit material moved and per unit value added has declined, i.e. is moving in a direction compatible with sustainable development, water consumption per person-hour invested in community programmes has increased. By using the normalisation factors it is possible to identify areas where effort should be focused, in general terms. Improving environmental performance relative to production and value added is to be applauded, but declining environmental performance relative to community investment shows an area where improvements should be made for the organisation to be able to show it is working towards sustainable development.

The purpose of this work is to illustrate that it is possible to develop indicators of environmental performance which are meaningful and transparent for a global mining company in the context of sustainable development. To realise the full potential of these indicators, normalisation factors which reflect sustainable development goals must be integrated into the structure. These must encompass physical, social, and economic considerations. The validation of these indicators in a case study – the leading global mining organisation Rio Tinto – will help to establish whether the indicators and normalisation
factors proposed are the right ones as far as the mining industry is concerned, and to establish how they will be implemented in a global mining organisation.
4. Case Study of Environmental Performance Indicators in Practice in the Global Mining Industry

4.1 The Need for A Case Study

In Project Document 1 and the previous three sections of this document the relationship between sustainable development and mining was examined and the need for key indicators of environmental performance was justified. The progress made by various institutions towards indicator development in various contexts were reviewed, together with their implications for a global mining organisation. The kind of environmental themes that should be considered at the level of the global mining organisation, as well as those that should not, were considered, and the need for normalisation of performance in these themes was explained. The approach to normalisation that is appropriate in a global mining organisation informed by the principles of sustainable development was outlined, together with a review of the possible normalisation factors that could be used.

This process has led to a number of key findings relating to mining and sustainable development, indicator structure, environmental categories appropriate for global mining organisations, and normalisation factors. In summary:

1. Mining is compatible with the principles of sustainable development, provided that:
   - It provides improvements in economic and social conditions without undermining non-substitutable ecological functions;
   - It provides improvements in economic conditions without undermining social conditions;
   - If improvements in economic and social conditions require non-renewable resources to be used the means of substituting that natural capital for human capital must be delivered (see Vol.1 PD1).

2. Any environmental indicators must be organised according to a pyramid-type hierarchy – with increasing concentration and selection of indicators towards the corporate apex (see this document, Section 1 - Figures 6 and 7, pages 35 and 36).

3. Any environmental themes considered must be relevant at the global level for a mining organisation, even though for some themes the effects of these global themes will be felt at the local level (e.g. biological diversity) (see this document, Section 2).

4. Normalisation must take account of economic, social and physical dimensions. (see this document, Section 3)

With these four findings in mind, the indicator structure set out in Table 33 and Table 34 was established (see this document, Section 3, pages 128 and 129).

Putting this structure into place in global mining organisation, it is contended, would provide mining companies and their stakeholders with the key information required to assess whether or not the performance of the organisation is moving in a path which is becoming less unsustainable. This information provides the basis for action, be it in the form of pro-active management of environmental performance by a mining organisation embracing the
principles of sustainable development, or be it in the form of reactive management of environmental performance by an unenlightened organisation being forced to take action by its stakeholders.
4.2 Objectives

Any implementation requires three 'hurdles' to be overcome:

1. Both the mining organisation and its stakeholders must agree that the principles of sustainable development, for mining, provide the framework by which operations should address their environmental, economic and social responsibilities.

2. Both the mining organisation and its stakeholders must agree that key performance indicators provide the mechanism by which progress can be monitored, communicated, and acted upon.

3. Both the mining organisation and its stakeholders must agree which specific indicators of performance will allow such progress to be illustrated meaningfully and transparently.

It is contended that to be a true contribution to the field of environmental technology, this work must not only be examined by those qualified to assess whether it represents a contribution to the field of knowledge (in this case environmental technology). It must also be tested by an organisation, to determine the extent to which mining organisations can implement the recommendations of the work and derive real benefit from improved environmental communication and performance.

In preparing for the primary test – the contribution to the field of knowledge – a case study of the secondary test will be presented. This will discuss in detail how a global mining organisation has responded specifically to this work. The objective for this phase is to assess the extent to which a global mining organisation is in a position to accept the findings of this work and implement them.
4.3 The Case Study Process

The procedure followed for this case study is as follows. Firstly a global mining company will be introduced. This will be followed by discussion of the qualitative reaction of this company to the principles of mining and sustainable development outlined at the start of this work, together with a qualitative assessment by the organisation of the indicator framework suggested and the environmental categories suggested as being appropriate for global mining organisations. A qualitative assessment of the normalisation factors will be carried out also, to establish the extent to which the organisation supports the metrics proposed. This will be followed by a gap analysis – identifying those areas where the organisation has the capability and quantitative data to allow the methodology proposed to be implemented\textsuperscript{15}.

The resulting data generated will allow current performance measures (if any) to be compared with those which could be implemented following the methodology proposed in this work, together with an assessment of the implications of the information generated. It is possible that both qualitative assessment and quantitative assessment of the methodology by the global mining organisation may differ from a similar assessment of the methodology by a subsidiary. For example, information necessary for expressing performance at the global level may not be familiar to corporate specialists, but may be familiar and available to site specialists. Accordingly, two cases will be presented – the case of the global mining organisation, and the case of the local subsidiary of the global mining organisation.

\textsuperscript{15} The supporting notes for operations prepared for the quantitative assessment and a sample data-set are included in Appendices 1 & 2 respectively (see Vol.4 APD1&2).
4.4 CASE STUDY 1 – RIO TINTO

4.4.1 Rio Tinto as a Global Mining Organisation

Rio Tinto is one of the world’s leading mining organisations as Table 36 illustrates.

Table 36: Relative Ranking for Net Income and Total Assets for Leading Mining Organisations (Brown, 1999)

<table>
<thead>
<tr>
<th>Company</th>
<th>1997 Net Income (million US$)</th>
<th>1997 Total Assets (million US$)</th>
<th>1997 Net Income Ranking (relative to other companies in this table)</th>
<th>1997 Total Assets Ranking (relative to other companies in this table)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alcan</td>
<td>475</td>
<td>9,466</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>Alcoa</td>
<td>594</td>
<td>13,604</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Anglo American Corp (Anglo)</td>
<td>1,149</td>
<td>7,437</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Broken Hill Proprietary (BHP)</td>
<td>255</td>
<td>22,825</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>De Beers</td>
<td>650</td>
<td>4,025</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>Gencor</td>
<td>496</td>
<td>5,386</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Rio Tinto</td>
<td>1,220</td>
<td>16,674</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

In the most recent year for which global figures are available, 1997, Rio Tinto produced the highest net income from the second highest asset base relative to its peers. Broken Hill Proprietary (BHP) has the largest asset base, but the lowest net income, while Anglo American has the second highest net income from only the fifth highest asset base. This may reflect the nature of the management of these operations, or the nature of the operations themselves – Anglo has substantial interests in high margin activities such as diamonds and gold (Anglo American Corporation, 1998), whilst BHP is more heavily focussed on lower margin activities such as steel and petroleum (Broken Hill Proprietary, 1999a).

Rio Tinto is also a global organisation, stating its nature of business thus,

“Rio Tinto is one of the world’s leading international mining groups. Rio Tinto’s substantial interests in mining include copper, gold, iron ore, coal, aluminium, borates, and titanium dioxide feedstock. The Group also mines diamonds, silver, zinc, lead, nickel, molybdenum, salt, talc, and uranium. Interests are located predominantly in North America and Australia, as well as in South America, Asia, Europe and southern Africa. Products are sold world-wide, but particularly in North America, Western Europe and throughout Asia.” (Rio Tinto, 1999a. Page 9)

These key locations are illustrated in Figure 23, although there may be a number of operations in any one area (for example, Rio Tinto has managerial responsibility for 23 mining and smelting operations in Australia at this time)
Rio Tinto was formed at the end of 1995 by the merger of the Rio Tinto Zinc Corporation (RTZ) and Conzinc Riotinto Australia (CRA) into a dual listed company (London and Melbourne) referred to as RTZ-CRA until June 1997 when the name Rio Tinto was adopted. RTZ had been formed in 1962 by the merger of the Rio Tinto Company and the Consolidated Zinc Corporation. At the same time, the Australian interests of these two London based companies were also merged to form CRA. The combined Rio Tinto group is headquartered in London, and is structured into six principal product groups:

- Iron Ore;
- Industrial Minerals;
- Copper;
- Aluminium (as Comalco);
- Energy;
- Gold and Other Minerals (Rio Tinto, 1999a, page 9)

This operating core is supported by global exploration and technology groups. Rio Tinto comprises subsidiaries, joint venture interests, associates, and joint arrangements, the most substantial of which are illustrated in Appendix 3 – "Rio Tinto Data for EPI Case Study" (see Vol.4 APD3, Tables 1 to 4).

Rio Tinto has great diversity not only in the geographical and material scope of its operations, but also in the scale of those operations. The largest operations in which Rio Tinto is involved include the Bingham Canyon copper/gold/silver/molybdenum mine in Utah; the Escondida copper/gold/silver joint venture with BHP in Chile; the Palabora copper joint venture with Anglo American in South Africa; the Richards Bay heavy mineral sand joint venture with Billiton, also in South Africa; and the Grasberg copper/gold/silver joint venture with Freeport.
MeMoRan in Irian Jaya, Indonesia. Each of these mines employ over 2,000 people. The smallest of Rio Tinto operations are mostly involved in processing and distribution of various industrial minerals such as talc and borates. These smaller operations may employ as few as 20 people each.

The geographical and social environment in which each mine operates varies from one facility to the next – mine location is mostly driven by geological circumstances. Thus some facilities are in heavily developed areas – Bingham Canyon for example is less than 50 miles from Salt Lake City in the USA – whilst others are in very remote areas of Western Australia (such as Hamersley Iron), the Andes (such as Borax Argentina and Escondida), or Indonesia and Papua (such as Grasberg, Kelian, Lihir, and Bougainville).

Thus Rio Tinto, the mining organisation with the largest net income in 1997, with interests across the planet, and engaged in mining a vast array of commodities, is a ‘global mining organisation’ in the context of this research. It is likely to face considerable challenges in reconciling data into expressions of ‘group performance’ when its interests are so diverse. The Sections following will explore Rio Tinto’s approach to sustainable development, performance indicators, the environmental themes proposed, plus the normalisation factors proposed, all at the qualitative level. Thereafter quantitative validation of the environmental performance indicators will take place. Firstly, Rio Tinto’s willingness to report on its performance in terms of the principles presented in Project Document 1 (see Vol.1 PD1) and indicators presented in this document (see Sections 1 to 3) will be assessed, then its capability to report its progress in those terms will be assessed, gaps identified, and implications discussed.

4.4.2 Qualitative Assessment of the Principles of Sustainable Development

Rather than present the qualitative response from the case study company, Rio Tinto, on whether it supports the principles of sustainable development described in Project Document 1, an alternative approach is preferred. Throughout this research, there have been numerous discussions between the author and executives across Rio Tinto and its subsidiaries concerning mining and sustainable development. By way of validation of the principles of sustainable development, three sets of statements - two public and one internal – which have emerged between Autumn 1997 (when the project began) and Autumn 1999 (when the project approached conclusion) will be presented. These will be assessed to establish whether Rio Tinto has embraced, or is likely to embrace, those principles.

Rio Tinto set out its corporate position on sustainable development for the first time in 1998, a few months after the key performance indicators project commenced. In its 1997 annual health safety and environment report, Rio Tinto made three statements relevant to the debate on sustainable development and mining in Project Document 1;

1. “The challenge [of sustainable development] is to deliver rising real incomes to twice the current world population, without undermining the environmental foundations of the world economy. ... Given the growth in population, no sustainable path to the future can take place without sustained economic growth. ... But this economic growth must now be
achieved without putting further pressure on environmental systems which are already degraded.” (Rio Tinto, 1999b, page 27)

2. “Within this context we... believe that a strong business performance reflects and enables a sound contribution to sustainable development; [and] note that mining companies which do not excel in the management of their environmental performance and community interactions will not themselves be sustainable.” (Rio Tinto, 1999b, ibid.)

3. “We believe that the eradication of poverty through the creation of sustainable livelihoods is an indispensable requirement for sustainable development. Approaches to each community are developed in consultation locally, but in general we seek to make a positive contribution to community development, by:

- providing employment opportunity;
- transferring technology and skills;
- stimulating economic activity;
- involvement in local partnerships.” (Rio Tinto, 1999b, ibid.)

In the first instance, then, by 1997/8 Rio Tinto had recognised that sustainable development required effective management of economic, environmental, and social factors, although this was very much underpinned by a belief in economic growth as the ‘engine’ for sustainable development. As was discussed in Project Document 1, economic growth, a priori, is no such thing (see Vol.1 PD1, Section 1.3.9). However, the qualifying statements made by Rio Tinto - such as the eradication of poverty, transferring technology and skills, and that mining companies that do not act in a responsible fashion to their environment and local communities will not last – suggest that Rio Tinto’s grasp of sustainable development was somewhat deeper than the argument that economic growth pays for environmental improvements and must therefore be consistent with sustainable development dismissed in Project Document 1.

By June 1998 Rio Tinto was moving further in its understanding of sustainable development, forming a working group to prepare a response to the DETR Consultation Paper on Sustainable Development. This response argued, among other theses, that,

“The mineral industry’s contribution to sustainable development is through the development of mineral resources that are managed at a local level such that a lasting legacy of diversified economic activity, education, skills, public health and rehabilitated land remains once mining ceases. Mining converts the intrinsic value of a metal in the ground into the capital and capacity that allows a community to establish itself according to its wishes.” (Rio Tinto 1999c, page 1)

Most recently, in September 1999,

“Rio Tinto’s chairman, Robert Wilson, announced that he has agreed to lead a sustainable development initiative involving the chairmen/CEOs of many of the world’s leading mining companies: Rio Tinto, Phelps Dodge, Placer, BHP, WMC, Anglo American, Noranda, Asarco, and Newmont.... Getting it right will involve looking at our businesses from top to bottom and from early stage exploration right
through to the end uses of our products. It will involve working with people outside the industry to be sure we are not just reassuring ourselves on the basis of what we are comfortable with... This means confronting some uncomfortable questions, and doing so in an open and politically dynamic environment. But the chairmen/CEOs group see this as the best starting point for the industry to reposition itself and to secure its long-term future.” (Rio Tinto, 1999d, pages 5 to 6.)

The first two expositions on Rio Tinto and sustainable development could be dismissed by cynics as a highly cost effective public relations exercise — it is far cheaper (yet ultimately far more costly?) to produce policy statements than to change behaviour. However, there is little ambiguity in the third — a statement of intent for internal as well as external consumption by the chairman of one of the world’s leading mining organisations. Wilson captures the business imperative of sustainable development. Global mining organisations such as Rio Tinto will not be sustainable unless they recognise and act upon the imperative to continually gain access to high quality resources. To do this at a time when, as Hodges (1995) put it in the discussion in Project Document 1, “Where once mining was widely regarded as the ‘highest and best’ use of land, irrespective of its suitability for other purposes, federal lands are now valued for multiple resources: wilderness, historic sites, wildlife or scenery, for example.” (Hodges, 1995, page 1306) (see also Vol.1 PD1 Section 1.4.3) requires a change in outlook and approach in the global mining organisations.

4.4.3 Qualitative Assessment of the Role of Key Performance Indicators.

Just as Rio Tinto’s appreciation of sustainable development has evolved over the course of this project, so has its reaction to the use of environmental performance indicators. In 1996/97, before the project commenced, Rio Tinto suggested that it would, “Continue to develop Group wide indicators for reporting HSE performance, including measures of eco-efficiency….. In the longer term we aim to develop Group wide targets which make sense in the context of our diverse businesses and geographical locations.” (Rio Tinto, 1997a, page 5) By 1997/98 the then co-chairmen of Rio Tinto – Robert Wilson and John Uhrig, stated that, “In a Group as diverse as Rio Tinto, it is not easy to set group wide targets that are both relevant and measurable. But as we work to improve HSE performance across our business, we will continue to search for appropriate benchmarks by which our progress can be judged.” (Rio Tinto, 1998b, page 1)

In the 1998 environmental and social report for Rio Tinto, Wilson put forward the company’s thinking thus, “Rio Tinto recognises the need for better performance indicators. These can be either quantitative or qualitative. They can be useful both as an internal management tool and as guide, externally, particularly for those in the communities around the Group’s operations. The relevance and importance of particular indicators varies considerably from operation to operation because of their diverse nature and differing locations. Rio Tinto’s thinking on appropriate global HSE indicators is well advanced.... However, meaningful aggregated reporting remains a challenge for a Group as large and diverse as Rio Tinto. External verification is also important. Rio Tinto does not
expect to be judged solely on what it and its operations assert about themselves.” (Rio Tinto, 1999b, page 5)

Thus a commitment to the development and use of performance measures of some form has existed from at least 1996. However, over the past three years there has been considerable development in Rio Tinto’s understanding of the role of such indicators. Back in 1996 the emphasis was on eco-efficiency; by 1997 the group had recognised the challenge of reconciling global and local issues; while by 1998 a number of developments were visible. These include the recognition that indicators should be useful to both internal and external audiences, that global indicators have a role, but that aggregation should only take place where it is appropriate to do so; together with a recognition of the need for external verification.

It can be concluded, then, that broad support exists in Rio Tinto for the use of performance indicators as envisaged in Section 1 – following the format illustrated in Figure 24 (see also this document, Section 1, Figure 7 – page 36).

**Figure 24 Increasing Selection of Data in Indicators Hierarchy**

![Diagram showing Increasing Selection / Concentration of Data](image)

Thus global warming, for example, would be seen in the central column, while water use, for example, could be reported at the local level for all group operations.

4.4.4 Qualitative Assessment of Burden Categories and Normalisation Factors

Having established that Rio Tinto, at the corporate level, publicly supports both the principles of sustainable development for mining set out in Project Document 1 and the principles for establishing performance indicators set out in Section 2 of this document, attention can turn to establishing the Rio Tinto reaction to the specific environmental themes and normalisation factors introduced in Sections 2 and 3 of this document.

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4.4.4.1 Qualitative Assessment of Burden Categories

Within Rio Tinto, this has taken place at the level of the Group HSE function. Rio Tinto maintains a small staff of environmental and health and safety specialists at the corporate level, but most Group HSE activity is carried out by specialists employed directly by the operations themselves.

The Group specialists are responsible for co-ordinating the implementation of policy, co-ordinating environmental audits and reviews, providing an environmental advisory service to operations, and for the management of Rio Tinto’s internal to external reporting functions. They maintain databases of information relating to energy use, emissions data, production, etc to support them in this. The corporate specialists are the key internal stakeholders regarding the specific aspects of environmental categories, since they will be aware of what will be required from a policy perspective as well as where there are gaps in current databases to support the indicators. Throughout the case study, corporate specialists based in Bristol, London, Melbourne and Sydney have provided reaction and information to assist with the validation of the environmental indicators.

Discussion at the Rio Tinto level was concerned primarily with those issues identified as being appropriate for consideration towards the global level in the mining organisation – resource extraction, energy, and global warming. In addition, two regional issues – acidification and water use - were considered. The remaining issues – ecotoxicity, land disturbance, reclamation, biological diversity, suspended solids, and dust – were not discussed in detail at the Rio Tinto level.

Inspection of the Group HSE reports over the past few years reveals that these are all issues considered to be of import for the Group. Data for discharges of cyanide from gold and aluminium operations, of suspended solids from all operations, of land disturbance and rehabilitation, for example, are all included in the annual HSE reports produced by Rio Tinto. The quantitative analysis of data gaps will reveal the extent to which this broad support for the themes introduced in Section 3 of this document has translated into measures of performance which adequately reflect the progress of Rio Tinto in addressing these issues. In this section, then, attention will focus on the qualitative response of Rio Tinto to the environmental themes of resource extraction, energy, greenhouse gases, acidification, and water use.

4.4.4.1.1 Resource Extraction

There was considerable debate concerning the extent to which Rio Tinto would find this an appropriate measure of environmental performance in practice. On one side of the debate lies Rio Tinto’s publicly expressed view that, “Metals, unlike many other materials are infinitely reusable and recyclable” (Rio Tinto, 1999c, page 3), implying that monitoring resource extraction as an environmental theme is unwarranted – any environmental effect being manifested by material depletion rather than extraction. Furthermore, from the perspective of the business unit or operation mining a specific ore-body, monitoring resource extraction alongside global warming and water consumption is illogical. The operation exists to extract...
that ore-body, but not to produce greenhouse gases, use scarce water, or produce any other unwanted 'externalities'.

Thus while it is useful to an operation to know how much it is contributing to environmental themes such as global warming, it is not useful to know the rate at which the operation is extracting global resources of that material. Furthermore, as was illustrated by Hodges (1995), mineral reserves are increasing rather than declining, suggesting that prevailing technology and exploration practices are identifying mineral reserves at a greater rate than they are being extracted, and thus the relevance of resource extraction, as an environmental theme, is questioned.

On the other side of the debate comes the argument that resource extraction at the level of the organisation is an environmental theme of import for global mining organisations. The imperative for improving extraction technology and exploration lies in perceived scarcity of materials. High prices during times of perceived scarcity act as a trigger to invest in techniques that will allow more mined product to be sold at these higher prices. Alternatively, relative scarcity acts as a signal to optimise those reserves which remain – promoting life cycle thinking to minimise cut-off grades and encourage recycling. Knowledge of relative scarcity depends upon knowledge of extraction rates and known reserves and resources and thus requires these trends to be tracked. Nonetheless, Rio Tinto indicated that the data existed to provide information on resource depletion should stakeholders indicate that such information was desirable.

4.4.4.1.2 Energy

During February 1999 telephone discussions and electronic correspondence with Rio Tinto Technical Services in Melbourne and Brisbane allowed the framework proposed in Section 2 of this document (see Section 2.10 - pages 66 to 68) to be reviewed. A number of suggestions were made regarding three issues:

1. How appropriate a single indicator of energy use would be
2. The extent to which current data could be utilised in providing meaningful indicator values
3. How any data gaps could be addressed in the longer term

From the perspective of site management, the focus of attention is currently very much on 'secondary energy', meaning in this case the energy actually used on site, while audiences external to the site might be more interested in 'primary energy', i.e. the wider energy system involved in the provision of the energy used on site. The view was expressed that it may be helpful to develop a framework capable of accommodating these interests, rather than focussing exclusively on primary energy related expressions.

16 The author is grateful to Neil Marshman, Elissa Newman-Sutherland and Silvana Gradwell, in particular, for their contributions to the validation and development of energy, global warming and acidification metrics.

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Accordingly, the framework illustrated in Figure 25 was proposed. As can be seen, there are two systems involved – the secondary energy system: purchased fossil fuel, purchased electricity and purchased explosives being the source of energy on the site. Purchased fossil fuels are used to generate electricity on-site (from which there are losses associated with thermal efficiency factors) and are used together with purchased and produced electricity in the mining and transport of material, the processing of material, heating and refining activities. In addition, explosives are used in the mining processes.

This secondary energy – measured and metered at the site level and then reported to Group – is sourced from primary fossil fuel, primary hydropower, and primary nuclear power. Losses from these energy sources in production and distribution are not recorded at the site level, which considers only energy crossing the site boundary. However, they can be calculated on the basis of knowledge of local energy supply conditions by Group specialists.

**Figure 25: Primary and Secondary Energy Systems and Flows in Rio Tinto Operations**

This framework is compatible with data recorded and reported by sites – who work to the secondary system components – and the calculations possible at the Group level – where specialists can derive the primary system from the data. While this schematic more accurately reflects energy flows in Rio Tinto as expressed through existing measurement and metering systems and calculations of associated primary energy requirements, it is, perhaps, too complex to be used in the indicator framework. A simplification of this information may be appropriate. The framework outlined in Figure 26 is proposed as a simplified expression of Figure 25. The breakdown of end-uses for energy is maintained, together with the primary energy system. However, the components between the two – the explosives, produced and
purchased electricity, and purchased fossil fuels components - are combined into explosives energy and fossil fuel/electrical energy. It is proposed that the more detailed breakdown of Figure 25 is included in the overall data framework of Rio Tinto, but at the indicator level the simplified model is used to provide primary energy data.

Figure 26: Simplified Expression of Primary and Secondary Energy Systems and Flows for Use in EPI Framework

During March 1999 Rio Tinto Technical Services in Melbourne extracted the necessary data and calculated the information required to express energy requirements as per Figure 26.

4.4.4.1.3 Global Warming Measures

The indicator framework proposed in Section 2 of this document (see Section 2.11 - pages 69 to 72) for global warming was based on work by UNEP and the NPI for the 'Insurance Industry Initiative' (Thomas and Tennant, 1998) (Figure 27).
During the month of February 1999 discussions with Rio Tinto HSE and Technical Services suggested the framework shown in Figure 28.

This framework follows the same rationale as that for energy; i.e., that a distinction must be made between users of the performance indicators. At the site level, it is suggested that information relating to on-site emissions relating to specific activities will be of greatest interest, while at the public level (including Group management) the focus will possibly be on the system – i.e. to include emissions arising from off-site activities related to the operation.
The broad categories, then, are compatible with those proposed by Thomas and Tennant — in that they cover energy and process related global warming potential — but more detail is provided at the site level on exactly where the Global Warming Potential arises. Transportation, which would be included in the ‘mobile energy related GWP’ for Thomas and Tennant, is considered to be a processing step for a mining operation, not an energy consideration. Nonetheless, it is suggested that this represents a semantic difference, agreement remains that the activity should be included.

4.4.4.1.4 Acidification

Three key environmental performance aspects were identified regarding acidification in Section 2: total atmospheric acidification potential from discharges, excesses over critical soil acid load from deposition, and excesses over critical water acid load from deposition and drainage (see this document, Section 2.12 — pages 73 to 75). The former requires the relative acidification potentials of different acid discharges to be quantified, while in addition, the latter two require local sensitivity and exposure to acid discharges to be quantified. As discussed during Section 2, no attempt has been made in this work to characterise local sensitivities to acid deposition. Discussions with Rio Tinto established broad agreement on the importance of acidification as an environmental theme and on understanding local conditions in addition to global parameters. There are insufficient data on critical load values for water-courses and terrestrial ecosystems in the environs of Rio Tinto operations, and the regional effects of acid gases released from point sources at Rio Tinto operations are not known. Thus, only acidification potential is addressed in this work. Through the use of generic data on sulphur content of different fossil fuels, it is possible to gain a general understanding of the nature of $SO_2$ production during fossil fuel combustion.

During the month of February 1999 discussions with Rio Tinto HSE and Technical Services established a preference for consistency with the approaches for energy and global warming. Returning to the discussion on the features of effective performance indicators in Section 1 of this document (see Section 1.2.3), the OECD (1993) stated that “[Environmental indicators] simplify the communication process by which the information of results of measurement is provided to the user.” (Group on the State of the Environment 1993, page 5). In order to maintain simplicity in this communication process, it is argued that the frameworks for energy, global warming, and atmospheric acidification — which all involve on-site and off-site elements — should use a common basis for the framework.

Accordingly, the framework shown in Figure 29 is proposed for atmospheric acidification potential (AAP).
Again, the framework remains consistent with the principles developed for global warming by the UNEP/NPI initiative (Thomas and Tennant, 1998), but is expanded to show the distinction between on-site generation, and off-site generation of AAP. The greatest level of uncertainty, at this time, relates to the generation of sulphur dioxide and, particularly, nitrogen oxides in the generation of electricity. For greenhouse gases and energy mixes, it is possible to determine data for each power station serving Rio Tinto operations through the use of data-sets from the International Energy Agency. However, no such data exists for atmospheric acidification.

4.4.4.1.5 Water

The comprehensiveness of Rio Tinto's approach to water management, as an environmental theme, has increased over the past three years. In its 1996 HSE report, Rio Tinto reported simply that, “Water is a precious resource that needs to be conserved” and reported water consumption for its various product groups – with freshwater use increasing across the Group from 1995 levels. (Rio Tinto, 1997a, page 18) By 1997 Rio Tinto was reporting that freshwater consumption had plateaued (Rio Tinto, 1998b, page 10), while by 1998, although freshwater consumption in the commodity groups was on the increase again, it was rising at a lower rate than production (Rio Tinto, 1999b, pages 30 to 31).

In its 1998 HSE report Rio Tint introduced ‘water management principles’ designed to help guide local management of water use:

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1. Water use and discharge planning conforms to the water use requirements of other users within the catchment;
2. Policy for water management is communicated by senior management through formalised objectives and targets;
3. Water use, storage, and discharge are defined in a site water balance that is updated to reflect changes to operational requirements;
4. Water management practices include the monitoring of supply and discharge;
5. Fresh water use is to be reduced through process improvement, recycling of wastewater and, where practicable, by the use of poorer quality water;
6. Water abstraction, storage or discharge does not irreversibly reduce the health of wildlife or habitats;
7. Water storage, treatment and discharge facilities are designed, constructed and managed based on best available practices available to local operating conditions. (Rio Tinto, 1999b, pages 32 to 33)

Whether the implementation of these principles across the Group leads to reduced pressure on local water resources or not will depend on the energy applied in putting them into practice. As far as reporting is concerned, Rio Tinto use five key metrics for water consumption: Freshwater consumption, poor quality water abstraction, impounded water consumption, recycled water use, at the Group level, and then freshwater consumption per unit of production at the commodity level (Rio Tinto 1999b).

Rio Tinto acknowledge, though, that, "The significance of water consumption depends on site specific availability and conditions" (Rio Tinto, 1999b, page 30) – a factor included in the proposed indicators for water use. However, while the indicators proposed refer simply to ‘total water abstracted’, Rio Tinto point out that, “In terms of water consumption, a mine’s environmental impact is likely to be lower if it uses less freshwater and draws instead from recycled, impounded or poor quality sources” (Rio Tinto, 1999b, ibid.).

Taking these observations into account, the framework presented in Figure 30 is proposed, introducing a further layer of information to be used at site level to guide water management.
4.4.4.2 Qualitative Assessment of Normalisation Factors

4.4.4.2.1 Validation of Financial Normalisation Factors

During the Normalisation Factors Phase of the project, the following financial normalisation factors were proposed as having the potential to be used in the EPI framework:

- Turnover
- Net Earnings
- Profit Before Taxation
- Economic Value Added
- Contribution to Sustainable Economic Welfare

The relative merits of the normalisation measures were discussed in Section 3 (see this document, Section 3.3 – pages 108 to 114). In summary, turnover provides an indication of the total revenue generated by the organisation which can be used to pay for goods and services provided in local communities, to pay royalties and taxation to government for use in national development programmes, and to be used for subsequent re-investment in operations and communities. Net earnings indicates how much capital is left after these costs are accounted for, profit before taxation compensates for any distorting effects introduced by differing tax schemes around the globe, and value added provides a measure of the actual contribution to local GDP of the specific operation rather than the double counting which would result should communities use the other measures for assessing the economic contribution made by various industries in their neighbourhood (i.e. the sum total is not the sum of turnovers). Contribution to sustainable economic welfare is discussed by Jackson et al (1997). It attempts to deduct certain environmental and social costs from GDP currently not incorporated in the system of national accounts (SNA).
The intention of the internal validation programme has been to establish how valid corporate financial specialists feel these normalisation factors are for use in Rio Tinto. The Group Controllers Unit, based at Rio Tinto Head Office, was involved in the assessment of the factors during the period of January and February 1999. The method adopted for gaining input from this group was through small group briefings and dialogue to achieve partnership rather than instruction or edict. Accordingly, this group - which is responsible for collating financial data from all Rio Tinto subsidiaries (operations fully owned by Rio Tinto) and affiliates (operations not fully owned by Rio Tinto) - has provided valuable input into the validation programme.

Contribution to sustainable economic welfare was rejected in Section 3 (see this document, Section 3.3.5.1). Although the principle of the model is compatible with the needs of a global mining organisation (provided one could identify a level of sustainable economic welfare at the global level for a global company) the data limitations encountered by proponents of ISEW are too great. The margin of error in environmental costs used in ISEW models is argued to be too great to be credible to decision makers at the site level with limited budgets. Furthermore, the financial specialists have rejected the use of economic value added as a useful measure at this time. While agreement was reached that this measure is useful in normalisation of environmental data, the view of the financial controllers was that there is as yet no universal agreement in the financial community over how value added is defined (Ovington, 1999). Strict definitions are used in financial reporting protocols to ensure that all companies are disclosing comparable information – potential investors then know that the turnover expressed by one company has been calculated in the same way as that expressed by another company. From the perspective of the EPI project, this is a critical limitation. The objective is to generate information which can be used easily by internal and external stakeholders alike. If value added is to be used, it may not be transparent to external stakeholders exactly what is included in value added, and what is not.

Turnover, net earnings and profit before tax were all accepted by the financial controllers as being meaningful measures of group financial performance. Turnover and net earnings, in particular were supported due to the extent to which they allow comparisons to be made between mining organisations. Due to the high costs (and risks) involved in development of large natural resource projects, resources companies frequently engage in joint ventures to spread risk and cost. Thus the revenue from a particular mine may require allocating to a number of different entities in the same way that environmental burdens have shared 'ownership'.

In 'Mining 1999', the Financial Times Energy Yearbook for the mining industry, operating and financial summaries are provided for over 650 mining organisations (Brown, 1999). Rio Tinto, and its peers such as Alcan, Alcoa, Anglo American Corp, Arco, BHP, Billiton, Codelco, Cyprus Amax, De Beers, Gencor, Minorco, Noranda and Royal Dutch Shell – all of whom have turnovers of greater than US$3 billion – report turnover and earnings. In addition, each of these companies reports its financial performance in terms of net turnover and 'net income'. Net income is defined as, "Net income applicable to all share capital after providing for minority interests" (Brown, 1999, page xlii). Thus, if Rio Tinto holds a 30% share in an
operation, it only attributes 30% of the income for that operation to its own profit and loss accounts. Net income has the same meaning as net earnings.

Net earnings was preferred to net turnover in relative terms as it was argued that this expression is more closely related to business efficiency – and thus the underlying financial health of the organisation – than the level of sales alone. However, since the costs which affect the level of earnings include community investment and salaries, it cannot be argued that an operation with high net earnings is necessarily making a high contribution to the economic sustainability of a community.

On technical grounds, then, value added is still the preferred expression for financial normalisation, but since there is currently no widely applied methodology for this, turnover and net earnings will both be used in the interim until such time as value added becomes more widely accepted on grounds of pragmatism. The group controllers office also agreed to provide financial information for the pilot companies carrying out internal validation of the framework. Data on operating cash flow, net earnings, net turnover, employment costs and employee numbers were made available to the project.

4.4.4.2.2 Validation of Community/ Social Normalisation Factors

Just as the financial normalisation factors under consideration included expressions unfamiliar to Group reporting systems, the factors proposed for the community / social dimension of sustainable development would require data not available from any existing internal databases. The two possibilities proposed were:

- Financial investment in community programmes
- Person-hour investment in community programmes

The rationale for the use of community programmes in the assessment was that all group companies in Rio Tinto have community programmes in place as part of the Group’s approach to corporate responsibility. While many operations have had these programmes in place for a number of years, it is only recently that such programmes have become mandatory for all group companies. Thus, it was anticipated that there would be data available for each operating company regarding the implementation of their community programme, each of which would be designed to address local community issues, such as cross-cultural awareness building, skills and enterprise training, employment, health care, and environmental stewardship.

Due to the variation in the purchasing power of one dollar around the globe, it was felt that financial investment in the local community alone would not be a satisfactory indicator across the Group on its own. The investment of time was argued to be a more meaningful expression of community and social investment. As with the financial normalisation factors, the involvement of Group specialists in community and social issues would be helpful to the validation process.
Through small group briefings and dialogue, the views of community and anthropology specialists in Rio Tinto were obtained in January and February 1999. The principle difference highlighted between Group financial reporting and Group community and social reporting was that, as yet, the reporting of financial performance is quantitative and specific, while the reporting of community performance remains qualitative and general. Nonetheless, it was anticipated that operating companies would be able to provide general information on community investment.

However, while it was agreed that the use of time as a measure of investment rather than money would be more meaningful, the view was expressed that investment in programmes is no guarantee of an acceptable outcome. The community affairs group is reviewing the potential to initiate assessment of stakeholder attitudes in individual operations (Litvin, 1999). The intention is to establish an approval rating for individual operations in their communities. At this stage it is not known exactly how such an assessment could be carried out, or how a representative sample would be identified. However, it is accepted that the concept would provide a more meaningful indication of progress towards local community wishes.

At this stage it is emphasised that, as with financial normalisation, while a more ideal normalisation factor has been identified at the theoretical level for implementation in the medium term, from a pragmatic perspective, the indicators of investment will provide some useful normalisation of environmental performance in the shorter term.

4.4.4.3 Summary

The consultation with Rio Tinto at the corporate level has allowed the following conclusions to be drawn:
1. Rio Tinto supports the principles of sustainable development for mining discussed in Project Document 1.
2. Rio Tinto supports use of environmental indicators to monitor progress and communicate concerning that progress with a wide audience as discussed in Section 1 of this document.
3. Rio Tinto supports the framework for the use of indicators at the global and local level presented in Section 1 of this document.
4. Rio Tinto supports the use of the broad environmental burden themes presented in Section 2 of this document.
5. Rio Tinto supports the use of economic, social and physical normalisation factors as proposed in Section 3 of this document, although rejects the use of economic value added until such time that an internationally agreed formula is in place which will allow inter and intra sectoral comparisons to be made. Furthermore, Rio Tinto has indicated that providing social performance data in the format suggested should be possible through revised reporting protocols coming into force around the Group, but will not be able to demonstrate historical trends through lack of data.
4.4.5 Quantitative Validation of the EPI Framework

On the basis of the qualitative validation by Rio Tinto of the principles of sustainable development and the use of performance indicators – including environmental themes and normalisation factors – the validation can progress to the quantitative element. In this section the capability of Rio Tinto to use current Group data to indicate performance in each of the themes agreed as relevant. This will require an assessment of quantitative data for each of the environmental themes and then quantitative data for normalisation factors.

The resulting data will be discussed in two ways; firstly to identify gaps in data at the Group level and how this limits performance evaluation for Rio Tinto; secondly to compare this indicated performance with currently reported performance by the Group. This will provide the basis for a operating company specific case study. This will identify where gaps in Group data reflect gaps throughout the organisation, and whether indicating performance at the level of the operating site or business unit is perhaps more meaningful for some themes than Group aggregation.

To aid the exposition, detailed data relating specifically to the environmental themes (resource use, energy use, discharges, emissions etc) will be presented in tables and figures in separate Appendices (Appendix 3 for the Rio Tinto case study, Appendix 4 for Borax – see Vol.4 APD3 & APD4). The broad conclusions and trends will be included in the main text, supported by and cross-referenced to specific tables and figures in the relevant Appendix. Where the exposition requires that information is presented with the discussion – as is the case for normalisation of site data, for example – then that information will be presented with the main text.

4.4.5.1 Environmental Burden Themes

4.4.5.1.1 Resource Extraction

4.4.5.1.1.1 Data availability in Rio Tinto

Rio Tinto publishes data on its mineral reserves and ore resources each year, following the Australasian Code for Reporting of Identified Mineral Resources and Ore Reserves, July 1996 – known as the JORC Code. Accordingly, data for each of the Group’s assets include proven and probable ore reserves for the relevant minerals in the ore-body, in terms of their tonnage and grade. In addition, the Group details mineralisation which has the potential to become economic in the future but which is not currently classified as Proved or Probable reserves – based on geological information only. These resources include measured resources, indicated resources and inferred resources. As Rio Tinto (1999a) put it, “Although there are reasonable prospects for eventual economic extraction, no detailed consideration has been given to mining, processing or economic factors, such as would occur in a feasibility study, and the material cannot currently be classed as reserves. Resources are stated as additional to any reserves reported elsewhere.” (Rio Tinto, 1999a, page 22)
Thus proved and probable reserves are combined to provide ‘Rio Tinto Reserves’ and to this value measured, indicated and inferred resources are added to provide ‘Rio Tinto Reserve Base’. Table 5 in Appendix 1 illustrates the relative sizes of global reserve and reserve bases in comparison to reserves and reserve bases in commodities where Rio Tinto has assets (Rio Tinto, 1998c and Rio Tinto, 1998d) (see Vol.4 APD3 Table 5).

4.4.5.1.1.2 Extraction Rates

Once acceptable baselines for reserves have been established, data for extraction rates are required in order to calculate depletion rates. The quality of data available to make this assessment varies from commodity to commodity within Rio Tinto. For reporting purposes, Rio Tinto expresses its use of abiotic resources in terms of production, rather than extraction, and it is not always possible to determine process losses to obtain a complete resource extraction value.

With the exception of the large Escondida mine (which accounts for just under 33% of Rio Tinto’s recoverable copper reserves) the data for the copper product group and the gold and other minerals product group mines\(^\text{17}\) allow the extraction rates to be extrapolated from the data. In the Energy product group (coal and uranium) the values given for the coal mines\(^\text{18}\) are given in production terms but, as coal production involves minimal processing, these values provide an indicator of extraction rates. Iron production data, however, make no reference to process losses, nor do industrial diamond production data.

Data for the aluminium product group and for uranium production give no indication of material grades and processing losses, so provide a broad indicator only. In the industrial minerals product group the data for borates, talc, and tioxide feedstock are expressed in production terms. It is not known whether process losses would make a significant difference to extraction values.

Table 6 in Appendix 3 represents an aggregated summary of the extraction calculations carried out for each of the operations where data are available (see Vol.4 APD3 Table 6). The limitations discussed excepted, there is a considerable amount of resource data publicly available for the Group.

4.4.5.1.1.3 Discussion

It is important to emphasise that the objective of this phase of the work is to determine whether it is possible to generate a representative picture of the environmental impacts of the Group’s activities. Publicly available information is being used wherever possible since this eases the reporting burden on the Group companies and avoids the considerable time lags that

\(\text{17}\) I.e. Bingham Canyon, Grasberg, Neves Corvo, Palabora, Morro do Ouro, Kelian, Flambeau, Barney’s Canyon, Rawhide, Ridgeway, Cortez, Green’s Creek, Peak, Renco, Patchway, Brompton, Lihir.

\(\text{18}\) I.e. Antelope, Cordero, Caballo Rojo, Spring Creek, Decker, Colowyo, Fort Union, Blair Athol, Tarong, West Cliff, Tahmoor, Howick, Vickery, Kaltim Prima, Hunter Valley, Mount Thornley, Oreganal, Recreio,
would be involved if the information were sought direct from the operations. There is a trade-off, however, in that this means there will be gaps in the data.

In the case of abiotic resource depletion, then, the objective here is to evaluate the implications of the data known already, and to note whether any gaps in data prevent meaningful interpretation of the data. For ease of analysis, the data calculated for resource depletion have been converted into graphical form. Three main components are represented:

1. The percentage of global assets controlled by Rio Tinto,
2. Rio Tinto operations’ relative direct depletion rates of the different commodities as a percentage of global assets,
3. Rio Tinto operations’ relative direct depletion rates of the different commodities as a percentage of Rio Tinto’s assets.

The data for these components are presented separately in Appendix 3 (see APD3 Figures 1, 2 & 3). Here, Figure 31 shows the relative values derived for each of Rio Tinto’s commodities for all three components, expressed in terms of reserves and reserve base.

Figure 31: Direct Abiotic Resource Depletion by Rio Tinto Operations, 1997

Figure 31 here and Figure 1 in Appendix 3 (see Vol.4 APD3 Figure 1) indicate the relative significance of Rio Tinto’s share of global commodity reserves. As can be seen, Rio Tinto has
a relatively high share of global reserves of borates, copper, industrial diamonds, talc, and titanium dioxide. For each of these commodities Rio Tinto controls over 5% of proven world reserves. When attention is turned to Rio Tinto's share of the global reserve base, it can be seen that in some commodities, such as bauxite, industrial diamonds, and iron ore, Rio Tinto's share becomes substantially more significant.

In other words, in these commodities, Rio Tinto controls resources which are not considered economically viable at this time, but will become more significant relative to world resources should circumstances change. In other commodities, Rio Tinto's relative share of world resources will fall substantially as technologies improve and/or cut off grades decline. In particular, Rio Tinto's relative significance in borates, copper, and talc will decline as resources from the reserve base become economically viable reserves.

Figure 31 above and Figure 2 in Appendix 3 (see Vol.4 APD3 Figure 2) indicate the relative significance of Rio Tinto activities in different commodities related to global reserves and the reserve base. It can be seen that in 1997 Rio Tinto extraction and production directly accounted for between 0.011% and 2.46% of global reserves of the various commodities. Rio Tinto made the most substantial relative reductions in global reserves in industrial diamonds, molybdenum, titanium, borates, and copper (in descending order). Relative to the reserve base, Rio Tinto's most significant reductions were in the same five commodities, but in the descending order of industrial diamonds, titanium, molybdenum, copper and borates. The dominance of industrial diamond reserve depletion relative to the other commodities is clear.

Figure 31 above and Figure 3 in Appendix 3 (see Vol.4 APD3 Figure 2) indicate the rate at which Rio Tinto is depleting its own reserves of the various commodities. Again, industrial diamonds dominates, with Rio Tinto extracting almost 29% of its industrial diamond reserves in 1997. At this rate of depletion, Rio Tinto will exhaust its reserves in less than four years, unless more reserves are purchased, or economic or technological circumstances bring diamonds from the reserve base into the reserves category. In relative terms, tin is the next most significant, with 24% of reserves extracted in 1997. However, unlike diamonds, where extraction represents only 5.5% of the reserve base, for tin extraction represents 14.5% of the reserve base. In other words, changes in economic and technological circumstances related to extraction will not make as substantial an improvement in abiotic depletion rates for tin as they will for diamonds.

In relative terms, Rio Tinto is depleting its reserves of industrial diamonds, tin, molybdenum, lead, and gold at the fastest rates (in descending order). Should circumstances allow all of the reserve bases to become economically viable, depletion rates for tin, molybdenum, industrial diamonds, zinc and lead will become the most significant.

4.4.5.1.1.4 Conclusions

The analysis carried out suggests that it is possible to use data on reserves and production to gain an understanding of the contribution of Rio Tinto towards the depletion of reserves of the different commodities. As has been emphasised, the data used here are not complete. For example, Rio Tinto’s uranium reserves have not been disclosed, and it has been suggested that
global values are very unreliable. Also, nickel production begins in 1998, so although reserves are known, the extraction rate is not. For some of the commodity groups the complexity introduced by joint ventures makes it difficult to determine extraction rates, since often only production rates, which do not take account of process losses, are available.

Nonetheless, the analysis carried out illustrates that comparison between the commodity groups, and between Rio Tinto reserves and global reserves provides useful information. For example, although Rio Tinto depleted its titanium reserves 'only' by 1.7% in 1997, the fifth lowest rate amongst the commodities with data, its depletion rate of 0.47% of global reserves was the third highest rate of these commodities.

In other words, while efforts within Rio Tinto to improve extraction technologies may focus on commodities such as tin or molybdenum, as examples, to reduce the depletion rate of the company’s reserves, in terms of global reserves Rio Tinto has a relatively higher impact in commodities such as titanium and borates and so may reduce its depletion loading by focusing effort in these areas.

4.4.5.1.2 Energy

4.4.5.1.2.1 Data availability in Rio Tinto

Rio Tinto collects data for its energy consumption and collates this data for all of its managed facilities. It can categorise energy consumption in the following ways:
1. By Contributing Activity (on site electricity production, mining, milling, smelting, refining and others)
2. By Commodity Group (aluminium, industrial minerals, copper, gold and others, iron ore and energy)
3. By Geographical Location (Australia, Africa, USA, New Zealand, Canada, Europe, Indonesia/ Papua, South America)
4. By Primary Source (fossil fuels, renewables, nuclear)

Table 7 in Appendix 3 illustrates the trend in energy use in Rio Tinto over the period 1993 to 1997 (see Vol.4 APD3 Table 7). This table illustrates how total energy use in Rio Tinto has increased by 13.3% to 1997 over 1993 levels. The use of the ‘current operations’ category allows the baseline to be adjusted to account for acquisition and divestment to avoid distortion of data. By using this category, it can be seen that underlying energy use has increased by 21.4% over the period. Table 8 in Appendix 3 illustrates how energy is used throughout the activities of Rio Tinto (see Vol.4 APD3 Table 8).

As the table highlights, smelting activities account for the highest proportion of all energy demand by the group, with the actual mining operations themselves only accounting for just over an eighth of all energy consumption in the Group. The majority of energy utilised by the Group is derived from fossil fuels - approximately 50% of the energy used by the Group is in
the form of fuels and reductants, with the other 50% coming from purchased electricity. Fossil fuels account for 20% of purchased energy, renewables approximately 25% and nuclear sources 5%. There is no further breakdown of data into oil, gas, coal, photo-voltaic, hydro etc. for the different electricity sources.

Discussions with Rio Tinto Technical Services in Melbourne have established that the energy requirements are calculated using data from the operations on usage of fossil fuels on site in processes, process reductants, etc, plus data on electricity usage and sources (most operations have direct supply contracts with specific power stations). The electricity data are then converted to primary energy information using standard data sets from the International Energy Agency (IEA) to establish the associated system losses to identify the primary energy required by the operations.

On the basis of the discussions with Rio Tinto Technical Services (Marshman, 1999) it is suggested that a more useful way of expressing the information for energy would be as illustrated earlier in Figure 25: Primary and Secondary Energy Systems and Flows in Rio Tinto Operations (see this document, page 146) and Figure 26: Simplified Expression of Primary and Secondary Energy Systems and Flows for Use in EPI Framework (see this document, page 147).

Of the primary energy needed to power Rio Tinto, some will come from renewable sources, such as hydro and solar power systems, some will come from nuclear sources and some will come from fossil fuel sources. This primary energy can either be used on-site to produce electricity, in reductants and heating systems, or as fuel for automotive operations or off-site to produce electricity. The schematics illustrate how this information can be categorised to monitor progress in each category.

This format covers the energy systems related to Rio Tinto’s processing operations, rather than just the energy delivered or used. This is more appropriate in the context of sustainable development, since the emphasis is on the issues to be addressed, rather than the extent to which operational responsibility can be assigned. However, Group data do not at present allow such an analysis to be carried out. Rio Tinto Technical Services were engaged to carry out an assessment of energy use following this format for four Group businesses: Kennecott Utah Copper, Quebec Iron and Titanium (QIT), Argyle, and Borax, to illustrate that such an assessment is feasible for the Group. The results of their assessment have been used in the second case study – Borax.

4.4.5.1.3 Greenhouse Gases

4.4.5.1.3.1 Data Availability within Rio Tinto

Rio Tinto collects and collates global warming data for all of its managed facilities. It can categorise global warming information in the following ways:
1. By Contributing Activity (mining, milling, smelting, refining and others)
2. By Commodity Group (aluminium, industrial minerals, copper, gold and others, iron ore and energy)

3. By Geographical Location (Australia, Africa, USA, New Zealand, Canada, Europe, Indonesia/Papua, South America)

4. By Source (Fuels, Purchased Electricity, Processes)

Table 9 in Appendix 3 illustrates the trend in greenhouse gas emissions over the years 1993 to 1997 (see Vol.4 APD3 Table 9). It is important to remember that Table 9 only reflects the arisings of greenhouse gases on-site within Rio Tinto. However, the Group does calculate the greenhouse gases arising from the production and delivery of electricity in its operations also. In 1995 the greenhouse gases reported above, for on-site releases, accounted for only 45% of the total (Rio Tinto 1998b, ibid.). Of the total (on-site and off-site) the relative proportion contributed by the various activities in Rio Tinto is shown in Table 10 (see Vol.4 APD3 Table 10).

Smelting operations are dominant in greenhouse gas releases from the Group, largely due to the major energy requirements of these processes illustrated in Table 10 in Appendix 3. The Group subsequently divides the greenhouse gas arisings associated with its activities according to those which arise on-site and those which arise off-site in electricity production.

4.4.5.1.3.2 Discussion

As was discussed in Section 2.11.2 earlier in the document and here in Section 4.4.4.1.3, this format does not recognise the importance of the total background system in the Group’s emissions of greenhouse gases. If the categories remain as on-site and off-site, then it is possible that on-site emissions could rise as off-site emissions fall if electricity production were to be moved to the mining operation itself. This substitution would be more clear if both sources of electricity were shown as one plus the other in the same category. The Group does include data on the production of electricity, rather than just its use, but there are other areas, such as the provision of non-electrical energy to the mining operations, which currently are not accounted for.

Rio Tinto does have the capability to generate the information specified earlier in Figure 28: Proposed Framework for Structuring Global Warming Potential (GWP) data within Environmental Performance Indicators for Rio Tinto. (see page 148). Discussions with Rio Tinto Technical Services in Melbourne have established that the data are available, with a caveat related to the fact that the data for greenhouse gas arisings associated with combustion processes are derived from conversion statistics from the International Energy Agency (IEA). For non-OECD countries it has been suggested that the conversions will be less accurate than those from OECD countries, and that direct process data will be more accurate for a specific process than those derived from IEA statistics (Marshman, 1999). The calculations carried out by Technical Services for this project have been used in the second case study – Borax.
4.4.5.1.4 Acidification

4.4.5.1.4.1 Data Availability in Rio Tinto

In order to assess the global effects of releases of acidic substances information on emissions and sensitivity of receiving media is required. A number of specific emissions have been characterised as having the potential to contribute to acidification of various media. According to CML (Heijungs et al 1992), sulphur dioxide, nitrogen monoxide, nitrogen dioxide, nitrogen oxides, ammonia, hydrochloric acid and hydrogen fluoride can all contribute directly to atmospheric acidification - and hence to deposition on soil. In addition, Wright et al (1998) in their environmental burden methodology, discuss aqueous emissions of potentially acidifying substances: hydrochloric acid, metacrylic acid, nitric acid, phosphoric acid and sulphuric acid. The two major sources of these types of releases in Rio Tinto operations will be direct emissions from processing operations and indirect emissions from the use of electricity at these operations. At this time Rio Tinto has no Group data concerning sensitivity of the environments which receive acidic discharges from operations, but it is possible that individual sites maintain such data where appropriate.

4.4.5.1.4.2 Direct Emissions

Rio Tinto gathers data from those of its operations known to contribute to the release of sulphur dioxide - namely those involved in the production of copper, titanium dioxide, aluminium, uranium, and nickel. Table 11 in Appendix 3 (see Vol.4 APD3 Table 11) illustrates the data available by product group for the years 1993 to 1997.

Copper smelting dominates sulphur dioxide releases from Group operations. During the years 1993 to 1996 the copper group made substantial progress in reducing SO$_2$ emissions (1996 values were 38% lower than 1993), but a sharp rise in 1997 saw the net change for the period 1993 to 1997 to be -6.1%. However, the rest of the Group’s activities have been less successful in reducing SO$_2$ releases to atmosphere, with aggregate values increasing from 1993 to 1997. Overall, Group releases of SO$_2$ to atmosphere have fallen only very slightly over the period 1993 to 1997 - a net reduction in SO$_2$ emissions from the Group of just 1.8%.

4.4.5.1.4.3 Indirect Emissions

As has been discussed, the production of electrical energy can lead to the release of gases with the potential to cause atmospheric acidification, such as SO$_2$. However, Rio Tinto does not collect or calculate such data at the present time for off-site power generation.

4.4.5.1.4.4 Data Availability through the US EPA ‘Community Right to Know’ Regulations

In the United States, many operations are required to submit information on releases to various media to the Environmental Protection Agency (EPA). The two relevant systems of gathering data here are the Toxic Release Inventory (TRI) and The Aerometric Information Project Document 2 - Development of Key Corporate EPIs for Sustainable Mining Organisations
Retrieval System (AIRS). Both databases are public domain under US legislation. The TRI contains information about releases and transfers of more than 650 chemicals and compounds to the environment. TRI stores data hierarchically by facility, year and chemical, and by medium of release (air, water, underground injection, land disposal and off-site) (Environmental Protection Agency 1998a). The Airs Facility Subsystem (AFS) contains emissions and compliance data on air pollution point sources regulated by the EPA (Environmental Protection Agency 1998b).

The data available from these databases cover many of the releases which have been identified as having the potential to contribute to acidification - not just atmospheric sulphur dioxide, the only release in this category reported by Rio Tinto. For example, TRI data for US Borax's Wilmington facility cover releases of ammonia, sodium hydroxide, and sulphuric acid, and AFS data for this facility add nitrogen dioxide, and sulphur dioxide releases, while data for Kennecott Utah Copper include ammonia, hydrochloric acid, nitric acid, and sulphuric acid. There are also data for Tale de Luzenac's US operations, not covered by Rio Tinto's SO₂ reporting, on sulphur dioxide and nitrogen dioxide.

4.4.5.1.4.5 Discussion

It is clear that there are insufficient data in Group databases to generate a complete inventory of potential acidifying releases. However, it is also clear that much of the data exists at the operations. Taking Kennecott Utah Copper as an example, drawing together such data as are publicly reported for the operation, Table 37 emerges for the year 1995:

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Quantity released to air (tonnes)</th>
<th>Potency factor (SO₂ equivalent)</th>
<th>Atmospheric acidification potential (tonnes SO₂ equivalent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulphur dioxide</td>
<td>5565</td>
<td>1.00</td>
<td>5565</td>
</tr>
<tr>
<td>Nitrogen monoxide</td>
<td>No Data</td>
<td>1.07</td>
<td>-</td>
</tr>
<tr>
<td>Nitrogen dioxide</td>
<td>No Data</td>
<td>0.70</td>
<td>-</td>
</tr>
<tr>
<td>Ammonia</td>
<td>1</td>
<td>1.88</td>
<td>1.88</td>
</tr>
<tr>
<td>Hydrochloric acid</td>
<td>0.25</td>
<td>0.88</td>
<td>0.22</td>
</tr>
<tr>
<td>Hydrogen fluoride</td>
<td>No Data</td>
<td>1.60</td>
<td>-</td>
</tr>
<tr>
<td>Sulphuric acid</td>
<td>31.9</td>
<td>0.65</td>
<td>20.74</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>5587.84</td>
</tr>
</tbody>
</table>

The dominance of sulphur dioxide releases in the mix is apparent. However, this may not be the case for those operations which do not deal with sulphide ores. The importance of including energy data in the evaluation is particularly apparent for these operations. However, as the data for acid gas releases from the Group's operations are restricted to on-site releases of gases, the wider impact of electrical power generation off-site as discussed in Section 2 (see this document Section 2.11.2) may be substantial.

Rio Tinto Technical Services were engaged to quantify the emissions of acidic substances to atmosphere by Borax companies according to the structure presented earlier in Figure 29: Proposed Framework for Structuring Atmospheric Acidification Potential (AAP) data within Environmental Performance Indicators for Rio Tinto (see page 150). Their results are will be...
discussed in the second Case Study. At the Group level, however, it is clear that it is not feasible using current data to indicate Group performance in this environmental theme beyond rudimentary quantification of SO$_2$ emissions – an unsatisfactory proxy for actual performance.

4.4.5.1.5 Water Use

In Section 2 it was established that the two key criteria for consideration of water use as part of a broader assessment of environmental performance for mining companies should cover how much water is ‘used’ and how much this represents of the water available (see this document, Section 2.9).

4.4.5.1.5.1 Data Availability in Rio Tinto

Rio Tinto gathers data from every one of its operations on water consumption. Consumption of water is divided into four categories: abstracted fresh water, abstracted poor quality water, impounded water, and recycled water. However, these water data are only available for all group operations for the years 1996 and 1997. Table 12 in Appendix 3 illustrates water consumption patterns at Rio Tinto by product group (see Vol.4 APD3 Table 12).

4.4.5.1.5.2 Discussion

Over the two years, total water demand in the Group increased by 16%, with approximately half of the increase sourced from poor quality water, and the other half from increased use of recycled water and impounded water. Although demand for freshwater increased only slightly, the large increase in use of poor quality water could increase the burden on water supplies.

Within the commodity groups, industrial minerals account for the largest proportion of water demand, but this commodity group reduced its overall water demand between 1996 and 1997. Demand in the aluminium group showed a very slight decrease, but this disguises considerable improvement in water utilisation - increased use of recycled water enabled fresh water demand and poor quality water demand to be greatly reduced. Both the coal and iron ore groups experienced substantial growth in demand for water from all sources, but the scale of water demand in these two groups is an order of magnitude smaller than that in copper and gold. Water demand in the gold group almost trebled, while the copper group increased by 15%, although the copper group, at least, managed to avoid increasing its fresh water demand to meet this increased demand.

The use of the four categories of water source is useful, as it allows a hierarchy of priorities in water use to be identified, i.e. reduce the amount of water used as the first step, increase recycling as a second. If there is still demand for water in the operation, attempt to source it from water impoundment. Only if this does not meet water demand should poor quality water be used. Fresh water should only be used if there is no alternative.
However, as with other indicators under consideration, this information alone is insufficient to be truly representative of the environmental burden at a local level. The stress placed upon local water resources by the mining operation will depend on the scale of the demand relative to local availability. Two operations with similar water demands will potentially place very different stresses if one operates in an area of much lower water availability than the other, as illustrated in Section 2 (see this document, Section 2.9.2). However, Rio Tinto does not collate such data at the Group level.

It is not known whether such information is available at the operations level. As was discussed in Section 2, in the absence of this information the use of global climate maps, such as those found in 'The Times Atlas of the World' (Bartholemew et al, 1990), could provide a starting point for knowledge about precipitation and evapotranspiration rates at a regional level more precisely than the continental data presented here will allow. However, this quantitative assessment has demonstrated that Rio Tinto collates only part of the information needed for an indicator of performance in water use at the Group level.

4.4.5.1.6 Land Use

4.4.5.1.6.1 Data Availability Within Rio Tinto Operations

Rio Tinto has been gathering data for the entire Group only since 1995. However, individual operations have been collecting data for their own management needs for longer than this. At a Group level, nonetheless, historical data are only available from 1995 onwards. Accordingly it is difficult to identify trends over such a short period with a high level of confidence. Rio Tinto gather data from each operation in the following format:

- The type of operation under consideration (i.e. open-pit, strip mine, underground mine, non-mining facility)
- The total amount of disturbed land at the end of the previous year
- The total amount of additional land disturbed during the year
- The total amount of land rehabilitated during the year
- The total amount of disturbed land at the end of the year

They then identify the type of land disturbed and rehabilitated at the operation, categorising land disturbance and rehabilitation as native, agricultural, forestry, recreation, and other. Taken together, the data allow the progress of the mining operation in disturbing and rehabilitating land to be tracked, and allow long term land use changes to be identified. For example, if more land is being disturbed than is being rehabilitated during the year for a prolonged period, then obviously the environmental impact on landscape from the operations will increase. Furthermore, if a high proportion of the land disturbed is native, but a high proportion rehabilitated is forestry, then this clearly identifies a trend in land use change over

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19 Water can be considered 'used' insofar as it will not be available for other uses while in use at the operation, even if it is returned in a similar state to when it was abstracted.

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time. Table 13 in Appendix 3 summarises progress for the Group, by operation type (see Vol.4 APD3 Table 13).

Open pit mines represent the most significant amount of land disturbance for the group, followed by the strip mines. All but one of the strip mines is in the coal group, and these operations, because they pursue a seam horizontally, have the potential to cause widespread surface disturbance if they do not exercise the highest levels of rehabilitation to ensure that land is reclaimed as the mine operation progresses along the seam. The open pit mines, due to their prevalence within Rio Tinto, account for the highest total disturbance overall, however. The table also illustrates that the 1,500 hectares of land rehabilitated during 1996 was offset by 3,000 hectares of extra land disturbance, leading to a 3% increase in land disturbed by the Group by the end of 1997 over the year end 1996 value.

45,000 hectares (450 square kilometres) is a substantial amount of land. To put this value into context the land area disturbed by Rio Tinto is of a similar order of magnitude to the land area of countries and states such as Barbados (430 sq. km), The Seychelles (455 sq. km), Andorra (465 sq. km) and the Isle of Man (572 sq. km). It is approximately 1% of the equivalent land area to countries like The Netherlands (41,526 sq. km), Denmark (43,075 sq. km) and Estonia (45,200 sq. km) and approximately 0.1% of the land area equivalent to states such as California (423,999 sq. km), Iraq (438,317 sq. km), Papua New Guinea (462,840 sq. km) (Bartholemew et al 1990).

The land disturbed and the land rehabilitated is categorised according to land use type, which could help to track long term changes in land-use. Table 14 in Appendix 3 shows the data for rehabilitation in 1996 (see Vol.4 APD3 Table 14). The table shows that in 1996 the vast majority of land was rehabilitated to native conditions. To be fully useful, baseline data for land uses prior to mining and a body of data covering a number of years will be needed to demonstrate both progress and land use-changes.

4.4.5.1.6.2 Discussion

As was discussed in Section 2, land-use is one of the most challenging themes to address appropriately in this work – as institutional direction on addressing this important theme for mining is lacking (see this document, Section 2.14.2). One of Rio Tinto’s group companies – Kennecott Energy – has offered one possible solution to the difficulty in assessing whether or not the Group is truly making progress or not. This is to introduce an assessment of the land available for reclamation, together with interim indicators for restoration which is not yet complete. Thus, the Group would assess how much land has been disturbed, and how much is available to be reclaimed at that particular moment. Thus year on year progress would be expressed in terms of what has been achieved related to how much is possible as the mine life progresses. However, at this time, data along the lines recommended by Kennecott Energy are not collated at the level of Rio Tinto.
4.4.5.1.7 Biodiversity

4.4.5.1.7.1 Data Availability Within Rio Tinto

Rio Tinto has no Group data on biological diversity associated with its activities. However, a number of individual operations, such as Richards Bay Minerals, have extensive information on biological diversity and changes in diversity associated with mining and rehabilitation.

4.4.5.1.8 Ecotoxicity

As was discussed in Section 2, an assessment of the effects of potentially toxic discharges from Rio Tinto requires information on emissions to soil and water and the sensitivity of these media (see this document, Section 2.13).

4.4.5.1.8.1 Data Availability in Rio Tinto

Rio Tinto only maintains data on releases of materials known to have the potential to be ecotoxic from its operations for discharges to the aquatic environment. The materials for which quantified data are available are cyanide, cadmium, arsenic, mercury, copper, zinc and lead. Heijungs et al (1992) also include chromium and nickel in their classification of potentially toxic metals. Nickel releases may become more relevant in Rio Tinto as the Empress Nickel Smelter project comes on line. However, both chromium and nickel releases tend be more closely associated with asbestos mining than with the ore-bodies utilised by Rio Tinto. (Ripley et al, 1996, page 279)

Tables 15 to 21 in Appendix 3 illustrate the data available, by product group, for the years 1993 to 1996 (see Vol.4 APD3 Tables 15 to 21). There has been a net increase in cyanide emissions over the period, with increases in the aluminium group offsetting any reductions elsewhere. However, the trend in the aluminium group is downward - a massive increase in emissions in 1994 over 1993 values (by more than 2,500%) was partly mitigated by reductions in the following two years. The trend for cadmium discharges is downward, with net reductions in all product groups reporting data.

Annual arsenic emissions more than doubled in the period, with year on year increases from the gold group chiefly responsible for the growth. Annual copper emissions from the Group have almost doubled over the period, led by the copper group, who represented the largest contributor to copper releases by the end of 1996, replacing the gold group. Annual zinc emissions have almost quadrupled over the period, with the figures dominated by the gold group. Annual lead emissions have more than trebled over the period, with emissions dominated by the copper group.

4.4.5.1.8.2 Discussion

The first observation to make about the data available from Rio Tinto is that they are restricted to aqueous releases of toxic materials. It is possible that there are discharges of these materials to air and soil which are not recorded. Also, it should be noted that there is a
general improvement in data quantity within Rio Tinto over the years 1993 to 1996. In 1996 in particular, contributions from an increasing number of operations were observed. However, the dominance of potentially toxic releases from two product groups - copper and gold - is clear. This was expected, given the nature of the sulphide ores. A number of metals, such as zinc, lead, cadmium, etc., are present in the sulphide ores containing copper and gold.

Regarding the effects of these emissions on the environment, two key factors should be stressed. The first is that heavy metal releases are only indicators of environmental quality. Speciation of these metals will determine their toxic potential, together with the sensitivity of the receiving media. Rio Tinto does not collate data on either of these variables. The importance of the latter can be illustrated using the approach of CML, discussed in Section 2 (see this document, Section 2.13.2). CML have adopted the following relative classification for toxic substances in the aquatic environment (Heijungs et al 1992, page 77):

**Table 38: CML Classification Factors for the Effect Scores Aquatic Ecotoxicity**

<table>
<thead>
<tr>
<th>Metal</th>
<th>Aquatic Ecotoxicity Potential (relative to Chromium)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsenic</td>
<td>0.2</td>
</tr>
<tr>
<td>Cadmium</td>
<td>200</td>
</tr>
<tr>
<td>Chromium</td>
<td>1.0</td>
</tr>
<tr>
<td>Copper</td>
<td>2.0</td>
</tr>
<tr>
<td>Lead</td>
<td>2.0</td>
</tr>
<tr>
<td>Mercury</td>
<td>500</td>
</tr>
<tr>
<td>Nickel</td>
<td>0.33</td>
</tr>
<tr>
<td>Zinc</td>
<td>0.38</td>
</tr>
</tbody>
</table>

It should be noted that CML do not classify cyanide as an ecotoxic - they have a separate classification for human toxicity, where cyanide is included. Nonetheless, using the data from the copper and gold product groups as an example, the following table can be generated to evaluate the potential aquatic ecotoxicity of the groups’ emissions:

**Table 39: Rio Tinto Aquatic Ecotoxicity Potential, Based on the CML Approach**

<table>
<thead>
<tr>
<th>Release Type</th>
<th>Releases from Copper group, 1995 (kg)</th>
<th>Releases from gold group, 1995 (kg)</th>
<th>Total releases from Rio Tinto, 1995 (kg)</th>
<th>Aquatic ecotoxicity potential factor (chromium equivalent)</th>
<th>Copper group aquatic ecotoxicity potential (kg chromium equivalent)</th>
<th>Gold group aquatic ecotoxicity potential (kg chromium equivalent)</th>
<th>Rio Tinto Group aquatic ecotoxicity potential (kg chromium equivalent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cadmium</td>
<td>27</td>
<td>24</td>
<td>51</td>
<td>200</td>
<td>5,400</td>
<td>4,800</td>
<td>10,200</td>
</tr>
<tr>
<td>Arsenic</td>
<td>117</td>
<td>655</td>
<td>781</td>
<td>0.2</td>
<td>23.4</td>
<td>131</td>
<td>156</td>
</tr>
<tr>
<td>Mercury</td>
<td>1</td>
<td>8</td>
<td>9</td>
<td>500</td>
<td>500</td>
<td>4,000</td>
<td>4,500</td>
</tr>
<tr>
<td>Copper</td>
<td>575</td>
<td>722</td>
<td>1,300</td>
<td>2.0</td>
<td>1,150</td>
<td>1,444</td>
<td>2,600</td>
</tr>
<tr>
<td>Zinc</td>
<td>365</td>
<td>29,132</td>
<td>29,961</td>
<td>0.38</td>
<td>138.7</td>
<td>11,070</td>
<td>11,385</td>
</tr>
<tr>
<td>Lead</td>
<td>75</td>
<td>41</td>
<td>117</td>
<td>2.0</td>
<td>150</td>
<td>82</td>
<td>234</td>
</tr>
<tr>
<td>Nickel</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Chromium</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.0</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>TOTAL</td>
<td>1,160</td>
<td>30,582</td>
<td>32,219</td>
<td>N/A</td>
<td>7,362.1</td>
<td>21,527</td>
<td>29,525</td>
</tr>
</tbody>
</table>
A key feature of this analysis is that it illustrates the importance of allocating potency factors to substances. Due to the sheer scale of its zinc discharges, the gold group dominates the total mass of the potential ecotoxic discharges included - with the gold group accounting for almost 95% of Rio Tinto discharges of the materials listed. Similarly, zinc discharges by Rio Tinto account for almost 93% of all Group discharges of the materials listed in 1995. However, once potency factors are assigned, the gold group's share of the total potentially toxic releases listed falls to just under 73% of the total potential aquatic ecotoxicity, and zinc discharges only account for 38.6% of the total potential aquatic ecotoxicity. The sheer potency of cadmium and mercury offset the relatively small quantities of these materials actually discharged.

While this kind of analysis is helpful in illustrating the importance of potency factors, it does not necessarily take account of local conditions very well. One of the key parameters relating to toxicity discussed earlier is the concentration of materials discharged, with higher concentrations of potentially toxic materials being more likely to cause toxic effects (see this document, Section 2.13). Most, but not all of the Rio Tinto operations disclosing aqueous emission data also include information on the concentration of materials in their discharges. However, knowledge of the concentration of releases is only useful if there is some understanding of the likely impact of that level of concentration. Rio Tinto does not maintain environmental quality standard data (EQS) for its operations. However, whether such data are available and useful at the business unit level will be explored in the second Case Study (see this document, Section 4.5).

4.4.5.1.9 Particulates

4.4.5.1.9.1 Data Availability in Rio Tinto

At the present time, Group reporting of airborne particulate emissions is restricted to the copper and aluminium product groups. In 1997 releases of a total of 8,782 metric tonnes of particulate matter were reported by the eleven facilities in these Groups. The trend in particulate releases by these groups is downward - from 21,957 metric tonnes in 1995, to 11,851 tonnes in 1996, to 8,782 tonnes in 1997.

4.4.5.1.9.2 Data Availability through the US EPA 'Community Right to Know' Regulations

In the United States, air release information is contained in the Aerometric Information Retrieval System (AIRS) The AIRS Facility Subsystem (AFS) contains emissions and compliance data on air pollution point sources regulated by the US Environmental Protection Agency (EPA). This information is available to the public through links to the EPA Internet web-sites. (EPA 1998a and EPA 1998b) Particulate information is included for those facilities which are required to report it.

Some of Rio Tinto's US operations are covered by this system, and accordingly there are data available regarding operations outside the copper and aluminium product groups. For example, Colowyo, a coal mining operation in the energy group has attributed particulate
emissions totalling 1,575 tonnes in 1997. A number of facilities in the industrial minerals product group are also inventoried. Data for eight of talc facilities in the USA are available, with total attributed particulate emissions of 1,342 metric tonnes.

4.4.5.1.9.3 Discussion

There are insufficient data to allow a meaningful assessment of the environmental burden from particulate emissions arising from Rio Tinto activities to be undertaken. In the first instance, Group reporting is restricted to just two of the six product groups, and the data from the US EPA would suggest that other facilities in the Group make a significant contribution to total Group particulate emissions.

In addition, according to Kiely, “Because of their very small size, [particulates] remain in the atmosphere for long periods and can travel great distances” (Kiely, 1997, page 101). Assessing the environmental burden caused by an individual mining operation at the global level will not be straightforward. Ripley et al (1996) explain that there are various sources of particulate emissions: the action of wind on disturbed land and stockpiles of ore and waste, machinery movement and exhaust, and while some smaller particulates will travel long distances, “The extraction stage primarily produces larger particles with limited dispersion, which have major effects on mine workers and, occasionally, on local residents” (Ripley et al, 1996, page 23).

Also, while the collation of data for only copper and aluminium may seem unusual, given that, according to Ripley et al (1996), “Particulate emissions would seem to be the most serious problem associated with the mining of industrial minerals” (Ripley et al, 1996, page 293) and “The particulate emissions [from extraction of sulphide ores such as copper] are relatively minor compared with those from mining iron ore and the releases from other industries.” (Ripley et al, 1996, page 160) However, it is important to distinguish between point emissions and fugitive emissions of particulates. The measurement of particulate emissions from the processing operations in aluminium and copper smelters is more feasible than estimated fugitive emissions from large surface mines.

Particulate emissions remain a relevant indicator of environmental performance in mining, but there are insufficient data at a Group level to identify the environmental burden caused by particulate emissions. The difficulties in measuring fugitive emissions are recognised as a limiting factor in developing a meaningful indicator of particulate emissions for the Group. This issue will be explored further in the second Case Study (see Section 4.5).

4.4.5.1.10 Sedimentation

4.4.5.1.10.1 Data Availability in Rio Tinto

Given the significance of suspended solids as an environmental burden from surface mining it is unsurprising that the Group does collect data for this theme. Although the data are by no means comprehensive all of the product groups report suspended solid release data. Some
operations report both absolute quantity of suspended solid and concentration in aqueous discharges. Table 22 in Appendix 3 presents suspended solid data, aggregated by product group, for the years 1993 to 1996 (see Vol. 4 APD3 Table 22).

The overall trend in suspended solid releases is downward, from 83,119 tonnes in 1993 to 10,173 tonnes in 1996. However, this reduction is almost entirely attributable to the industrial minerals group, whose suspended solids releases have fallen from almost 75,000 tonnes in 1993 to almost 2,500 tonnes in 1996. Even within industrial minerals, this reduction has been achieved by just one operating company, QIT (Quebec Iron & Titanium), a titanium dioxide production facility whose suspended solids releases fell from 74,827 tonnes in 1993 to 2284 tonnes in 1996.

4.4.5.1.10.2 Discussion

The significance of the reduction at QIT should not be overlooked. In 1993 suspended solid releases from QIT accounted for 90% of Group releases. By 1996 this figure had fallen to slightly over 22%. While QIT's suspended solid release fell by almost 97% - due largely to a shift in the nature of its process - the remaining operations have collectively achieved a reduction of slightly less than 5% over the years 1993 to 1996.

It could be argued that due to the sheer scale of the issue at QIT significant effort was demanded to reduce the problem, while at the other operations other themes may be more significant. However, the increase in suspended solid releases at many operations in the Group, possibly corresponding to increased production, illustrates that this is an issue which may require attention in the future.

However, useful as total suspended solid data are, they must be used in conjunction with knowledge of the local ecosystems, to determine a better understanding of likely effects. Large quantities of suspended solids would suggest an increase in sedimentation, but concentration data will indicate the likely effects on ecosystems. For example, United Nations Food and Agriculture Organisation guidelines indicate the probable effects of suspended sediment on fisheries:

<table>
<thead>
<tr>
<th>Suspended Sediment Level</th>
<th>Effect on Fisheries</th>
</tr>
</thead>
<tbody>
<tr>
<td>less than 25 mg(\cdot)(1^1)</td>
<td>no harmful effects</td>
</tr>
<tr>
<td>25 to 80 mg(\cdot)(1^1)</td>
<td>small decreases in numbers and growth rates</td>
</tr>
<tr>
<td>80 to 400 mg(\cdot)(1^1)</td>
<td>good fishery cannot be supported</td>
</tr>
<tr>
<td>greater than 400 mg(\cdot)(1^1)</td>
<td>few or no fish</td>
</tr>
</tbody>
</table>

Rio Tinto Group data cover 70 operations. 27 of these operations reported suspended solid data to the Group in 1996, and of these 27 operations, only 20 reported concentration data. Concentration of suspended solids in aqueous discharges reported exceeded 25 ppm for 3 operations. Bietz (1989) has reported that coal mining and washing can produce suspended solids at the high end of the UN FAO scale, yet only 3 of the 12 coal operations in the Group report concentration data.
Thus, progress is being made in assimilating Group data on this issue, but as yet is incomplete. Concentration of suspended solids is important information to be used in conjunction with quantities released. In this way, progress can be measured more meaningfully, since reductions in concentrations could be caused by increased dilution, rather than an actual reduction in releases. Consideration to broadening group data must be given in the future. At the present time less than half of the operations in the Group report sufficient data to allow a meaningful assessment to be made, and a number of those that do report use estimates rather than measured data.

4.4.5.2 Normalisation Factors

Turning to normalisation factors, the objective is to establish the extent to which quantitative data are available to support the qualitative validation discussed earlier (see this document, Section 4.4.4.2).

4.4.5.2.1 Financial Normalisation Factors

Rio Tinto reports turnover and net earnings in £Sterling, Aus$ and US$, following United Kingdom Accounting Standards (UKAS). The latter currency is the main currency used in the management of the business, while the incorporation of Rio Tinto in London and Melbourne with listings on these stock exchanges requires that the Group also must present in the former two currencies. This requires extensive currency translation as the accounts from the multitude of subsidiaries, joint ventures, associates and joint arrangements introduced in Section 4.4.1 are consolidated into Group accounts for Rio Tinto expressed in three currencies. (Rio Tinto 1999a, page 80)

4.4.5.2.1.1 Exchange rate effects

According to Rio Tinto (1999), profit and loss accounts are translated at average rates of exchange. (Rio Tinto, 1999a, page 81) Balance sheet items are translated at year end exchange rates. These translation procedures are applied to all three accounting currencies. Most exchange differences are charged or credited to the profit and loss account in the year which they arise. However, exchange differences on the translation of the net assets of overseas companies, less offsetting exchange differences on foreign currency loans financing those net assets, are dealt with through reserves.

The significance of this for normalising environmental performance in Rio Tinto at the operations level can be illustrated through an operation which is based in Canada — QIT. QIT operates its business using Canadian dollars, but reports through Rio Tinto in US$. Figure 32 illustrates the performance of QIT for energy requirements and secondary greenhouse gases for 1995 to 1997 — firstly normalised against US$ at average rates of exchange and secondly at constant 1996 exchange rates. This second series shows the underlying performance of QIT compared to the first.
As Figure 32 shows, however, the fluctuations in performance caused by exchange rate changes are heavily outweighed by underlying operational factors. The same is the case, albeit to a much lesser extent, for Australian operations, such as Argyle diamonds, shown in Figure 33.

Figure 33: Exchange rate effects on reported performance for an Australian operation
Thus exchange rate changes will have a distorting effect on reported Group performance, but should not disguise the overall trends in that performance. Nonetheless, caution should be exercised for operations whose currencies fluctuate widely from one year to the next.

4.4.5.2.1.2 Turnover and earnings

According to Rio Tinto, turnover comprises sales to third parties at invoiced amounts which vary between ex works and carriage, insurance and freight (CIF) – i.e. delivered – price depending on contract terms. (Rio Tinto, 1999a, page 97) This means that turnover will vary depending on whether the customer collects product from the mine, the distribution centre, or has it delivered. Terms for an individual customer will change from one year to the next depending on their preference. This can either double, or halve, the turnover received by Rio Tinto, without affecting realised profits at all. A large proportion of Group products is sold under medium to long term contracts and is included as sales as and when deliveries are made. Gross turnover shown in the profit and loss account includes the Group’s share of the turnover of joint ventures and associates. (Rio Tinto, 1999a, ibid.)

Thus turnover as reported by Rio Tinto is readily comparable with other enterprises since similar accounting rules are used. However, it does not translate easily into business performance when freight costs are a significant proportion of costs – thus it must be used in conjunction with earnings, where no agreement on value-added exists.

Rio Tinto’s reported turnover and earnings, for 1995 to 1998, are shown in Figure 34. Such figures are also maintained for each subsidiary, joint venture, joint arrangement and associate. Rio Tinto reports Group performance as a function of its ownership of each asset. Thus, turnover includes only 30% of Escondida’s turnover, for example, but 100% of Borax’s turnover.
Figure 34: Rio Tinto Net Earnings and Turnover, 1995 to 1998 (based on data in Rio Tinto, 1999a, page 91)

4.4.5.2.2 Social Normalisation Factors

As for financial factors, Rio Tinto does not yet have the capacity for reporting social performance in the format required by the EPI framework. As was discussed in Section 4.4.4.2.2, investment in community programmes is the preferred metric, expressed in terms of time rather than money. Data are available for direct financial investment in community programmes from Group companies for 1995 to 1998 (see RTZ-CRA, 1996, page 43; RTZ-CRA, 1997a, page 41; Rio Tinto, 1997b, page 2; Rio Tinto, 1998a, page 36; Rio Tinto, 1999a, page 54). From 1998 onwards Group companies are also allocating costs for the time spent on community programmes by their employees. This is logical, since the time invested on the company’s behalf by paid staff represents an additional charge attributable to community programmes in the cost structure. This will allow the amount of time invested in community programmes to be extracted from the data. However, for the years prior to this policy change, the only Group data relate to direct investments – such as charitable donations and capital projects.

Thus, the social performance data currently available in Rio Tinto are a poor proxy for the desired information – reflecting only part of the investment made by the Group and not taking into account the purchasing power of such investments as are reported. Nonetheless, the available Group data are presented in Figure 35.
4.4.5.2.3 Physical Production Normalisation Factors

During Section 3, it was concluded that measuring physical performance for a multi-commodity mining organisation is the most challenging aspect of normalisation and aggregation (see this document, Section 3.5). Financial values, whether one agrees with their meaning or not, are at least amenable to aggregation. However, comparing production values from aluminium smelters with coal mines for environmental purposes presents an altogether different challenge than that presented by fluctuating exchange rates. For a multi-commodity group such as Rio Tinto, the preferred ‘common denominator’ for production relevant to mines, smelters, and distribution facilities is material moved.

Rio Tinto collates production data from its operations on the basis of their nature of business, however. For example, Borax reports ore reserves and mine and refinery production on a B₂O₃ basis – i.e. the amount of boric oxide in its production, rather than the tonnage of production itself. The coal mines report on a tonnes of coal shipped basis, while the copper facilities report on a variety of metrics: mines like Bingham Canyon, Escondida, and Palabora report the amount of rock they move, while others, such as Neves Corvo, just report the amount of ore they hoist. Smelters report the amount of copper concentrate they produce, and the amount of copper contained in their production. Some associates, such as Freeport, report only the amount of ore which reaches the mill and the copper produced in concentrates.
Thus even at the commodity level the only comprehensive data across the Rio Tinto Group concerns contained product in production. Tonnes of product, and tonnes of material moved, are not reported consistently at the commodity group level, and subsequently not reported consistently across the wider group, as Table 40 shows for the copper operations.

Table 40: Physical production metrics used in the copper product group in Rio Tinto (based on Rio Tinto, 1999a, pages 30 to 36)

<table>
<thead>
<tr>
<th>Facility</th>
<th>Rock mined</th>
<th>Ore hoisted</th>
<th>Ore milled</th>
<th>Head-grade</th>
<th>Concentrates</th>
<th>Contained Metal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kennecott Utah Copper</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Escondida</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Palabora</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neves Corvo</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Atlantic Copper</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Freeport</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: □ denotes ‘data not reported for this metric’
✓ denotes ‘data reported for this metric’
- denotes ‘metric not relevant’

Rock mined forms the basis of production for the Group. Most of the copper operations have both mines and smelters, and so report both figures relevant to mining – such as rock mined and ore hoisted; and to smelting – such as concentrates produced, or contained metal in production. Many product groups do not even discuss rock mined. Thus at the level of Rio Tinto it is not possible using currently maintained data to attempt to normalise aggregated environmental performance using aggregated production measures.

What is also clear, however, is that such data must exist at the level of the operation to allow proper management of that facility. Mine activity scheduling must take account of the amount of rock that must be moved, so even though Rio Tinto does not report such data for Freeport and Neves Corvo, that data should exist at the operation. Similarly, even though the industrial minerals operations, in particular, report contained reference mineral in production (see Table 41) they must also manage their facilities on the basis of material moved in processes.

Table 41: Production related metrics used by selected Rio Tinto operations (Rio Tinto, 1999a)

<table>
<thead>
<tr>
<th>Group Commodity</th>
<th>Sole expression of physical activity / production reported by Rio Tinto</th>
</tr>
</thead>
<tbody>
<tr>
<td>Borates</td>
<td>Contained B₂O₃ in production</td>
</tr>
<tr>
<td>Diamonds</td>
<td>Carats</td>
</tr>
<tr>
<td>Titanium Dioxide</td>
<td>Contained TiO₂ in production</td>
</tr>
<tr>
<td>Uranium</td>
<td>Contained U₂O₈ in production</td>
</tr>
</tbody>
</table>
4.4.6 Discussion

The objective for this section is to assess the extent to which the data available in Rio Tinto allow environmental performance to be indicated in line with the framework established in Sections 2 and 3 and discussed here. Three major issues arise from this case study: gaps in data for burden themes, gaps in data for normalisation, and sectoral inconsistencies in data reporting for different operations.

4.4.6.1 Data gaps in burden indicators

There are several gaps in data which preclude the determination of the contribution to a number of environmental themes made by Rio Tinto. Rio Tinto has no data for primary energy requirements for its companies, although it has the capability to carry out such calculations. The same is the case for greenhouse gases and atmospheric releases of acidic matter - Rio Tinto has data for process releases of SO\textsubscript{2}, for example, but no data on releases from motor vehicles on site, or from power stations off-site. Water use data are comprehensive at Group level but, without weighting for local conditions, fail to give a meaningful indication of where attention should be focussed.

In the case of ecotoxicity the Group has wide-spread data for discharges of materials to aquatic media, but no data on the sensitivity of those media, and no data at all for terrestrial systems. On land-use, data quality is variable for the Group - comprehensive for strip mines and dredging operations, and limited to totals disturbed, rehabilitated and land use type for open pit mines. Biological diversity suffers in a similar fashion. Data for some mines are of a high quality, but for most operations it is completely absent. This reflects, it is suggested, the extent to which local management believe the issue is significant to them. Strip mines which are continually rehabilitating land have meaningful management data - such as progress of land restoration and restoration of biological diversity to pre-disturbance conditions. Open-pits, however, may regard such information as irrelevant until the closure phase of their activities. It is argued here that such an attitude is misguided, since restoration of some parts of the mine is possible long before closure, and without meaningful data on biological diversity it is impossible to assess how successful any eventual rehabilitation has been.

Data for sedimentation and dust are available throughout the Group, but it is suggested here that this information is more useful at the local level, and requires fugitive emission data to help local operations manage this issue. Resource extraction data are comprehensive, although the issue remains contested in Rio Tinto as a meaningful indicator, given that economic reserves are growing more quickly than extraction (an argument which can only be validated with meaningful data on extraction, it has been argued in this work – see this document, Section 2.8.1).

4.4.6.2 Data gaps in Normalisation Factors

There are also gaps in data availability in the normalisation factors discussed in Section 3. Economic data are limited to earnings and turnover; social data are limited to financial investment in community programmes - although as has been noted, the expansion of...
reporting in this will allow the person-hour investment to be calculated from 1998 onwards - and physical activity data are limited to production of the various commodities across the Group. Thus it may be possible to compare Group operations on financial and social performance (although such an exercise would have limited value given the factors required are not available) but not on a physical basis beyond the commodity groups at the activity level. In other words, it may be possible to compare a copper smelter with another copper smelter, but not with an aluminium smelter or a borate mine. Perhaps this reflects the usefulness of the data at the site level. While it may be possible to generate a value for material moved which allows Group aggregation to occur, this must be used in conjunction with locally meaningful production data.

### 4.4.6.3 Data failures relating to sectoral inconsistencies

The one key failure in the data available at Rio Tinto has as yet not been highlighted, however, and that relates to share of ownership versus share of management. To elaborate - Rio Tinto reports its financial and physical performance on the basis of how much of an asset it owns. For example, Rio Tinto has a 30% share in Escondida, and therefore reports 30% of the financial flows from that activity as attributable to Rio Tinto. It owns 30% of the ore-body, and so reports 30% of the reserves as being in Rio Tinto’s charge, and 30% of the production as attributable to Rio Tinto, even though BHP manages the operation. For environmental data, however, because it does not manage Escondida, it does not report any environmental data from that operation.

Conversely, even though Rio Tinto owns on 17% of Lihir, because the Group manages that operation, it reports 100% of the environmental performance. Thus total energy consumption as reported by Rio Tinto, for example, is total energy consumption at those sites it manages, regardless of ownership, and no energy consumption from those operations it does not. BHP reports 57% of the energy use at Escondida, reflecting its share of ownership of the operation. (Broken Hill Proprietary, 1999b) Thus Rio Tinto’s policy of reporting only for those operations it manages is inconsistent with others in the sector.

There are two implications of this for the work on performance indicators. Firstly it means that at the Group level, it is meaningless to normalise Rio Tinto’s environmental performance against financial, social and physical factors, since they are not compatible. Secondly, it means that all parties engaged in joint ventures in the mining sector must agree a framework for environmental reporting to be used throughout the sector. Thus Rio Tinto would report consolidated environmental performance arising from its involvement in mining projects, even those it does not manage. This would require BHP, for example, to determine energy use, for example, using the same formula as Rio Tinto so that the two could be consolidated meaningfully.

Current practice in reporting ore-bodies and production, for example, is to report the total ore-body and production, and then report the share attributable to the mining company in question. A similar approach should be used for environmental performance. This would allow a distinction to remain between those operations where a mining company had direct influence over environmental performance - as manager of the operation - and where...
influence is only indirect - as non-managing partner. This would allow environmental performance to be normalised and, more importantly, would more accurately reflect the actual environmental performance of a mining company than the current approach which distorts a company's performance.

Thus it has been instructive to collect data from Rio Tinto and to examine the implications arising from that, but it has not been possible to use that data to reflect on how the use of the performance framework proposed would provide information on environmental performance better aligned with the principles of sustainable development than current practices. This will be addressed through the use of a second case study - a 100% owned subsidiary of Rio Tinto engaged in mining a single commodity.
4.5 CASE STUDY 2 – BORAX

4.5.1 Borax as a Global Mining Organisation

Borax is a fully owned subsidiary of Rio Tinto. Its earnings compared to that of its parent are illustrated in Figure 1 in Appendix 4 (see Vol.4 APD4 Figure 1) (based on data in RTZ-CRA, 1996, page 30; RTZ-CRA, 1997a, page 24; Rio Tinto, 1998c, page 8; Rio Tinto, 1999a, page 85). Relative to the rest of Rio Tinto, Borax’s earnings are illustrated in Figure 2 in Appendix 4 (see Vol.4 APD4 Figure 2).

As the two figures illustrate, Borax contributes around 10% of Group earnings, with levels remaining robust in the past three years. Borax operates globally, with major Group locations illustrated in Figure 36 (based on Borax, 1995).

Figure 36: Borax key geographical operating locations

Borax operates the world’s largest borate mine at Boron, in the Californian Mojave desert, 120 miles north-east of Los Angeles. The ore is mined by conventional open pit methods and processed locally into a wide range of boron products, some of which are refined further at the Borax Group’s refineries at Wilmington, in the Los Angeles harbour area and Coudekerque, France. Wilmington also serves as a bulk terminal from which borates are shipped to the group’s terminals at Rotterdam and Valencia. The Borax group owns and operates other smaller borate mines at Tincalayu and Sijes in the Argentinean Andes. These minerals are processed at Borax Argentina’s Campo Quijano refinery. (see RTZ-CRA, 1995, page 67)

Like its parent, Rio Tinto, Borax has great diversity in the geographical location and scale of its operations and in the functions performed at those operations. Borax employs around...
1,500 people, approximately 1,000 in its Californian mine and bulk terminal, 250 in South America, and the remainder mostly at the various operations in Europe and Asia-Pacific.

While based upon one element — boron — Borax is otherwise a microcosm of Rio Tinto. It operates globally with mining, chemical processing, and distribution functions. Some of its operations — like Boron — are large facilities with many hundred employees, whilst others — like Borax España’s Nules facility— employ only a few dozen. Some operations — such as Borax Rotterdam — operate in highly industrialised parts of the developed world, whilst others — such as Borax Argentina — operate in remote parts of nations that continue to develop.

Thus Borax faces the same challenges relating to indicators of environmental performance informed by the principles of sustainable development as any other global mining organisation — finding environmental themes relevant across the Group, agreeing how to normalise performance on social, economic, and physical dimensions, and addressing issues at the global and local scale.

On 9th April 1999 a conference call was held at the offices of Borax Europe in Guildford, UK. The US operations of Borax were represented by Dave Weiss, Manager Environmental Affairs, and Mark Ellis, Manager Government and Public Affairs. The Non-US operations of Borax were represented by Dan Harris, Director of Operations and Distribution, Borax Europe and International, and Keith Shettle, Environmental Scientist. For the purposes of this report and to avoid unnecessary repetition, their input will be discussed by subject, rather than by operation. The discussion will be summarised by addressing the qualitative review of the overall framework, followed by the quantitative aspects concerning specific components of the framework. This review will not be attributed to specific individuals, but to the operating company concerned.

4.5.2 Qualitative Aspects

4.5.2.1 Principles

1. The groups supported the principles of development of key indicators of environmental performance with two conditions:
   - That they be useful to site operations in the management of their operations rather than useful solely to Rio Tinto and their stakeholders
   - That the reporting cycle adopted be compatible with site requirements such as ISO 14001.

4.5.2.2 Normalisation

The group concurred that appropriate normalisation of data should be carried out. This already happens at some locations in the Borax Group, such as Boron, for specific issues, such as production of waste per equipment operating hour, for example.
4.5.2.2.1 Production
Discussion concerned the most representative factor for normalisation of production. In Borax, for example, for European processing activities, tonnes product was felt to be more meaningful than tonnes ore. It was felt that that mines and refineries could prefer different measures of physical production.

4.5.2.2.2 Financial
Discussion concerned the long-term stability of financial measures - with earnings related measures felt to be the most stable long term measures. Cost reduction programmes, for example, tended to produce dramatic changes in operating costs, such as wages and salaries, on an infrequent basis, while earnings tended to be more stable in the longer term.

4.5.2.2.3 Reporting Requirements
While the indicators proposed were felt to be relevant to Rio Tinto as a whole, it was hoped that discretion would be left to individual operations to specify which of the issues available would be chosen for reporting purposes for their sites.

4.5.2.3 Quantitative Aspects
Discussion on the quantitative side concerned the relevance and sourcing of required data.

4.5.2.3.1 Energy
Energy was felt to be a relevant measure of environmental performance. The indicator framework proposed was accepted, together with data and calculations provided by Rio Tinto Technical Services.

4.5.2.3.2 Global Warming
Global Warming was felt to be a relevant measure of environmental performance. The indicator framework proposed was accepted, together with data and calculations provided by Rio Tinto Technical Services.

4.5.2.3.3 Acidification
Acidification was felt to be a relevant measure of environmental performance, as a general principle. The only discharges from Borax relevant to this indicator occurred in the primary energy system and in the secondary system in the use of automotive equipment and at the Boron co-generation facility. However, it was agreed that for other operations, such as the smelters at QIT and KUCC, which process hard rock and sulphide ores respectively, acidification would be a high priority indicator.

4.5.2.3.4 Water Use
Water use was felt to be relevant. Because a number of its operations are in arid areas, Borax recognised the significance of normalisation of water use. However, the Group does not collate meteorological data at the corporate level to facilitate such an analysis.
4.5.2.3.5 Aquatic Discharges

The group agreed that aquatic discharges normalised for local environmental quality standards were an acceptable initial indicator of environmental performance. However, it was suggested that it was important to emphasise the 'potential' aspect of this indicator. While it was agreed that reduction in discharges would provide a reduction in the probability of harm to an aquatic ecosystem, it was argued that the bio-availability of aquatic discharges would be the determinant of likely harm, rather than just the quantities of metal alone. That point having been made, it was accepted that across the Rio Tinto Group, the indicator proposed would provide a useful starting point for reporting on aquatic discharges, and was an improvement on the current method of simply reporting tonnage of metals discharged.

Quantities of aquatic discharges are already collated for the Rio Tinto Group, but the group committed to providing local environmental quality standard data wherever possible, and local permit levels in the absence of EQS figures.

4.5.2.3.6 Biological Diversity and Land Use Changes

The group felt that whilst reclamation related measures were of relevance to strip mining operations, they would only become key performance indicators for open-pit activities such as Boron during the closure phase of the mine life-cycle. Data for this category are currently very limited.

4.5.2.3.7 Sedimentation

The group was comfortable with the use of sedimentation as a performance indicator, and already collate data for Group reporting purposes.

4.5.2.3.8 Dust

The group accepted the relevance of inclusion of dust emissions as an indicator of environmental performance. Point source data are currently collated by the Group. Fugitive emissions data are required. The group committed to generate these data based on computer simulation software for Boron. There are no fugitive emissions data for European and Argentinean operations.

4.5.2.3.9 Production

The group discussed the various production normalisation factors at some length. It was agreed that normalisation against production would be an important component of the EPI framework. However, there was no consensus on what should be the primary indicator of physical activity. At the processing and distribution related functions of Borax Europe, for example, expressions related to throughput volumes, rather than contained B₂O₃, were preferred. For the mine related functions however, there was more comfort with extraction related figures such as tonnes of material moved, and tonnes of ore extracted. Some Group data already exist for these factors at Borax; however, the group committed to generating full data for all the production factors for Borax.
4.5.2.3.10 Community Affairs

The group agreed on the importance of community related variables, but felt that for Rio Tinto as a whole, the integration of community affairs data in the mainstream of group management had only come about since the end of 1997. Data are required for community investment. The group felt that while data might be available for financial investment, person-hour investment data would not be measured. Also, the quality of financial data (related to community) would be poor before 1998.

Subsequent discussion with the community affairs officers at Borax Europe’s head office has indicated that from 1999 onwards, reporting on community investment will be comprehensive – relating both to the amount of financial resources required, but also the amount of time required, since overhead would need to be allocated on an hourly basis for community activities requiring employee time. (Shrimpton, 1999)

4.5.3 Quantitative Data-Sets from the Operations.

Given the discussion above concerning the aspects to be considered as part of the environmental performance indicator framework and application, then, it is instructive to examine the information gathered by the operations, and how these data can be presented.

Borax manages eleven facilities at nine operations: three mines, four refineries, and three distribution centres (Boron contains both a mine and a refinery, and Wilmington contains both a refinery and a bulk shipping distribution centre). In addition, Borax has two technical and commercial centres, plus a number of small (less than 12 staff) sales offices around the globe. For the purposes of this study, environmental performance data and community and financial performance data were considered using the same protocols as internal Rio Tinto protocols. I.e., for environmental performance, only the operations were obliged to report data, whereas for financial and community performance, all operations and the corporate centres were considered. Borax were able to generate data for their operations at the Group level and, in many categories, at the individual operation level.

The most challenging categories for the Group to generate data for were biological diversity and land use. While internal marketing systems tracked product delivered to customers, due to the high volumes of intermediate product transferred between operations, it proved difficult to generate comprehensive production data for the years 1995 and 1996 for all individual operations. From 1997 onwards, however, production data are comprehensive for the categories under consideration.

4.5.3.1 Resource Extraction

Borax collates data for each of its mining operations – calculating the amount of boric oxide (B$_2$O$_3$) contained in the various minerals which are found in each of its ore-bodies. Mineralisation is usually in the form of Kernite ($Na_2O$·$2B_2O_3$·$4H_2O$), Borax Decahydrate ($Na_2O$·$2B_2O_3$·$10H_2O$), Colemanite (2$CaO$·3$B_2O_3$·$5H_2O$) and Ulexite ($Na_2O$·2$CaO$·5$B_2O_3$·16$H_2O$) in lacustrine evaporite deposits buried beneath surface sediments.
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(see Kesler, 1994, page 309). For ease of comparison, mineralisation is reported as proven reserves of contained B₂O₃. Thus, data for Borax operations are limited to the upper left portion of the McKelvey Box discussed in Section 2 (see this document page 57) and represented for borates in Figure 37.

**Figure 37 Mineral Resource Classification System of the US Bureau of Mines and US Geological Survey (McKelvey, 1973)**

![Mineral Resource Classification System](image)

Borax’s performance relating to resource extraction indicators proposed in Section 2 is presented in Figure 3 in Appendix 4 (see Vol.4 APD4 Figure 3) (global data from Lyday, P.A., 1995 to 1998; Rio Tinto data from Rio Tinto, 1997 and Rio Tinto 1999a).

Borax’s rate of extraction has not increased, relative to global reserves, over the period 1995 to 1998. In fact, its rate of extraction of global reserves declined slightly from 0.43% pa in 1995 to 0.42% p.a. in 1998. Thus the argument put forward that rates of discovery and improvements in extraction technology are allowing reserves to increase at least in line with extraction appear to hold in the case of Borax. At the global level this would appear to be the case, but the argument put forward throughout this work is that for mining, sustainable development must take place at the local level —since local reserves will be depleted by a mining operation regardless of new discoveries elsewhere.

For Borax, the significance of this only becomes clear when one looks at local performance measures. This is presented in Figure 38 and Figure 39.
Figure 38 Extraction of $\text{B}_2\text{O}_3$ from mineralisation by local Borax operations, 1995 to 1998

Looking at Figure 38 in isolation, it would appear that any efforts towards reducing the impact of resource extraction in Borax would proportionally have the greatest effect at Boron, since this operation accounts for the majority of $\text{B}_2\text{O}_3$ extraction in Borax – approximately 95% of the Borax Group’s extraction of this resource from global reserves takes place there. However, Figure 39 illustrates the extent to which local reserves are being depleted.

Figure 39: Extraction of $\text{B}_2\text{O}_3$ from mineralisation by local Borax operations as proportion of local reserves, 1995 to 1998
Even though Boron is extracting more B₂O₃ than Argentina, and thus having a greater impact on global reserves than its Andean counterpart, at the local level Borax Argentina's extraction rates might give greater cause for concern. While at Boron reserve extraction rates have declined from approximately 3% of local reserves p.a. to approximately 2.6% of local reserves p.a. over the period 1995 to 1998, for Borax Argentina, extraction rates have risen from approximately 16.5% p.a. to 17.5% p.a. over the same period. It is in this context that considering static reserve life may be appropriate – at 1998 rates of extraction Borax Argentina has less than 6 years to either reduce its extraction levels or discover new reserves. Put another way, if the mine is to close, Borax Argentina has only six years to ensure its contribution to the local community will meet the requirements of sustainable development as understood for mining.

4.5.3.2 Energy

Most of the smaller Borax operations import energy directly through their local electricity systems. In addition, Boron has its own co-generation plant which produces more energy than is required at Boron. Also, the refineries at Campo Quijano, Coudekerque, and Wilmington use substantial quantities of natural gas. Based on data reported from Borax, Rio Tinto Technical Services were able to provide Borax primary energy requirements based on the reporting format discussed earlier in Figure 26 (see page 147). Tables 1 to 3 in Appendix 4 summarise energy requirements for the Borax Group (see Vol.4 APD4 Tables 1 to 3).

The differences between the amount of energy used to run the operations (Vol.4 APD4 Table 3), the amount of energy required for the energy purchased by the sites (Vol.4 APD4 Table 2), and the actual energy required to provide the energy to run the operations (Vol.4 APD4 Table 1) are quite different. Borax currently reports how much energy is actually used at the site. This includes energy subsequently 'exported' to the local electricity grid from the co-generation facility. Primary energy, however, which illustrates how much energy is actually required to provide the energy services needed by the operations, is much greater - almost double the secondary energy figure in each year - even though exports of energy are deducted from the primary energy figure since they fall in another system.

4.5.3.3 Greenhouse Gases

Given the dominance of fossil fuels in the fuel mix for Borax's operations, it is important to quantify greenhouse gas emissions for the Group. As for energy, Rio Tinto Technical Services have indicated greenhouse gas performance following the framework presented in Figure 28 earlier (see page 148), based on data provided by Borax.

Borax currently reports greenhouse gas emissions arising on-site, on the basis that this reflects their direct sphere of influence. If they cannot control emissions, then they do not include them. However, Table 4 in Appendix 4 (see Vol.4 APD4 Table 4) illustrates the significance of the electrical generation function at Boron. Effective management of this function is important, and customers for the electricity generated by Boron should be demanding improvements in performance at the Boron co-generation plant. However, this is not part of
the Borax ‘primary’ system – which includes greenhouse gas arisings associated with the provision of services needed, whether they arise on-site or off-site, and deducts those associated with exports to other systems. Because these exports are so substantial, the Borax primary system is smaller than the secondary. This fact is lost in currently reported data.

4.5.3.4 Acidification

Current Rio Tinto reported data on acidification are restricted to atmospheric emissions from sulphide-ore smelters. Borax does not fall into this category and accordingly does not report emissions of SO\textsubscript{x} and NO\textsubscript{x} in Rio Tinto’s HSE reports. However, on the basis of data from the Boron co-generation plant and energy mixes at the remaining Borax facilities, Rio Tinto Technical Services have been able to indicate expected levels of SO\textsubscript{x} and NO\textsubscript{x} emissions following the format presented in Figure 29: Proposed Framework for Structuring Atmospheric Acidification Potential (AAP) data within Environmental Performance Indicators for Rio Tinto (see page 150). Table 5 in Appendix 4 illustrates NO\textsubscript{x} emissions, and Table 6 in Appendix 4 illustrates SO\textsubscript{x} emissions (see Vol.4 APD4 Tables 5 to 6).

It should be emphasised that these data are indicative rather than absolute, but they do illustrate a number of key issues. Firstly, emissions of SO\textsubscript{2} in 1998 associated with the needs of Borax operations – which convert to approximately 3,000 tonnes – are still small compared with direct emissions from the sulphide-ore smelters which dominate reported direct emissions from Rio Tinto (around 90,000 tonnes SO\textsubscript{2}). Secondly, NO\textsubscript{x} emissions are significant – approximately 25% of the Borax H\textsuperscript{+} total in 1998. Thirdly, once again, the importance of considering the primary system becomes apparent – with 850 kilomoles of H\textsuperscript{+} from NO\textsubscript{x} emissions arising in the co-generation facility at Boron exported to the grid. However, as for Rio Tinto, data only are available at this time for emissions, not for dispersion patterns and sensitivity of receiving environments to identify areas where levels of acidification exceed critical loads.

4.5.3.5 Water Use

Following Rio Tinto guidelines, Borax reports water consumption data for each of its operations according to whether it is freshwater, poor quality water, impounded water, or recycled water. Table 7 in Appendix 4 summarises Borax Group performance (Rio Tinto 1997a, page 29; Rio Tinto 1999b, page 39) (see Vol.4 APD4 Table 7).

The data for 1995 to 1998 illustrate a year on year decline in both total water abstraction, and in demand for the most critical component of water abstraction – freshwater. However, as was discussed in Section 2, the environmental impact of water consumption depends to some extent upon levels of water availability in the locations under consideration (see this document, Section 2.9.2). The data may not reveal the underlying performance in water consumption in the group where small increases in water consumption in areas of water scarcity could outweigh larger declines in consumption in areas of water abundance in the overall mix. Figure 40 illustrates performance for Borax when water abstraction is normalised.
for levels of water availability at the location in question, based upon the normalisation factors outlined in Table 42\textsuperscript{20}.

Table 42: Weighting factors for Borax operating locations

<table>
<thead>
<tr>
<th>Location</th>
<th>Precipitation (mm)</th>
<th>Evaporation (mm)</th>
<th>Median Precipitation</th>
<th>Median Evaporation (mm)</th>
<th>Weighting Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boron (Californian Desert)</td>
<td>~100-200</td>
<td>~0-200</td>
<td>50</td>
<td>~3.3</td>
<td>~5.32</td>
</tr>
<tr>
<td>Borax Argentina (Andes)</td>
<td>~100-200</td>
<td>~0-200</td>
<td>50</td>
<td>~3.3</td>
<td>~5.32</td>
</tr>
<tr>
<td>Wilmington (Los Angeles)</td>
<td>381</td>
<td>~200-400</td>
<td>~81</td>
<td>~3.2</td>
<td>~3.284</td>
</tr>
<tr>
<td>Borax Rotterdam (Northern Europe)</td>
<td>~700-1000</td>
<td>~400-700</td>
<td>~300</td>
<td>~0.8</td>
<td>~0.8867</td>
</tr>
<tr>
<td>Borax Francais (Northern Europe)</td>
<td>~700-1000</td>
<td>~400-700</td>
<td>~300</td>
<td>~0.8</td>
<td>~0.8867</td>
</tr>
<tr>
<td>Borax España (South-Eastern Spain)</td>
<td>~400-600</td>
<td>~200-400</td>
<td>~200</td>
<td>~1.3</td>
<td>~1.33</td>
</tr>
</tbody>
</table>

Figure 40: Reported and weighted water abstraction for Borax, 1995 to 1998

One must treat the normalised figures in Figure 40 with great caution for two major reasons. Firstly, with the exception of Los Angeles, data for precipitation and evaporation are drawn from standard climate charts (Bartholemew, et al, 1990) and therefore reflect regional, rather than local conditions, and therefore deliberately provide a range, rather than specific figures. Secondly, they assume that water availability depends on water precipitation and evaporation.

\textsuperscript{20} Water precipitation and evaporation data from Bartholemew et al, 1990.
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— all other factors being stable over time. However, as discussed during Section 2, there is great uncertainty over treatment of groundwater (see this document, Section 2.9). Boron, the largest absolute and relative consumer of water in the Group, draws its water from aquifers in addition to surface sources. Thus, because Boron is located in a desert, it is assigned a high normalisation factor relative to global values, but this may not fully reflect the local situation.

With these caveats in mind, however, it is still possible to determine that Borax’s normalised water demand is higher than its absolute demand because more of its demand falls in arid areas than in wet areas. Nonetheless, water use reductions appear to have occurred across the Group, leading to an overall reduction in normalised requirements from 1995 to 1998.

4.5.3.6 Ecotoxicity

As for Rio Tinto, Borax does not have data on critical thresholds for aquatic and terrestrial systems. Group companies have, however, all provided environmental quality standard data for their locations for the major discharges from Rio Tinto locations with the potential to have a toxic effect on the environment. Following the principles established by Wright et al (1998) and Heijungs et al (1992), among others and discussed in Section 2.13, it should be possible to use discharge data and EQS data to indicate the potential ecotoxicity in the aquatic environment relative to a reference material. There are no speciation data, however, so the results of such an assessment would be at best indicative.

**Table 43: Environmental Quality Standards for selected materials at Borax locations**

<table>
<thead>
<tr>
<th>Operation</th>
<th>Argentina</th>
<th>Boron</th>
<th>Espana</th>
<th>Francia</th>
<th>Rotterdam</th>
<th>Wilmington</th>
</tr>
</thead>
<tbody>
<tr>
<td>EQS for Arsenic (µg/l)</td>
<td>50</td>
<td>N/A</td>
<td>500</td>
<td>50</td>
<td>1000</td>
<td>No data</td>
</tr>
<tr>
<td>EQS for Cadmium (µg/l)</td>
<td>0.2</td>
<td>N/A</td>
<td>100</td>
<td>No data</td>
<td>100</td>
<td>No data</td>
</tr>
<tr>
<td>EQS for Copper (µg/l)</td>
<td>2</td>
<td>N/A</td>
<td>200</td>
<td>500</td>
<td>1000</td>
<td>No data</td>
</tr>
<tr>
<td>EQS for Cyanide (µg/l)</td>
<td>5</td>
<td>N/A</td>
<td>100</td>
<td>100</td>
<td>1000</td>
<td>No data</td>
</tr>
<tr>
<td>EQS for Lead (µg/l)</td>
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<td>N/A</td>
<td>200</td>
<td>500</td>
<td>3000</td>
<td>No data</td>
</tr>
<tr>
<td>EQS for Mercury (µg/l)</td>
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<td>N/A</td>
<td>50</td>
<td>No data</td>
<td>50</td>
<td>No data</td>
</tr>
<tr>
<td>EQS for Zinc (µg/l)</td>
<td>30</td>
<td>N/A</td>
<td>3000</td>
<td>2000</td>
<td>3000</td>
<td>No data</td>
</tr>
</tbody>
</table>

Boron reported that EQS values are not applicable to its operations as it is ‘zero discharge’—there are no aqueous effluent streams from its facilities. Only one other facility failed to report EQS data — the Wilmington refinery and distribution centre. This is unfortunate as, in fact, Wilmington is the only Borax facility that actually discharges any of the materials in Table 43 into aqueous systems — albeit in quantities at least two orders of magnitude lower than the copper and gold facilities elsewhere in Rio Tinto. Nonetheless, without EQS values it is not possible to generate aquatic ecotoxic potential values for Borax for 1995 to 1998.

4.5.3.7 Land Use and Biological Diversity

Borax’s reporting on land use and biological diversity is in line with that reported by all Rio Tinto operations; i.e. no quantitative data at Group level for biological diversity, and annual
net land disturbance/ reclamation together with land use of reclamation. All Borax reclamation is to native conditions. Figure 4 in Appendix 4 illustrates Borax’s land use performance for 1995 to 1998 (Rio Tinto 1999b, page 41; Rio Tinto 1998b, page 31; Rio Tinto 1997a, page 26) (see Vol.4 APD4 Figure 4).

Borax is increasing the amount of land in use at its operations, as its mine expansions are not being offset by reclamation work. Boron accounts for over 90% of land use throughout the Group operations, and also for all reclamation work. The chart allows both total land use, and assessment of changes to be tracked. Net land use totals alone do not give an indication of the scale of changes upwards and downwards during the period (expansion of 3000 hectares and 3500 hectares of reclamation, and 500 hectares of expansion with no reclamation both provide a net increase of 500 hectares)

4.5.3.8 Sedimentation

Borax reports releases of suspended solids for all operations (Rio Tinto 1999b, page 41; Rio Tinto 1998b, page 31; Rio Tinto 1997a, page 26). For most operations, there were zero suspended solids releases for the years 1995 to 1998. The two exceptions were Wilmington and Borax Argentina. Their discharges are detailed in Figure 5 in Appendix 4, which illustrates that Borax’s suspended solids discharges are reported to have declined to zero by 1998 from a 1996 high of slightly under 200 tonnes (see Vol.4 APD4 Figure 5).

4.5.3.9 Dust

For a mining group whose extraction activities take place in desert regions, and whose distribution operations handle a product that is essentially a powder, Borax’s reporting of dust emissions is limited. Only Boron has reported point source emissions of dust for all years 1995 to 1998, joined only in 1998 by Borax Argentina. Prior to 1998 there are no available data at all for fugitive emissions of dust. From 1998 onwards, Boron operations are reporting the results from their use of site and boundary dust monitors and Californian EPA approved simulation software to estimate fugitive dust emissions – from area sources and mobile sources – in addition to monitored point source emissions.(Weiss, 1999)

Boron’s estimates suggest that fugitive emissions of dust account for approximately 50% of site emissions across the mining, refining and distribution functions at the Boron operation. This could be extrapolated backwards in time for Boron, on a pro rate basis on the assumption that dust emissions are related to tonnage of material handled, to provide an approximation of total dust emissions for that operation for the entire time series. However, with no fugitive emission data for Argentina and only one data point for point source emissions at Boron, such an exercise would demonstrate little. The rest of Borax has no quantitative information at all and so it is concluded that it is not statistically meaningful to attempt to present Borax dust performance on the basis of the limited data that are available.

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4.5.3.10 Normalisation Factors

4.5.3.10.1 Financial Normalisation Factors

As is the case throughout Rio Tinto companies, Borax collates data on its turnover and earnings, but does not calculate the economic value added by its activities, nor is it able to determine the contribution to sustainable economic welfare made. (Rio Tinto, 1999a, page 85; Rio Tinto 1998a, page 12; RTZ-CRA 1997a, page 24; RTZ-CRA 1996, page 30) As a wholly owned subsidiary of Rio Tinto, 100% of Borax’s financial, production, social and environmental performance is attributable to the Rio Tinto Group. Figure 41 illustrates Borax’s financial performance for 1995 to 1998.

Figure 41: Borax earnings and turnover, 1995 to 1998

Earnings have remained stable over the period, while turnover has stabilised after a step downward from 1995 to 1996. As an industrial mineral, Borax’s earnings and turnover are less susceptible to dramatic price fluctuations experienced in the commodity markets by other Rio Tinto product groups. Borax sells direct into end-uses, the majority of which are related to construction. Accordingly, Borax’s prices - and turnover - are influenced directly by world economic conditions. For metals such effects are felt indirectly through the metal exchanges.

4.5.3.10.2 Social Normalisation Factors

Borax collates community investment data for all its operating locations – both operations and corporate facilities. The operations tend to invest in initiatives specifically at the local level, while corporate investment tends to be partly aimed at local initiatives and partly at wider initiatives. From 1998 onwards, community investment data will be improved on two counts. Firstly, financial investment will be expanded to include indirect financial costs from the
communities programmes such as management costs. Secondly, this will allow the determination of the investment of time made by Borax and all other Rio Tinto operating companies in community programmes (Wheeler, 1999). Figure 42 illustrates the currently quantified contribution throughout Borax to community programmes.

Figure 42: Direct cash investment by Borax in community programmes, 1995 to 1998

As the figure shows, the majority of currently quantified community investment is made away from the operations. There are six commercial, technical and administrative facilities supporting local markets in Borax, and each has a community programme. The two corporate centres also contribute to global initiatives. However, Figure 42 illustrates that total investment by Borax in community programmes has risen over the period 1995 to 1996.

Furthermore, the emphasis of the investment has changed markedly over the period. Investment at Borax Argentina – which operates in a remote part of the world and where infrastructure in the form of healthcare and schooling for example is poorly developed – has increased both in absolute terms and as a proportion of Borax investment. Conversely, investment in community programmes in Rotterdam and Wilmington (Los Angeles) has either remained stable or declined over the period, reflecting a relative shift away from investment in community programmes in already developed parts of the world.

However, as was recognised in Section 3, investment data alone are limited on two counts. Firstly it does not reflect the purchasing power of the investment at the local level (if it were possible to reflect that in the chart for Borax, it is suggested that this would show an even greater relative increase in investment in remote areas than currently shown) and secondly it
does not convey how effective this investment has been (see this document, Section 3.4). Any interpretation of social performance data must not overlook this limitation.

4.5.3.10.3 Physical Normalisation Factors

Borax operations collate a wide range of data to track physical performance (Gunson, 1999; Bullock, 1999). The mines track how much rock they move, how much ore they extract; the refineries track how much product they produce; the distribution centres track how much material passes through their facility and where it goes. All operations track how much B2O3 is in the material they handle. This is helpful for the purposes of this research for two reasons. Firstly it will allow different production metrics to be examined and secondly it will help illustrate a point made during Section 3 – that double-counting really is a distortion (see this document, Section 3.5.3). This latter point will be addressed before turning to the former.

Figure 43 illustrates how much material is moved at each Borax operation. The majority is waste rock stripped at Boron and Tincalayu to get at the B2O3 bearing ore beneath. Refined product is distributed through Boron and Borax Argentina, but also through Borax Français, Wilmington, Borax Rotterdam, and Borax España. The chart illustrates the total material moved in these operations.

**Figure 43: Material movement by Borax operations, 1995 to 1998**

![Material movement chart](image)

The narrow bar in the centre of each stack illustrates how much material is actually moved by the Group. The processes originate in Boron and Borax Argentina – all Wilmington and the European operations are doing is additional processing and distribution – but it is the same material shipped out of Boron and Argentina. The difference between the two stacks – which is small due to the dominance of waste rock in the mining processes – is double counting.
When considering the physical performance of Borax as a Group, the central bar must be used, while individual operations will consider their component of the stack.

In addition to quantities of material shifted, Borax operations also track how much $\text{B}_2\text{O}_3$ is contained in the material passing through their operations. Compared with total material moved, total $\text{B}_2\text{O}_3$ contained in production for the Group will provide an insight into how much 'extra' activity is required. If levels of material movement are rising relative to $\text{B}_2\text{O}_3$ in production, this suggests that either the mines are having to shift more rock to get to the ore, that the ore body is declining in grade, or that a great deal of movement of material between sites is necessary to ship product to customers. Figure 44 illustrates Borax's production data.

**Figure 44: Total delivered production versus total $\text{B}_2\text{O}_3$ in delivered production for Borax, 1995 to 1998**

As Figure 44 illustrates, the amount of $\text{B}_2\text{O}_3$ in delivered production has risen over the period 1995 to 1998, while the actual tonnage produced and sold to customers has remained flat. Given the decline in material handled tonnage, this would suggest that either Borax has been mining higher grades of ore closer to the surface of the mines - which runs counter to mining logic, which follows an ore body downwards - or the Group has achieved greater efficiency in its processing and distribution operations – reducing the 'borate miles' travelled by products to get them to customers.

**4.5.4 Discussion**

As for the Rio Tinto case study, the objective here is to assess the extent to which the environmental, financial, social, and physical performance data gathered allow meaningful performance trends to be identified. The objective of this work has been to develop key indicators of environmental performance for global mining companies. In this Section the data collated will be used to test the hypothesis that the indicators proposed are more consistent with that objective than those currently in use in global mining organisations such
as Rio Tinto and its subsidiaries. This will require the comparison of current indicators with those proposed for both the environmental themes and normalisation.

In the first instance, however, it should be observed that data on the whole was far more comprehensive for Borax than for Rio Tinto. This is not a reflection on the attitudes of the two organisations, more on the practicality of generating information for a smaller business unit than for a large one. Energy data, greenhouse data, atmospheric acidification data, for example, all required the use of Rio Tinto Technical Services to extrapolate current data common to all Rio Tinto operations. Aquatic ecotoxicity and water availability data required local information which could more easily be provided by six sites than sixty.

Nonetheless, there are themes where Borax fails to provide data. In toxicity for example, Borax data only address aquatic discharges and aquatic media although, as was seen, only one site releases potentially toxic materials (although whether or not the others make discharges to terrestrial media cannot be verified without measurement). For acidification, no data are available on local sensitivity to deposition. For land reclamation interim data are poor, reflecting the low level of importance attached to reclamation until the closure phase for Borax’s open-pit operations. Borax’s data for biological diversity are as weak as its parent, again relating to the management of older open-pit operations with no baseline information on biological diversity. Dust data are much better for Borax than for the wider Rio Tinto Group – encapsulating fugitive emissions (albeit through the use of simulation software) as well as point source data.

The data for normalisation factors, however, were as widespread as for Rio Tinto for financial and social data, but much more comprehensive for production data. It was possible to collate data for a wide range of production metrics across the Borax Group, which should ultimately allow activity based comparisons to be made.

Of greater import than the assessment of data quantity, however, is the assessment of what is indicated by that data. For each environmental category three main figures will be presented – the first comparing trends shown by currently used data and proposed data, and the next two comparing performance using normalisation factors for the two data-sets. Activity based comparisons will also be possible for themes like energy use, showing how the data can be desegregated where appropriate.

This section will focus on the themes where there was dissonance between currently reported information and information which could be reported differently using the indicators proposed. For Borax these themes are energy, greenhouse gases, acidification and water use. Dust emissions, sedimentation, land use, biological diversity, aquatic ecotoxicity, and resource extraction data are either already compatible with the indicators (resource extraction, sedimentation) or there was insufficient information to make a comparison (biological diversity, land-use changes, aquatic ecotoxicity, dust).
4.5.4.1 Energy

Energy consumption trends are outlined in Figure 45 and Figure 46.

**Figure 45: Proposed versus reported Borax energy requirements, 1995 to 1998**

[Graph with proposed and current energy requirements for 1995 to 1998]

Figure 45 and Figure 46 allow a number of observations to be made. The first is that the proposed energy data, which include energy requirements associated with the provision of energy used on site, but exclude energy exported from co-generation facilities is much greater than that currently reported. The 'credit' from exports of electricity is more than offset by the 'debit' of more complete energy accounting.

**Figure 46: Normalised energy performance for currently reported data and proposed data, Borax 1995 to 1998**

[Graphs showing normalised performance indices for 1995 to 1998]

The second is that relative performance trends show a greater improvement, relative to 1995, in primary energy efficiency than currently reported energy data. These improvements have been shown 'across the board'. For energy, improvements are shown for performance against financial, community and physical factors. And for physical factors, efficiency per tonne production improvements have exceeded those per tonne moved – suggesting that improvements in the management of the operations have either reduced the amount of internal movement between sites, or have occurred in the refineries rather than at the mine sites.
This can be verified by examining activity based performance. As Figure 47 illustrates, refining energy requirements in Borax are much greater, per tonne contained B$_2$O$_3$, than for mining. Thus even relatively small improvements in efficiency here will offset similar changes on the mining side. For Borax, when examined in conjunction with Figure 46, Figure 47 suggests that refinery improvements have exceeded those in mining operations for Borax.

**Figure 47: Unit energy requirements in mines and refineries, Borax 1995 to 1998**

### 4.5.4.2 Greenhouse Gases

Borax’s greenhouse gas trends are shown in Figure 48 and Figure 49.

**Figure 48: Current versus proposed greenhouse gas emissions for Borax 1995 to 1998**
Figure 49: Normalised greenhouse gas performance for currently reported data and proposed data, Borax 1995 to 1998

For most operations in Borax, the ‘absolute’ emissions of greenhouse gases are higher than those currently reported. This reflects the emissions of greenhouse gases associated with off-site electricity generation and off-site processing of fuels used at the operations. However, because Boron Operations is a net ‘exporter’ of energy, it is also a net exporter of greenhouse gas emissions, thus its absolute value is lower than the value for emissions at its property. Thus the absolute value for greenhouse gas emissions for the Borax Group is lower than that at its sites.

The other feature of the figures to remark upon is the trend in emissions. According to currently reported figures, emissions are declining, from 0.469 Megatonnes CO$_2$e in 1995 to 0.431 Megatonnes CO$_2$e in 1998, despite the fact that Borax Rotterdam and Borax Espana did not start reporting values until 1996. Although the absolute values for the Group are lower due to export effects at Boron, the trend in the emissions associated with Borax itself is upward, from 0.315 Megatonnes CO$_2$e in 1995 to 0.333 Megatonnes CO$_2$e in 1998.

This illustrates the significance of ensuring that any reporting captures the relevant system for consideration. In tracking only emissions arising on-site, Borax has overlooked trends occurring in its wider greenhouse ‘system’. Its improvements in management of issues at its sites have been offset by deteriorating performance in its wider sphere of influence. The emissions will take place as a result of Borax activities, regardless of whether they occur inside or outside Borax’s site boundaries, and therefore it is important that Borax tracks these trends.

The significance of this issue is highlighted in Figure 49. While relative performance across all normalisation factors for currently reported performance is improving, under the proposed framework for data it is markedly deteriorating.

4.5.4.3 Acidification

Currently, Borax does not report acidification to Rio Tinto as current practice in the Group is to report only direct process emissions from smelters and refineries related to sulphide ores.
Only six operations had emissions greater than 3,000 tonnes of SO₂ in 1998. However, fossil fuel combustion processes at Borax — both at the site and upstream — do generate sulphur dioxide and nitrogen oxides. In fact, as Figure 50 shows, the total for these emissions is substantial. If acidic gases were allocated in the same way as current practice for energy consumption on site, the on-site total given in Figure 50 would result for the Group.

Figure 50: Current (on-site) versus proposed (total) acid gas emissions for borax 1995 to 1998

Figure 51 Normalised acid gas emission performance for currently reported data and proposed data, Borax 1995 to 1998

Although Borax’s underlying emissions of acidic gases are on the increase (despite on-site levels dropping), Figure 51 illustrates that - as for energy and greenhouse - the efficiency of Borax’s operations is improving in terms of the normalisation factors under consideration. As before, this is most noticeable on the community investment side, but relative performance against financial and physical criteria is also better than the underlying trend. Nonetheless, Borax must focus upon total releases of acid gases, even though its site totals – made up of mobile equipment activity and energy use in the main, are still considerable.
4.5.4.4 Water Use

Borax’s total water consumption pattern is shown in Figure 52 and Figure 53. As was discussed in Section 4.5.2.3.4, Borax’s weighted water use is much greater than the currently reported figure, illustrating that water demand is high in areas of relative water scarcity compared to demand in areas of relative water abundance.

Figure 52: Current (aggregated) versus proposed (weighted aggregated) water abstraction levels for borax 1995 to 1998

![Figure 52](image)

Figure 53: Normalised water abstraction performance for currently reported data and proposed weighted data, Borax 1995 to 1998

![Figure 53](image)

Nonetheless, the trend in water consumption is downward for both absolute values and normalised for financial, social and physical factors. Both reported water use and weighted water use have fallen by approximately the same amount over the years, suggesting that water conservation measures have been used throughout the Group. In addition, the charts illustrate that relative performance has improved to a greater extent than the baseline level; water use
per unit community investment, for example, fell to approximately 60% of 1995 levels by 1998, while actual water consumption fell to approximately 90%.

However, one further trend which can be detected by comparing the two charts in Figure 53 is that weighted performance (on the right) is beginning to plateau towards 1998, while currently used absolute volumes (on the left) continue to fall. This suggests that water conservation measures may be becoming less effective at those areas with water scarcity than those with water abundance. The currently used figures will disguise this fact, and divert attention away from the underlying environmental problem – water use in areas of scarcity.

4.5.4.5 Site Performance

As was concluded in Section 1, aggregation of indicator data can remove transparency in underlying trends (see this document, Section 1.5). Acidification and water use are a case in point. For both, Borax's performance, in terms of releases and use per physical, social and financial unit is either fluctuating with 1998 values similar to 1995 (in the case of full acid release accounting) or is improving (in the case of normalised water use per unit).

It was also concluded for these issues in particular, that while Group measures can be produced, they may not be meaningful in the local context. This will be examined for Boron and Borax Français – both include refining and distribution functions, but the former also includes a mine. Starting with acidic gas emissions, Figure 54 illustrates the underlying trend in acidic gas emissions (calculated in terms of SO_2 e) while Figure 55 compares normalised performance at Boron and Borax Français.

**Figure 54: Relative trends in acid gas emissions for selected Borax operations, 1995 to 1998**
Figure 54 shows that in relative terms, emissions of acidic gases associated with Boron’s operations have reduced at a greater rate over the period 1995 to 1998 than the rest of the Group and that Borax Français’ emissions – all from purchased electricity production – have in fact risen to a level in 1998 almost four times higher than the 1995 level. Furthermore, Borax Français’ performance fluctuates a great deal in comparison to that at Boron. This fluctuation is unconnected with production levels at Borax Français. Figure 55 illustrates that for the years where data are available for the operation (1997 and 1998) normalisation for production does not affect the overall trend. However, Borax Français’ community investment has increased at a greater rate than acidic emissions over the four years.

At Boron, by contrast, while the normalised trends are more consistent with underlying performance than for the French operation, acidic gas emissions have declined at a lower rate per tonne material moved than per tonne B2O3 in production – suggesting increased efficiencies in the removal of B2O3 from the ore rather than removal of ore from the ground. This assessment is useful on two counts. Firstly it shows that site performance may exhibit different trends than for the overall Group, and so it is necessary to consider site data. Were site sensitivity data to be available, it would be possible to assess whether Boron’s improving performance is still likely to cause more harm than Borax Français’ declining performance to the environment. Without this critical component of the information, all the information reveals is whether, locally, performance is likely to be causing more or less harm over time. Secondly, it shows that within operations, normalised performance may be improving in certain areas more than in others. For mining operations to manage their environmental performance in a manner consistent with the principles of sustainable development for mining, they must improve performance across all dimensions.

On water use, Figure 56 illustrates relative trends in normalised water consumption, while Figure 57 compares normalised performance at the two sites.
Figure 56: Relative trends in water abstraction levels for selected Borax operations, 1995 to 1998

The charts tell a story for Boron in the case of water similar to the earlier ones for acidification – namely that water use per tonne material moved is improving at a greater rate than water use per tonne B₂O₃. For both Boron and Borax Français, performance per unit investment in community programmes continues to improve at a greater rate than for the other dimensions.
4.6 Conclusions

The case studies for Borax and Rio Tinto have been informative for a number of reasons. Firstly, they have highlighted the difficulty large mining organisations have in presenting meaningful data on their environmental performance in the context of sustainable development. Current reporting practices in Rio Tinto have emphasised the collation of performance data for management purposes, and presenting that in Group environmental communications. This approach contrasts markedly with the approach taken for financial reporting to shareholders, which emphasises the performance of the assets owned by the shareholders, rather than those managed by the reporting company.

This approach requires a unified reporting framework to be used by all mining companies to allow data to be reported meaningfully even where more than one mining company is involved – which is frequently the case. This is in place for financial reporting at the present time, although it has been argued in this work that even though a unified approach exists, it does not report financial data that are of maximum value in the context of sustainable development (earnings and turnover rather than added value or contribution to ISEW).

For environmental reporting, however, the focus on management data rather than asset data is misleading. This approach is compounded when the data used by management relate to their site, rather than the effects of the activities at their site. Examples include energy use, and releases of acidic and greenhouse gases, which currently are reported by considering activities inside the mining operation (an approach which penalises those operations who operate cogeneration facilities). As the data for Borax suggest, this approach can have two consequences. Firstly, the data do not reflect properly the impacts which relate to the mining activity – the effects of electrical energy generation should be assigned to the activity using that energy (in the case of imported energy this means they should be assigned to the mine, and in the case of exported energy they should not). Secondly, they can disguise the underlying trend in performance. As the case of Borax’s greenhouse performance showed clearly, reported performance can be improving while underlying performance is deteriorating unnoticed.

Furthermore, the cases show the importance of recognising local conditions. Looking at water use, for example, the case of Borax illustrated that attention should focus on areas of water scarcity rather than abundance to achieve the least unsustainable environmental performance. Also, the cases illustrated the importance of normalising data. In the case of Borax, ‘efficiency’ improvements provide an insight into underlying attitudes in the organisation which might otherwise be disguised. For example, performance per unit community investment expenditure has improved at a greater rate than either underlying performance or relative performance on the financial or production fronts. However, there is no in-built mechanism which recognises the different levels of need for social investment in the indicators, so the relative impact of investment in Rotterdam compared to investment in the Andes is not identified in these indicators. Perhaps this factor is most meaningful at the local level, where it is important that improvements relative to social investment keep pace with improvements in financial and production performance. In the case of Borax, the
normalisation exercise demonstrated, nonetheless, that the Group’s environmental performance has become more efficient, in relation to the dimensions of sustainable development identified in Project Document 1, than its underlying performance might suggest.

There remain areas of weakness for the indicators in terms of data availability and use. The challenge of providing meaningful data on biological diversity for the mining operations studied here is of concern, given the importance of this issue to mining identified in Section 2 (see this document, Section 2.15). Furthermore, data on site sensitivities to acidic and toxic discharges limit the usefulness of the information presented in those themes thus far. As for biological diversity, the importance of these environmental issues to mining were highlighted in Section 2 (see this document, Sections 2.12 and 2.13).

Perhaps the most important conclusion to be drawn from this phase of the work is that mining organisations must measure, report, and act upon those areas of environmental concern that are important, rather than those which are easy to measure and/or manage. Focusing on the upstream effects of energy provision, for example, could reduce the impact associated with the mining operations to a greater extent than site issues, as the case of energy and acidic emissions for Borax illustrated. Emphasising those operations which are managed by Rio Tinto, rather than those operations where they are involved, is useful to environmental managers at sites managed by Rio Tinto and their stakeholders, but is not necessarily helpful to others. If the mining operations at a site not managed by, but part owned by Rio Tinto are closed due to an environmental incident, Rio Tinto’s shareholders will still see a drop in the value of their investment. They may require information which reflects environmental performance across all of the assets in which they have a share. Global NGOs may also require this information rather than the information currently reported. These issues will be discussed further, together with a review of the findings of the earlier phases of this work, in Section 5 - the review and conclusions phase of this project.
5. Review, Evaluation, and Concluding Remarks

5.1 Overview
The objective for this project in the portfolio has been to assess whether or not NRCan were correct in their assertion that sustainable development for minerals and metals requires environmental, social, and economic issues to be addressed and, if so, to identify the implications of this for decision making and sustainable operations. Specifically, this project has aimed to examine the extent to which environmental performance indicators will help in the management of sustainable operations and how they are influenced by the principles of sustainable development for mining.

This phase will evaluate the extent to which this project has been successful in achieving those objectives, highlight the key research findings from this project, identify limitations in the findings and areas where future work is required, and position the work in the context of the research portfolio and environmental technology.

5.2 Conclusions

5.2.1 Mining is Compatible with Sustainable Development
This work has concluded that NRCan were correct to assert that sustainable development, for minerals and metals, requires environmental, social, and economic issues to be addressed. This work concurs with Lele that sustainable development is not, a priori, equivalent to sustaining growth. Despite the fact that currently mineral reserves are growing more quickly than mineral consumption, it is accepted that this cannot continue indefinitely. In fact, it is proposed here that the debate between those that argue for obvious physical limits to growth and those that champion the role of human agency in developing substitutes for physical resources is an intellectual cul-de-sac. Resource consumption cannot be continued indefinitely, without reversing the thermodynamic law of entropy, but the limit will not be reached as quickly as many envisage, because of human capacity to develop alternatives to scarce resources.

5.2.2 Human Agency
It is the human agency which is overlooked in strict environmental interpretations of sustainable development. While there are certain ecosystem functions which cannot be substituted, there are other aspects of the ecosystem which can, without compromising human development. The physical limits to energy generation presented by depletion of fossil fuels has led to a search for technological solutions. Harnessing the energy from fossil fuels is relatively straightforward but alternatives such as fuel cells, solar power plants, wind turbines, and wave power are all technologically complex. It is only through the use of fossil fuels, however, that society can generate the energy it requires while it develops alternatives. It is this thesis, ignored by those who see fossil fuel depletion as necessarily inconsistent with
sustainable development, that is central to an understanding of the role of mining in sustainable development.

5.2.3 Global and Local Considerations

Mining operations deplete scarce physical resources at the local level. Regardless of the global abundance of a mineral, an ore-body is finite. To contribute to the sustainable development of a community, this work has found that mining operations must ensure that the human capital generated through their presence – through the direct exchange of knowledge between mining companies and local populations, and through the use of economic wealth arising from mining operations to invest in infrastructure that further enhances local natural capital, without undermining those environmental functions for which no substitute will be possible.

This work found the following ‘sustainable development rules’ to apply for mining, therefore. Sustainable development, in so far as it relates to mining, depends upon stewardship of both natural and human capital, ensuring that:

1. mining provides improvements in economic and social conditions without undermining non-substitutable ecological functions;
2. mining provides improvements in economic conditions without undermining social conditions;
3. if improvements in economic and social conditions require non-renewable resources to be used the means of substituting that natural capital for human capital must be delivered.

If mining is to adopt the integration of social, economic and environmental consideration in decision making, as proposed by NRCan, this requires that those making decisions have the information they require. This research has focussed on the implications of this for environmental performance in mining operations by looking at environmental performance indicators for mining rather than looking at attempting to generate indicators of sustainable development outright. This has not been the objective of this work. Mining companies have environmental, social and economic responsibilities relating to sustainable development which must be discharged at both the global level and at the local level.

The social and economic benefits of mining, at the global level, relate principally to the benefits which arise from the use of mined products and the wealth arising from the trade and use of minerals. This must be offset by an understanding of global supplies of minerals – ensuring that effort is expended in enhancing technology to find, extract and use minerals more efficiently and recycle them where possible. Locally, however, there is no benefit to be gained from finding new deposits, or increased recycling (unless the recycling plants are local). The benefits from mining must extend beyond wages and indirect benefits through supporting industries which only last as long as the mine itself. Mining must ensure that the benefits are in the form of human capital which can be reinvested in the local community – education, healthcare, training and enterprise – long after the original mine has closed.

The global environmental costs of mining, in so far as they affect directly individuals far from the mine, relate to resource depletion, greenhouse gases, water use, for examples. While at the
local level, these issues are joined by acidic discharges to atmosphere, land and water, toxic discharges to the same media, land use, loss of biological diversity, dust and sedimentation. It has become clear in this work that for mining to be sustainable, it must focus attention on local issues. This is particularly so as a mine can last generations – giving it the opportunity to witness first hand whether its actions are contributing to inter-generational equity as well as intra-generational equity.

5.2.4 Focus on Generic Issues

This work has focussed on those issues which are generic in the mining industry – those which are likely to apply at most mining operations around the world – but has not focussed on specific local issues which may apply only at one particular site. This would be a research programme in its own right, and would contribute as much to the fields of sociology and anthropology, if not more, than to the field of environmental technology. This work, however, recognises that if sustainable development is to be fully incorporated into decision making, at the local level, then the environmental performance discussed here in the context of environmental technology must be joined by measures of social and economic performance which are meaningful at the local level as well as at the global.

5.2.5 The Importance of Indicators

The use of indicators was found to be helpful in the context of decision making for sustainable operations, provided they were organised in a pyramid, where information would be aggregated and selected towards the corporate level apex. For example, the global corporation would examine greenhouse gas performance for each of its operations, and for the corporation as a whole, but for contribution to aquatic toxicity, it would be concerned with all of its operations, but should not attempt to aggregate their performance.

The research identified that the environmental issues which are important for mining may not necessarily be appropriate for other sectors, and vice-versa. For example, some environmental issues of global import – such as ozone layer depletion – are predominantly impacted by sectors other than mining, while others – such as resource depletion – are impacted to a great extent by mining operations. The challenge has been to ensure that those environmental themes chosen are meaningful to mining and are within their sphere of influence.

5.2.6 Relative Measures of Performance

From a decision making perspective, it was found that at the corporate level, it is difficult to achieve a sense of whether performance is improving or deteriorating without the use of relative measures of performance to complement absolute measures. For example, the total amount of greenhouse gases arising from mining operations over their lifetime depends, in simplistic terms, on how much ore is in the ore-body, and how much greenhouse gas is produced to remove that ore from the ore-body. Mining rates change over time, and consequently, rates of greenhouse gas emission change over time. While it is important for a mining operation to know in any one year how much greenhouse gas it has emitted, it is also important to know how much greenhouse gas has been emitted per tonne of ore that year, and
track how this changes over the lifetime of the mine, with an objective to minimise the total
over that time.

This principle also applies to social performance and economic performance. Again, with a
finite ore-body, with emissions changing over time, it is important for decision makers to
know how much social and economic benefit is being gained per unit of environmental
impact, as total impacts will change over the life of the ore-body and, again, the objective is to
maximise the benefit overall.

5.3 Gap Analysis and Future Research Needs

5.3.1 Different Decision Audiences

Having established these principles, it was revealing to examine the extent to which the
information currently reported by mining companies reflects these needs. Historical financial
performance reporting appears to have been aimed at financial shareholders interested only in
the flow of revenue arising from their share. Environmental reporting has been historically
aimed at regulatory compliance. Examining the reporting practices of the one of the world's
largest mining companies – Rio Tinto – has revealed that the two approaches are
incompatible, and are inconsistent with decision making incorporating the principles of
sustainable development.

For example, to know whether the economic flows from a mining operation are helping
society move in a more, or less sustainable direction, one would need to know whether the
cash flows are helping to ensure that the opportunities of future generations are at least as
good as those of the current generation, and that the costs the current generation are being
asked to bear and that future generations will face, are compensated adequately by the cash
flows. However, currently reported financial information does not allow such an assessment
to be made – focussing on costs and benefits which arise on the basis of transactions. Losses
of welfare through environmental pollution, social disruption etc are poorly quantified.
Furthermore, the state of methodological development to allow such losses to be quantified is
currently sufficient only to establish that there is promise in such a framework, but not
sufficient to be utilised yet.

The same is true for social welfare and for environmental welfare. What becomes clear
through this research is that the mining industry needs to change, fundamentally, its entire
approach to decision making on the basis of the information it gathers internally and reports
to an external audience. At the global level, there appears to be little cohesion in decision
making frameworks used in the mining sector. The case of Rio Tinto has highlighted this
difficulty by showing how it shares (or doesn't) information with its joint venture partners –
the other global resources companies such as Billiton, BHP, BP-Amoco, Anglo American,
and Freeport McMoRan – on its environmental performance.

The information which results is of little use to decision makers attempting to ensure mining
moves in a less unsustainable direction. Currently, the mining industry reports environmental
information to a regulatory audience, and financial information to an institutional investment

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audience. If decision making for mining is to be based on sustainable development principles, and those principles require an integrated approach to managing economic, social and environmental issues, then a starting point must be the collation and dissemination of such issues in an integrated, rather than disparate, way.

5.3.2 Blind-Spots
The two case studies illustrate that while in certain instances, the failure is systemic – in that reporting structures do not allow information at the local level to be conveyed to the corporate level – in others it is more fundamental. For example, the case of Borax illustrates that there is much information necessary to corporate indicators available at the local level, but not reported at the corporate level. Examples include amounts of material moved, fugitive dust emissions, primary energy requirements. There is also much information necessary to understand the local effect of operations – local sensitivity to potentially toxic discharges, baseline biological diversity, local sensitivity to acidic discharges, for examples- where there has been little or no attempt by the operations in the case studies presented to generate such information.

The environmental reports of other multinational mining companies suggest that the weaknesses identified in Rio Tinto and its subsidiaries apply equally to other parts of the sector. Some mining groups – such as WMC and BHP are already using relative performance indicators to a greater or lesser extent than Rio Tinto, and both have begun to identify the importance of the primary system for energy and greenhouse emissions if not for acidic discharges, but neither have addressed biological diversity, land use, local water availability, for examples, in a meaningful fashion. Anglo-American has not even progressed as far as performance indicators at this time. There is certainly no exchange of environmental information between these companies even though sustainable development requires management that moves beyond managerial responsibility for an issue at the level of an operation towards a more integrated approach which will require the participation of local communities, employees, regulators, global NGOs, shareholders and the corporations themselves.

5.3.3 Future Research
An objective in this particular project was to establish what the indicators of environmental performance, informed by an understanding of sustainable development, should be for a global mining company, and thence to test the capacity of the industry to implement those indicators. This objective has been achieved. There are numerous areas where there is an absolute necessity for further work to be carried out before a definitive set of indicators of environmental performance can be established for global mining organisations to aid decision makers.

5.3.3.1 Deposition and Sensitivity
Firstly, this research has identified areas where the state of scientific knowledge lags behind the needs of sustainable development. Firstly, current knowledge regarding the fate of acidic...
discharges from mining operations and the sensitivity of receiving ecosystems is limited, although efforts by SETAC, for example, may soon provide the tool needed to indicate dispersion and sensitivity. In Europe, for example, mapping of acidification ‘hotspots’ has provided a tool to illustrate likely impacts from deposition falling certain areas. This must be complemented by tools to assess the dispersion of such emissions. It may be that this is an exercise which should be carried out at the level of the mining operation for site effects and by power utilities for ‘upstream’ effects.

5.3.3.2 Biological Diversity
Secondly, biological diversity is currently the subject of considerable effort in the scientific community. Identifying meaningful indicators for biological diversity remains a challenge for the scientific community, although the efforts of the United Nations in this regard are noteworthy. The mining industry appears to have addressed this challenge with varying degrees of success. Richards Bay Minerals, the Billiton / Rio Tinto joint venture has been praised for its efforts in reclamation and biological diversity. However, this has only served to highlight the gulf between the pioneering organisations and the majority in the industry. Across the Rio Tinto sectors, strip mines with continuous reclamation programmes had excellent knowledge, while the mature open-pit operations had almost none. Come mine closure, it may be difficult to assess whether the return of chickens to roost is a favourable or unfavourable event for these operations.

5.3.3.3 Discount Factors
Turning to normalisation factors, the importance of contribution to economic development over the life of the mine was identified, together with a need to inform a society with choices as to where to invest its capital whether the returns from mining would offset the eventual cost of closure. Mining highlighted the problem in current investment appraisal techniques where there is a temporal dislocation between costs and benefits. A discount factor to represent the opportunity cost of investment is needed, but as this is set by current generations, it favours current positive cash flows, and discounts future ‘clean-up’ costs. The research did not resolve this dilemma, but recognised its influence on investment decisions.

5.3.3.4 Social Welfare
Social normalisation is fraught with difficulty when attempting to carry out such an exercise at the corporate level. This research concurred with the World Bank view that if there is such a thing as a common denominator for social development, then it is knowledge. Mining operations in developing nations may be occupied with ensuring that they play their part in ensuring that sanitation, health-care and infrastructure development takes place, whilst those in developed nations may attempt to ensure that positive relations are maintained with local communities through employment opportunities and support for local initiatives. At the corporate level the need for a single denominator led to the selection of time spent on community problems, as this transcends the objectives of the individual programmes, and removes the distortions presented by the buying power of a dollar in different parts of the
world when financial investment is considered. Ultimately, however, it is acknowledged that investment, even of time, is no guarantee of progress.

5.3.3.5 Validation

It is this theme which runs through the research. It was possible to generate a meaningful set of indicators for environmental performance based on the principles of sustainable development which have illustrated that currently reported (and managed) performance runs counter to underlying performance in many areas. A mine with declining greenhouse emission on-site, due to a decision to purchase power off-site is not necessarily contributing to sustainable development, even though it may think that its environmental performance has improved. The use of normalisation factors highlighted the importance of ensuring improvements per unit of environmental performance were reflected in social investment, financial return, and production, not just in one at the expense of the other.

However, a decision maker must decide whether the performance of the mining operation is good enough – is it sustainable? In some circumstances the indicators help such decision making because there is a clear threshold – critical load of acidic and toxic substances – where excess becomes unsustainable. However, in others, such as resource depletion, land use, social investment, financial return, value judgements must be made. Just because social investment is increasing, for example, is it enough? Conversely, just because land use is decreasing, has it declined enough. Is the trade-off being made compatible with sustainable development? This research project has not attempted to answer these questions, and it is clear that the successful implementation of such a decision-aiding tool depends upon a framework to socially validate the indicators proposed.

5.3.3.6 Extending the Indicators

There are clearly two areas of future work which arise from this project. The first is extending the indicator set ‘horizontally’ into social and economic performance measures. This work has highlighted were these might aid the environmental performance indicators discussed herein – particularly the development of the Index of Sustainable Economic Welfare (ISEW) and the development of measures of social welfare from social investment. The second is extending the indicator set ‘vertically’ away from the corporate apex – the focus of this work-towards site specific needs at the operations level. This requires a sociological approach to understand the specific cultural aspects of the relationship between a community and a mine which this research has not attempted to address.
5.4 Concluding Remarks

In the context of the field of environmental technology, however, this project has helped the portfolio advance current knowledge and has helped future advances contribute to the application of such knowledge. This research has shown that it is meaningful and possible for a global mining company to take a sustainable development approach to decision making, and has supported the argument that sustainable development is consistent with mining, within given parameters. Furthermore, this research has demonstrated that the approach currently taken by the industry to managing the impact of its operations is not consistent with sustainable development.

This research has proposed a framework to be used, and has shown through case-study the implications and requirements for implementation of such a framework. Definitive conclusions about the actual environmental performance of the mining companies in the case studies were not desired, and it is argued that the extent of the assumptions in the methodology used in the case-studies precludes such conclusions being made.

Instead, this research has shown the need for the framework proposed, the need for the sector to co-ordinate its effort to those with an interest in its performance to make decisions about the performance of the actors in the sector, regardless of whether they manage the assets they own, and regardless of whether they manage the utilities which cause impacts related to their operations, in order that any decisions made regarding the environmental performance of the mining industry are made with the principles of sustainable development at the forefront.