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1. Overview

Natural Resources Canada (NRCan 1995) address the sustainable management of mining as part of their public discussion work on sustainable development relating to minerals and metals. They argue that,

“The need to prevent or minimise the environmental impacts associated with mineral and metal operations, such as the production of waste and effluent, is an underlying theme of this paper. Governments, industry and other stakeholders have come to recognise that preventing or minimising the creation of pollution or other environmental problems is often a more efficient and effective strategy for environmental protection than end-of-pipe solutions. The [minerals and metals] industry has made major strides in improving its environmental performance... The fact remains, however, that the environmental impacts of mineral and metal operations, while often localised, can still be substantial if not properly managed” (Natural Resources Canada, 1995, page 36).

The objectives for this project are to examine the extent to which formalising the management of the environmental impacts of mineral and metal operations through the use of emerging standard environmental management systems (EMSs) can help operations move in a direction more consistent with the principles of sustainable development. In the first instance this will be done by examining environmental management systems in the context of a case study - the Borax Group of companies. Borax is a mining to fine chemicals company with mines in California and Argentina and further processing operations in Los Angeles, USA; Widnes, UK; Nules, Spain, and Coudekerque, France. Borax has distribution operations at Rotterdam, Holland; Los Angeles, USA; Runcorn, UK; and Valencia, Spain with research facilities operating in California and in Guildford, UK. The Borax Group is wholly owned by RTZ-CRA.

This project will then go on to look at the management of a specific environmental issue – energy consumption – in the context of the Borax Group’s European operations. Natural Resources Canada identify energy efficiency as one of four components of sustainable operations (along with mine reclamation, metals toxicity and recycling), stating that,

“The mining industry accounts for some 13 percent of total Canadian industrial energy demand. Fossil fuel use has been identified as the major contributor to human generated greenhouse gas emissions, which in turn have been linked to the issue of climate change. At the same time, energy efficiency is an important component of industrial competitiveness.” (Natural Resources Canada 1995, page 44)

This project will assess the extent to which formalised EMSs will focus attention upon such issues, and the extent to which such attention might translate into improvements in environmental performance.
2. The Purpose and Benefits of an Environmental Management System to a Global Mining Organisation.

This section will look at the process by which an organisation adopts its strategic position, the ways in which changes in values in society may influence strategy, the ethical foundation by which these values are formed, the challenges of this value shift for industry, and the way the mining industry has responded to the challenge.

2.1 The Changing Business Environment and The Business Need for Environmental Management

The strategic position adopted by an organisation is based on its perception of its environment, through the analysis of the structure of the markets and industrial areas in which it operates. Many tools exist to do this, and it is not the purpose of this project to discuss these in any detail. Nonetheless, the generic process by which the company arrives at its strategic position is described by Johnson and Scholes (1993):

Figure 1: Steps in Environmental Analysis (from Johnson & Scholes 1993, page 76)

The main drivers of a firm’s strategy relate to those factors which are external to the firm. The strategy of the firm is the way the firm organises its internal structures and systems to respond to, or to anticipate, changes in the external environment. Molina’s (1989) modelling of a socio-technical constituency, developed to illustrate technology policy, can be adapted to show the variety of external forces which can influence the strategic position of a firm. The diagram below shows a central strategy shaped by the limits of the physical world, and driven by the forces arising from the competition and collaboration of various parties such as
financial institutions, international organisations, consumers generally, each with a stakeholding in the strategy and performance of the firm.

**Figure 2: The Socio-Technical Constituency of an Organisation (adapted from Molina, 1989)**

The key issue to consider in this work, then, is the extent to which the development of an environmental management system represents a response to changes in the operating environment of the Borax Group. Any internal drivers, such as a desire for greater integration of environmental management through the Group companies for example, is a means to an end, rather than an end itself, and there will be external drivers encouraging internal changes. One such external influence on an organisation is very complex and yet extremely powerful, that is ‘the values of society’. Johnson and Scholes (1993) introduce this in the following terms,

“Values of society change and adjust over time, and, therefore policies which were acceptable twenty years ago may not be so today. There has been an increasing trend within many countries for the activities of companies to be constrained by legislation,
public opinion and the media. ... Companies which operate internationally have the added problem of coping with the very different standards and expectations of the various countries in which they operate." (Johnson & Scholes 1993, page 158)

Organisations face challenges when there is conflict between the expectations of the various constituents with a stake-holding in its operations. Banks and shareholders will look to maximise the return on their investments, employees will look to maximise their salaries without jeopardising their job security, residents will look to minimise environmental disruption through pollution, government will look to satisfy a wide variety of objectives, suppliers will seek to sell their products to the organisation at the highest price without risking losing their business, whilst buyers will seek to buy the goods and services of the organisation at the lowest price possible.

This, of course, is a gross over-simplification of the situation confronting an organisation, yet already it becomes clear that the objectives of some of the stake-holders will come into conflict. Further, many stake-holders in an organisation will belong to more than one constituency. For example, an individual could be a resident, a buyer, and a shareholder in an organisation all at the same time. The strategy which emerges will have to take into account the strengths of the various forces acting from the stake-holders and seek to find a compromise.

The draft International Organisation for Standardisation (ISO) proposal for its 14000 series of international standards identifies four main reasons why organisations increasingly wish to achieve and demonstrate sound environmental performance as part of their corporate strategy.
1. They may wish to control the impact of their activities, products or services on the environment.
2. They may be faced with increasingly stringent legislation and economic policies devised to foster environmental protection.
3. They may be encountering increasing concern from interested parties on environmental matters, including sustainable development.
4. Environmental reviews and audits which may be carried out by the organisation may not be enough to show that it meets, and will continue to meet, legal and policy requirements. (International Organisation for Standardisation, 1995)
2.2 A Brief Overview of the Ethical Issues involved in Business Responsibility to the Environment

Why is business interested in environmental performance at all? The prevailing view of the essential conflict regarding the environmental responsibilities of business, as discussed by writers such as Chryssides and Kaler (1993) is this, ‘All business, (indeed all human) activity uses resources and has impacts upon the environment. How, if at all, should business act to limit the use of resources and the impact upon the environment?’

One view is that the only ethical responsibility, of any kind, an organisation has is to obey the law. This is the view held by Milton Friedman (1970) and Albert Carr (1968) among others. Friedman argues that an employee, or an organisation, exists as an agent to maximise the profits of shareholders. Any action which does not serve this end is, according to Friedman, positively immoral. As Carr argues, “So long as a businessman complies with the laws of the land and avoids telling malicious lies, he’s ethical. If the law, as written, gives a man a wide-open chance to make a killing, he’d be a fool not to take advantage of it. If he doesn’t someone else will.” (Carr 1968, in Chryssides and Kaler 1993, page 111)

Carr goes on to report the case of a firm manufacturing a well known mouth-wash which was summoned before the Federal Trade Commission for using a cheap form of alcohol, possibly deleterious to health. Carr reports that, “The company’s chief executive, after testifying in Washington, made this comment privately: ‘We broke no law. We’re in a highly competitive industry. If we’re going to stay in business, we have to look for profit wherever the law permits. We don’t make the laws. We obey them. Then why do we have to put up with this ‘holier than thou’ talk about ethics? It’s sheer hypocrisy. We’re not in business to promote ethics. Look at the cigarette companies for God’s sake. If the ethics aren’t embodied in the laws by the men who made them, you can’t expect businessmen to fill the lack.’” (Carr 1968, in Chryssides & Kaler 1993, page 113)

A further argument discouraging organisational and individual actors from changing behaviour on ethical grounds comes from those belonging to the ‘Ethical Egoism’ school of thought. Writers such as Smith (1776), Locke (1722), and Whelan (1989), among others, favour the view that the best way to further the interests of society is to further the interests of yourself (and possibly your kith and kin). Smith argued that, “Each 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 the 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 society. .... By directing industry in such a manner as its produce may be of the greatest value, he intends only his own gain, and he is in this, as in
many other cases, led by an invisible hand to promote an end which was no part of his intention. Nor is it the worse for society that it was no part of it. By pursuing his own interest he frequently promotes that of the society more effectually than when he really intends to promote it. I have never known much good done by those who affected to trade for the public good." (Smith 1776, Book IV Chapter II)

This argument built upon that established by John Locke, who argued that in the long run the interests of individuals would coincide with those of the wider society because all individuals would act to maximise their happiness, and that,

"The necessity of pursuing true happiness [is] the foundation of all liberty ... [and] the government of our passions [is] the right improvement of liberty." (Locke 1972, Page 592)

Whelan applies this argument to the environment, stating that,

"The best way to provide for future generations is to exploit resources, not conserve them. Market forces and human ingenuity will always take care of shortage by providing solutions which leave us better off than before." (Whelan 1989, page 29)

In other words, the market system should operate in the best interests of all, with necessity encouraging the development of new technologies which would make best use of the remaining resources available. However, this concept has been questioned by writers such as Amory Lovins (1976) and Robert Pirsig (1989). Pirsig writes the following,

"What's wrong with technology is that it's not connected in any real way with matters of the spirit and the heart. And so it does blind, ugly things quite by accident and gets hated for that. People haven't paid much attention to this before because the big concern has been with food, clothing and shelter for everyone and technology has provided these. But now where these are assured, the ugliness is being noticed more and more and people are asking if we must always suffer spiritually and aesthetically in order to satisfy material needs. Lately it's become almost a national crisis - anti-pollution drives, anti-technological communes and styles of life, and all that." (Pirsig 1989, page 171)

Lovins argues that,

"Technical fixes, i.e. smarter and more prudent uses of energy, would buy us time without requiring a fundamental change in our attitudes and values" (Lovins 1976, page 72)

The central change in stake-holder values being encountered by the mining industry, along with industry in general, is the increasing awareness that the costs and benefits associated with industrial activity at a global level go beyond western society to affect other cultures, and indeed other forms of life also. This takes our traditional concept of justice, articulated by John Rawls (1973) to mean that,

"Each person is to have an equal right to the most extensive basic liberty compatible with similar liberty for others" (Rawls 1973)

and changes it to mean that things other than persons are to have a right to justice. It is not the purpose of this project to decide how one decides what has a right to justice and what doesn't,
but it is important to recognise that this change in values, nonetheless, will have a great impact on the ways in which industry operates.

This then, is the basis of concepts such as sustainable development and environmental stewardship, whereby society mandates business to exploit natural resources for society’s benefit, but recognises that neither society nor business has a right to act in such a way that they would damage the ability of others to enjoy the natural world and its products, now and in the future. Repetto (1986) defines sustainable development as,

“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 leave future generations with poorer prospects and greater risks than our own.” (Repetto, 1986)

Hawken (1995) expressed the imperative for sustainability in the following terms,

“To create an enduring society, we will need a system of commerce and production where each and every act is inherently sustainable and restorative. Business will need to integrate economic, biologic and human systems to create a sustainable method of commerce ... Our human destiny is inextricably linked to the actions of all other living things. Respecting this principle is the fundamental challenge in changing the nature of business.” (Hawken 1995, page 3)

The ethical foundation of environmental protection is based on values that were developed for humanity, but apply equally to the environment. In terms of ethical duties there are the arguments of Immanuel Kant (1982), who argued that there are certain duties which are universal and that there is a categorical imperative to show respect for others. He argued that one should,

“Act only according to the maxim by which you can at the same time will that it should become a universal law.” (Kant 1982, page 28)

He further argued that one should,

“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.” (Kant 1982, page 70)

There is a categorical imperative not to kill, and yet pollution kills. There is a duty to treat humanity as an end in itself, never as a means only, and yet pollution shows a lack of respect to the environment. Rawls talked about a right to justice, but what of the right of the environment to justice? Locke (1972) and Thomas Jefferson talked about freedom, liberty, and the pursuit of happiness (see Bryson 1994, pages 49 to 51), but pollution restricts the pursuit of happiness as quality of life is diminished.
2.3 The Need for Environmental Management in the Mining Industry

From the point of view of the mining industry, however, it is not so important that one can put forward a moral case for environmental performance improvement, what is of more pressing importance is the way this impacts upon the business environment. Hunt (1994) argues that although in the past the profile of the environment as a general issue in people’s minds has tended to correspond to wider economic circumstances, six key factors have acted to maintain the prominence of the environment as a general issue.

- Scientific evidence of specific aspects of environmental damage
- Increasing public awareness of environmental issues
- Greater satisfaction of basic needs
- Increasingly stringent pollution control measures
- The trend to externalise environmental costs through taxes and charges
- Growing emphasis on environmental matters in education. (see Hunt 1994, page 1)

Hunt suggests that,

“As a result of this growth of environmental concern, companies now face scrutiny of their environmental policies, goals, management practices and performance by a wide range of interests, including:

Legislators and Regulators - UK Government, EC, HMIP, NRA, Local Authorities.

Opinion Shapers - Media, Pressure Groups, General Public

The Marketplace - Trade Customers, Consumers, Competitors

Lenders and Insurers - Banks, Investors, Shareholders, Insurers

Workplace and Community - Employees, Trades Unions, Neighbours, Local Authorities” (Hunt 1994, page 2)

The minerals industry of which Borax is a part has environmental effects from a wide range of operations. These have been summarised by Richards (1996) as shown in Table 1.

Shillito (1994) suggests that, in theory, commercial interests alone should encourage an organisation, or industry, to self-regulate its environmental effects effectively. He suggests that organisations with poor environmental performance risk financial loss, will find it increasingly difficult to get insurance cover for environmental impairment liability, will find insurance cover increasingly expensive, will be unable to protect their corporate image, will be unable to prevent loss of confidence by banks and shareholders, will be unable to protect themselves against excessive regulation, and will be unable to benefit from marketing ‘green products’. (see Shillito 1994, page 1)
### Table 1: Environmental Effects From Mineral Extraction Operations (from Richards 1996, page 88)

<table>
<thead>
<tr>
<th>Process</th>
<th>Examples of Environmental Effects</th>
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<tbody>
<tr>
<td>Soil stripping and storage</td>
<td>Loss of habitats, agricultural land, archaeological features</td>
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<td>Visual effects</td>
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<td>Dust</td>
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<td>Gases from vehicle exhausts</td>
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<td>Effects on stored soils</td>
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<td>Effects on water courses and aquatic organisms</td>
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<td>Energy consumption effects</td>
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<td>Overburden extraction and storage</td>
<td>Land take for storage mounds</td>
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<td>Loss of archaeological features</td>
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<td>Gases from vehicle exhausts</td>
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<td>Energy consumption effects</td>
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<tr>
<td>Dewatering</td>
<td>Drawdown effects: ecological; impacts on water resources</td>
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<td>Discharge effects: on water courses; aquatic organisms; water supply</td>
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<td>Effects on cessation of pumping; minewater discharges</td>
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<td>Mineral extraction</td>
<td>Visual effects</td>
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<td>Noise</td>
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<td>Vibration (from blasting)</td>
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<td>Loss of geological features</td>
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<td>Gases from vehicle exhausts</td>
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<td>Vibration</td>
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<td>Gases from vehicle exhausts</td>
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<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>

Buckley (1991) discusses the financial risks associated with poor environmental performance, arguing that there are at least twelve major forms of financial cost faced by companies as a consequence:

1. Statutory penalties for breaching regulations
2. Forfeiture of assets
3. Clean-up, repair and rehabilitation costs
4. Compensation claims, citizens’ lawsuits
5. Closure by regulatory agencies or court injunctions
6. Upgrading, retrofitting or replacing equipment to more stringent standards
7. Delays in approvals for future projects
8. Lost market share from poor public image or product boycotts
9. Falls in share prices 
10. Higher cost of finance 
11. Reduced credit from suppliers 

The response from the mining industry to this change in the attitudes of its stakeholders has been charted by the environmental supplement, published six-monthly, of Mining Journal, one of the industry’s leading publications. In February 1991 it paraphrased the views of Tim Haddon of Amax Gold,

“Environmental issues have not, historically, been a major concern to miners. Moreover, mining as an industry is perceived to cause environmental damage. It is also an industry which is perceived by the public to resist change.” (see Rosin 1991a, page 1)

Mining Journal reported that the industry was looking at setting up an International Council on Metals and the Environment (ICME) to develop a co-ordinated approach to the many environmental and health-related issues facing the industry. (see Rosin 1991a, ibid.)

In September 1991 Rosin reported for Mining Journal on the proceedings of an international conference held in Berlin, entitled ‘Mining and the Environment’. The conference produced sets of environmental guidelines for the minerals sector and for development assistance agencies, reproduced in Appendix 5 (see Vol.4 APD5). The mineral guidelines form the basis of many environmental policies adopted by mining organisations today. Rosin, however, also noted two unintentional outcomes of the conference. The first issue concerned the difficulty in achieving a compromise in developing countries between environmental concerns and the desire for economic growth. Rosin observed that,

“The Berlin Meeting concluded that, because environmental problems are largely site specific and countries are at different stages of industrial development, each government must be allowed to strike its own balance between economic accelerator and environmental brake. This pragmatic approach overlooks two crucial factors. Firstly, pollution rarely obeys national boundaries and, secondly, neither does public opinion.” (Rosin 1991b, page 1)

The second issue was concerned with, as Rosin put it,

“The woeful inadequacy of the international mining community to set any sort of agenda for the environmental debates mushrooming around the world.” (Rosin 1991b, ibid.)

The mining industry reacted too late to be involved with setting any of the agenda for the Rio Earth Summit and, as the Mining Journal concluded,

“As a result of this inactivity, the mining industry is continually having to react to events rather than invite other organisations to respond to our agenda. ... Unless the mining industry moves onto the offensive, the writing is on the wall.” (Rosin 1991b, ibid.)

By 1992 the cost implications of adverse environmental impact were becoming apparent to the mining industry, with the Mining Journal commenting in August 1992 that,
"One element of a mining company’s operating cost is that which is devoted to safeguarding the environment. This charge has increased as the implications of pollution, in its many guises, have become ever more apparent over the past decade, and legislation has been toughened accordingly." (Rosin 1992, page 1)

Elsewhere, however, there was concern that environmental legislation was no longer driven by analysis of costs and benefits. The Economist led its August 8th edition in 1992 with the leader “Environmentalism Runs Riot” and sounded this cautionary voice,

"Government intervention is essential to make sure that polluters pay the true cost of their dirty deeds. But too much intervention, or the wrong sort, can easily distort the market in ways that do more harm than good. .. When air, water and soil are truly filthy ... the gains to health and happiness from almost any environmental programme will exceed its economic costs. Once the most egregious pollution has been cleaned up - as it has been, by and large, in the rich countries - the iron law of diminishing returns starts to take hold. ... The science, too, may be shaky. It has taken less time for governments to impose tough curbs on power stations that emit large amounts of sulphur dioxide than it has for scientists to become sceptical of the links between sulphur dioxide and the death of forests that was once attributable to acid rain.” (Anon, 1992b, page 9)

Thus the mining industry found itself in a position where the expectations of its stake-holders were shifting, the regulatory regime it was required to meet was becoming ever more demanding, it was marginalised from the policy making process at a global level and was reacting to legislative changes at a local level. What it was not doing, yet, was being involved in driving environmental policy at any level, nor was it having much of a say in national legislation regarding the environment. Coppin (1992) summarised a view that the mining industry was increasingly coming to share, that,

“We pollute our own back yard, or someone else’s, at our own peril. This relationship exists at three levels: at the global level, our relationship with the international community; at the national level, if there are concerns about large-scale or long term pollution; and at the local level, where there are regional and sub-regional local effects.” (Coppin 1992, page 11)

As has been shown, Borax is faced with a rapidly changing external situation with regard to the environment. The case for sound environmental management is double-faceted. The first facet concerns the disadvantages of poor environmental performance, and the second concerns the business advantages to be gained from positive environmental management. The disadvantages have already been discussed. As The Economist put it in 1992,

“So effectively have environmentalists greened public opinion that it takes an unashamed reactionary to question the wisdom of becoming ever greener and cleaner. Most environmental pressure groups are convinced that the environment is so important that standards cannot be set too high, and must be met regardless of cost.” (Anon 1992b, page 9)
2.4 The Need for an Environmental Management System in the RTZ Borax Group

Whilst, compared with industries such as energy production, chemicals manufacture, and transportation, minerals extraction and conversion companies such as Borax have relatively low emissions to the environment, these firms still attract public attention. Richards (1996) suggests that this is due to, among other factors,

"... The continuing need to obtain planning permission to take land out of other uses, to extract minerals and the nuisance effects caused by noise, dust, traffic and visual impacts. Also, the minerals industry is primarily concerned with the extraction, for consumption, of non-renewable resources. It is, therefore, important that the industry pursues high environmental standards in its policies and practices, both for reasons of sustainability and for the benefit of communities affected by minerals operations."

(Richards 1996, page 88)

The importance of these issues to the Borax Group has been recognised by the management of the group, and environmental management within the group has responded positively to the challenge of continual improvement of the quality of the management of environmental, health and safety related matters. There is, however, no formal management system in place for the governance of all environmental, health and safety quality matters within the group. In Section 4 the existing procedures for environmental management for all the group companies will be reviewed (see also Appendices 6 to 11 (Vol. 4 APD6 to APD11)).

The benefits of an integrated EHS quality management system to the Borax Group are many and various. A raft of international standards have been established, or are being established, which address the management of environmental affairs. These will be reviewed in Section 3. The main three standards, however, are the Eco-Management-and-Audit-Scheme (EMAS) being driven by the European Community countries, British Standard 7750 which is driven by the British Standards Institute, and ISO 14001 which is driven by the International Organisation for Standardisation. BS7750 and EMAS are already in use, while ISO 14001 is still in the final drafting stage at the present time. There are, as yet, no standards for integrated environment, health and safety management, but one of the next ISO series; ISO 20000, will address these matters. There is already a British Standard to give guidance on ‘Occupational Health and Safety Management Systems’, BS8800 : 1996, which shows how effective occupational health and safety management systems can be based on the same system elements as ISO 14001. There are some differences between the standards, as will be shown in Section 3.4, but they all embrace principles which an integrated environmental management system at Borax would adopt:

1. A Borax Group environmental, health and safety policy which is compatible with, in the first instance: the Rio Declaration, in the second instance: the mining industry environmental guidelines established at the Berlin Conference, and in the third instance: the environmental policy of the RTZ-CRA Group.
2. Operating company environmental, health and safety policies which are compatible with those guidelines established at Rio, Berlin, RTZ-CRA, and the Borax Group. These policies will be appropriate to the environmental issues encountered at each operating company. For example, operations at Boron, USA, include mining activity, whereas those in Europe do not.

3. A procedure for identifying the significant environmental, health and safety aspects of each of the Borax Group companies’ activities.

4. A mechanism for ensuring that the Borax Group companies can identify the legal requirements of their activities, and for making sure that they are able to keep the requirements current.

5. Environmental objectives and targets which are set according to the environmental policies of the Borax companies, the significant environmental aspects of their operations, and the regulatory framework in which they operate, with compliance with the law as the minimum acceptable standard of performance at any site.

6. An environment management programme to achieve the objectives and targets set by Borax. Responsibility for achieving the targets assigned and the means and time frame for achieving these targets established.

7. The provision of resources to carry out the tasks required to meet the requirements of the Borax environmental policies, including human resources, technology, finance, training.

8. The needs of the Borax organisation for training identified and those people whose work could have a significant environmental impact identified and trained, and the training needs of the work-force for environmental awareness and training in the importance of environmental management, the environmental benefits of improved personal performance, the procedures and requirements of the EMS, and the potential consequences of deviating from the policy and practices indicated by the EMS.

9. A communication system within the Borax Group to transfer information regarding the environmental aspects of operations and the running of the environmental management systems of the group companies across the relevant functions and locations within the group.

10. Emergency action plans to identify potential emergency situations and to respond to them if they arise in order to prevent and mitigate the environmental impact they might have.

11. Systems to monitor and measure the key characteristics of Borax operations which could have a significant environmental impact, and to use measurement and monitoring data to determine whether or not relevant environmental legislation is complied with and whether or not environmental objectives and targets established by the Borax Group companies are being met.

12. Systems to respond to situations where Borax environmental policies and legal requirements are not being conformed to, or where non-conformance is likely to occur.
13. Audit systems to review the working of the Borax EMS to ensure that it is fully implemented and maintained, covering audit scope, frequency, methodologies, and responsibilities for conducting audits and reporting the results.

14. A top management review of the EMS to ensure its continuing suitability, adequacy and effectiveness at determined intervals.

15. All of the above documented fully and kept up to date.

The benefits to the Borax Group of adopting a system based on the principle elements outlined above can be classed as generic or specific. Generic benefits of environmental management systems, reported by Sayre (1996), include the following:

1. Protect human health and the environment from the potential impacts of Borax's activities, products and services.
2. Assist in maintaining and improving the quality of the environment.
3. Meet customers' environmental expectations.
4. Maintain good public and community relations.
5. Satisfy investor criteria and improve access to capital.
6. Provide insurance at a reasonable cost.
7. Gain an enhanced image and market share.
8. Satisfy vendor certification criteria.
9. Improve cost control.
10. Limit liabilities.
11. Provide resource conservation.
12. Provide effective technology development and transfer.
13. Provide confidence to interested parties (and shareholders) that:
   • Policies, objectives and targets are met,
   • Emphasis is on prevention first,
   • Reasonable care and regulatory compliance regularly occur,
   • System design includes continual improvement. (Sayre 1996, pages 24 to 25)

From Borax's point of view some of these generic benefits are far more significant than others. For example, the perception within Borax is that there is no market pressure for a certified environmental management system. However, it would only take one major customer to insist that an EMS be in place and externally certified to change this situation. Likewise, there is no regulatory insistence on certified environmental management systems being in place but, again, this could change.

There has been no guarantee from regulators that the adoption of certified environmental management systems would lead to a relaxation of regulatory pressure on Borax and other companies but, again, this could change. Nonetheless, of greater importance to Borax at the present time would be the benefits of being absolutely sure that the group is meeting the law and has systems in place to ensure that any change in performance will be for the better, since recent evidence is that regulatory environmental controls are becoming more strict.
Further, the documentation of procedures and systems into an integrated management system provides the specific critical insurance against loss of knowledge should an accident befall a senior member of environmental staff. It is absolutely critical that there should be no operational crisis for Borax should the manager responsible for environmental affairs on a site be injured or killed. It will be highly beneficial for the organisation if a system is in place whereby any replacement is able to identify immediately the following:

1. The current operational policy of his site, and how it is linked to the wider policies of the Borax Group, RTZ-CRA, the Berlin Guidelines, and the Rio Declaration,
2. The current significant environmental aspects of his site,
3. The current objectives and targets being pursued at his site, and who is responsible for meeting them,
4. The laws and regulations he must ensure compliance with, as well as any renewal dates he must be aware of, as well as the mechanism for keeping this knowledge current,
5. The measurement and monitoring programmes in place to identify whether objectives and targets, including compliance, are being met and the time scale of such monitoring activity, as well as calibration methods and renewal dates for the equipment,
6. The procedures for reviewing progress towards these targets, and for reporting progress within the organisation,
7. The procedure to follow should an emergency occur,
8. The audit system for his site, when the next audit is, and who is responsible for reporting the findings and following them up,
9. How the management review system works, and
10. How to keep the environmental management system up to date.
2.5 The Benefits and Disbenefits of Registering the Borax Environmental Management System.

Once an environmental management system has been adopted by the group, a decision should be made as to whether or not external certification of this system should be sought. Donald Theissen, director of 3M's Corporate Product Responsibility Department, identifies five main benefits to an organisation in registering their environmental management system to a recognised standard such as ISO 14001. (Theissen 1996)

1. "Evidence of environmental responsibility to stakeholders, including employees, customers, the public and government organisations.
2. Registration may become a condition of doing business for many suppliers, especially in Europe, and probably in other regions such as the U.S., Canada and Japan...
3. Governments are increasingly looking for the type of systematic approach to environmental management afforded by ISO 14001 [and BS7750 / EMAS].
4. While it is generally agreed that conformity with ISO 14001... does not ensure superior environmental performance ... most stakeholders believe that such conformity will lead to environmental improvement and to eventual reduction in a company's regulatory and tort liability.
5. Registration of an organisation's environmental management system to ISO 14001 can be a potential basis for some forms of regulatory relief." (Theissen 1996, page 25)

The last issue requires elaboration. An ENDS Report in March 1996, headed, “Chemical firms use EMAS, ISO 14001 in push for deregulation”, stated that,

"A desire for less regulatory oversight is the main driver for chemical companies to adopt environmental management systems, industry representatives told a conference in March. The sector is mostly reserving judgement about the EC eco-management and audit scheme (EMAS), and seems to be opting for the international ISO 14001 standard.” (Environmental Data Services 1996a, page 5)

In fact, the environmental standards themselves where born in response to fears over ever tightening legislation over environmental performance by industry. In Europe, for example, the European Commission responded to growing awareness in the 1980s among regulators in OECD countries that,

"They were fighting a losing battle by trying to tackle each new environmental problem with end-of-pipe technical fixes. ... In response, the European Commission proposed a regulation that would require manufacturers to put in place management structures - built on regular audits - that would lead them to question the environmental impact of their activities... In addition, companies would be required to publish information about environmental impacts.” (see Patel 1996, page 27)

As Patel (1996) reports, the response from industry in the UK to the prospect of being forced to change operations fundamentally according to terms laid down by the EC rather than themselves was to approach the British Standards Institution to develop an environmental
management system standard, which was to become BS 7750, whilst at the same time lobbying the national and European government that mandatory regulations would be unnecessary if a standard existed for firms to subscribe to voluntarily. (see Patel 1996, ibid.)

One aspect of regulation concerns avoiding the disbenefits of enforced environmental management - it may yet transpire that the European Commission insists that companies register to EMAS or ISO 14001 as part of any consent to operate - but another concerns the potential for actual regulatory benefits from pursuing certification. Sissell (1996) reports that, in the United States, the Environmental Protection Agency (EPA) has suggested that firms with ISO 14000 in place could be able to take advantage of the agency’s audit privilege policy, whereby, among other things,

“That policy gives companies that voluntarily disclose non-compliance an opportunity to take corrective action before fines are levied.” (Sissel 1996, page 30)

Theissen (1996) suggests that,

“Early indications from U.S. EPA and some states such as Pennsylvania and California signify that their regulators might be willing to treat ISO 14001 registrants more favourably than non-registrants. Potential examples of relief include fewer inspections, more or less restrictive permitting, less command-and-control and others.” (Theissen 1996, page 30)

Theissen adds that the existence of a verified management system for a company’s environmental effects could help a company should they receive an environmental enforcement action, since officials could take this into account when determining the penalty.

In Europe Peter Michael Lange, Manager for International Affairs and Environmental Politics at Bayer, who have registered their Dormangen site, with over 55 plants and 8,000 staff, to EMAS, has been quoted as saying,

“We now expect the authorities to ease reporting obligations and permit procedures for companies which have implemented EMAS. If such concessions are not granted, however, EMAS merely becomes an additional burden costing a lot of money. If this becomes the case, my company would be against registering further sites.” (see Environmental Data Services 1996, page 6)

A further benefit of pursuing an environmental management system within Borax concerns documentation. As with BS 5750 and ISO 9000, to which Borax Group companies are already registered, the certification of an environmental management system as meeting the requirements of a particular standard will require comprehensive documentation of practices and procedures concerned with environmental management at Borax.

The principle elements which would form the basis of systematic environmental management at Borax, i.e. policy, environmental impacts, objectives and targets, legal requirements, roles and responsibility, measurement and monitoring, emergency preparedness, internal communication and internal review, would have to be documented in a manner acceptable to an external verifier. The documentation of such practices, however, is actually desirable for improved management of environmental affairs across the Borax Group since it would provide a clear reference point for all those concerned with the management of environmental
issues within Borax, as well as providing an operating framework for someone coming into the activity without any prior experience.
3. The Environmental Management System Standards

3.1 EMAS

3.1.1 The Eco-Management and Audit Scheme

The Eco-Management and Audit Scheme (EMAS) was launched in European legislation (1836/93/EEC “Regulation allowing voluntary participation by companies in the industrial sector in a Community eco-management and audit scheme”) passed in June 1993. Each EU member state was required to implement the scheme by April 1995 (see Lane et al, 1994). Originally, it was the intention of the EC to make registration to EMAS mandatory for the industrial sector, but this was deferred after the introduction of voluntary schemes such as BS 7750.

A consultation document for an Eco-Management and Audit Regulation (EMAR) was released in December 1990, with the EC proposal published in March 1992. The voluntary scheme, which entered into force in the 12 member states at that time in July 1993, one month after adoption by the Council, will be reviewed in July 1998. At that time a decision will be made as to whether or not the scheme should be enforced as a full Regulation.

3.1.2 The Objectives of EMAS

The guiding objective for EMAS is to promote continuous environmental performance improvements within industry by committing sites to a number of requirements:
1. Establish and implement environmental policies, programmes and management systems
2. Periodically evaluate in a systematic and objective way the performance of the site elements
3. Provide environmental performance information to the public.

Lane et al (1994) identify a number of possible objectives for an organisation in joining the EMAS scheme:
1. Showing the community that the company is committed to caring for the environment
2. Acting as a source of motivation for employees
3. Demonstrating the company’s good environmental management to potential investors and insurance companies
4. Using registration in marketing initiatives (see Lane et al 1994, Annex 1)
3.1.3 The Components of EMAS

The system by which these objectives are to be met is illustrated below:

Figure 3: EMAS System Schematic (From Hillary 1993)

As the model shows, there are a number of stages an industrial site must go through in order to achieve full implementation of an environmental management system based on EMAS:

- Environmental Policy
  1. Must commit the company to relevant environmental legislation compliance
  2. Must commit the company to improvement of environmental performance on a continuous basis
  3. Must be documented in writing
  4. Must be adopted at the highest management level
  5. Must be periodically reviewed
  6. Must be publicly available (see Hillary 1993)

- Initial Environmental Review
  Comprehensive analysis of environmental issues, impact and performance of site activities, covering:
1. Assessment, control and reduction of the impact of the activity concerned on the various sectors of the environment
2. Energy management, saving and choice
3. Raw materials management, savings choice and transportation as well as water management and savings
4. Waste avoidance, recycling, reuse, transportation and disposal
5. Evaluation, control and reduction of noise within and outside the site
6. Selection of new production processes and changes to production processes
7. Product planning (design, packaging, transportation, use and disposal)
8. Environmental performance & practices of contractors, subcontractors and suppliers
9. Prevention and limitation of environmental accidents
10. Staff information and training on environmental issues
11. External information on environmental issues.

• Environmental Programme
This outlines the site specific objectives and deadlines arising from the results of the initial environmental review

• Environmental Management System
This must include the following:
1. Environmental policy
2. Environmental objectives and programmes
3. Organisation and personnel
4. Environmental effects register
5. Operational control
6. Environmental management documentation and records
7. Environmental audits

• Environmental Auditing
Environmental auditing of the site activities is intended to cover the same issues as the initial environmental review. EMAS doesn’t require all of the site activities to be audited at exactly the same time, but requires that any audit cycle for an activity is determined by the following:
1. The nature, scale and complexity of the activity
2. The nature and scale of emissions, waste, raw materials and energy consumption and their interaction with the environment
3. The importance and urgency of problems identified by the environmental review or previous audit
4. Any history of environmental problems.
EMAS does insist that the maximum interval between audits should be three years.

• Environmental Objectives
The results of the environmental audits should be used to help management set objectives designed to bring about continuous improvement in environmental performance
• Environmental Statement

Under EMAS sites must publish public environmental statements after it has completed its initial environmental review and established its policy and programme, and thereafter on the completion of each full audit cycle. Simplified annual statements may also be required if significant changes occur within the audit cycle. According to EMAS, the statement must include:

1. A description of the site’s activities
2. An assessment of all the significant environmental issues related to site activities
3. A summary of figures on pollution emissions, waste production, consumption of raw material, energy and water, noise and any other significant environmental aspects, as appropriate
4. Other environmental performance factors
5. A presentation of the company’s environmental policy and the site’s programme and management system
6. The deadline for the next statement
7. The name of the accredited environmental verifier that validated the statement
8. Identify significant changes since the last statement
3.2 BS 7750

3.2.1 The Origins of BS 7750

BS 7750 was formally launched in the UK on March 8th 1995. 20 companies, many of whom had been working on pilot programmes for the standard, received their certificates at a launch ceremony hosted by Michael Heseltine, formerly UK Environment Secretary and then president of the Board of Trade. The standard was the first of the three main standards to be launched, beating EMAS to launch by one month (see Roberts 1995, page 48).

As discussed in the opening sections, BS 7750 was developed by the UK’s British Standards Institution (BSI) after the Institution was approached by European industry to produce a quality standard for the environment which would allow firms to demonstrate their commitment to the environment and to improve their management of environmental issues. A voluntary scheme of this nature was seen as far more desirable than a mandatory scheme based on EMAS and BSI was the chosen organisation based on its experience with BS 5750, which became a blueprint for ISO 9000.

BS 7750 was launched in pilot form on April 6th 1992 (Rothery 1993) and by 1994 had been adopted in the UK, the Netherlands, and Denmark (see Lane et al 1994) Drafting consultants were used by EPC/50, the committee responsible for developing BS 7750, and their brief was to produce a standard for environmental management which must:
1. Be compatible with ISO 9000
2. Be capable of stand-alone use
3. Be applicable to manufacturing, process and service industries
4. Consider the total organisation
5. Consider the total process
6. Be capable of certification
7. Be compatible with national and EC regulations (see Sheldon 1995)

The finished standard adheres to those guidelines, and BS 7750 was successful in encouraging the EC to rethink its strategy. The current version of EMAS is strongly influenced by BS 7750, and the management systems specification of BS 7750 were subsequently accepted as being consistent with those in EMAS.

3.2.2 Objectives of BS 7750

The BS 7750 specification states an intention for the standard to enable any organisation to establish an effective management system, as a foundation for both sound environmental performance and participation in environmental auditing schemes. The standard itself specifies requirements for the development, implementation, and maintenance of environmental management systems aimed at ensuring compliance with stated environmental policy and objectives. (see Rothery 1993)
3.2.3 The Components of BS 7750

BS 7750 is built around a framework of continuous improvement through the execution of a number of key stages, linked into a loop to give a cycle of improvement. Each stage has a number of requirements which must be fulfilled:

- Commitment & Preparatory Review
  1. Commit to the establishment of an EMS as required by BS 7750
  2. Commit to implement the procedures laid out in the EMS effectively
  3. Review legal requirements
  4. Evaluate environmental effects of the organisation
  5. Review existing environmental management practices
  6. Assess previous instances of non-compliance

- Establishment of an Environmental Policy
  1. Must be initiated and actively supported by management at the highest level
  2. Must be compatible with other organisational policies, such as safety and quality, and any parent company environmental policy
  3. Must include a commitment to meet all legal requirements
  4. Must include a commitment to achieve a continual improvement in environmental performance
  5. Must relate to organisation’s activities, products and services, and their respective environmental effects
  6. Must be comprehended, implemented and maintained at all levels in the organisation
  7. Must be made available to the public
  8. Must provide for the publication of environmental objectives

- Organisation and Training of Personnel
  1. Must allocate responsibilities for any individuals involved in activities which can have significant environmental effects
  2. Must identify in house verification procedures
  3. Must appoint management representative for BS 7750
  4. Must ensure appropriate training is given
  5. Must ensure contractors are aware of requirements of EMS

- Determination of Environmental Effects and Compilation of Registers
  1. Must compile register of effects identified as significant by establishing and maintaining procedures for identifying, examining and evaluating the environmental effects, both direct and indirect, of its activities, products and services, and for compiling a register of those identified as significant
  2. Must compile a register of legislative, regulatory and other policy requirements
• Determination of Environmental Objectives and Targets
The organisation must set environmental objectives and targets which ensure legal compliance as a minimum and are based upon consideration of
1. The environmental effects register
2. The financial / business requirements of the organisation
3. The views of relevant interested parties.

• Environmental Management Programme
The organisation must establish environmental management programmes which set out
1. How the targets are to be achieved
2. Who is responsible for achieving them

• Environmental Management Manual and Documentation
The organisation must establish and maintain a manual which:
1. Sets out environmental policy, objectives, targets and programmes
2. Includes key roles and responsibilities
3. Includes interactions between the system elements
4. Includes direction to related documentation
5. Covers abnormal operating conditions and potential emergency situations

The organisation must ensure documents are controlled

• Operational Control
The organisation must ensure effective controls exist for activities which significantly affect the environment

• Environmental Management Records
These must include
1. Register of environmental effects
2. Register of legislative requirements
3. Results of audits
4. Training records
5. Relevant contractor and procurement records

• Environmental Management Audits
BS 7750 requires an audit programme to determine:
1. If the environmental management programme and manual are implemented and conformed to
2. The effectiveness of the EMS in fulfilling the environmental policy

• Environmental Management Reviews
A review is required to ensure the EMS remains suitable and effective.
These stages are linked together into a cycle as shown in Figure 4:

**Figure 4: BS 7750 Management System Schematic**

```
12. Environmental Management Reviews
   ↓
10. Environmental Management Audits
   ↓
  9. Environmental Management Records
   ↓
  8. Operational Control
   ↓
  7. Manuals and Documentation
   ↓
  6. Environmental Management Programme
   ↓
  5. Environmental Objectives and Targets
   ↓
  4. Environmental Effects
   ↓
  3. Organisation and Personnel
   ↓
  2. Environmental Policy
   ↓
  1. Preparatory Review
```

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3.3 ISO 14001

3.3.1 The ISO 14000 Series

ISO 14001 was developed by the International Organisation for Standardisation (ISO) as part of the ISO 14000 series of environmental management systems standards. ISO is the Geneva based non-government organisation responsible for promoting the development and implementation of voluntary international standards. (see Litvin 1996) The most well known of these standards is probably ISO 9000, the widely adopted quality standard. ISO consists of 112 national standards Bodies.

ISO commissioned a committee to guide the ISO 14000 series through from concept to delivery. This committee, Technical Committee 207 (TC207) came into being in May 1993 and included representatives from 41 participating and 14 observer nations. The scope of TC207's effort has been to produce standards which facilitate standardisation in the field of environmental management tools and systems. The scope of effort has excluded:

- Defining test methods for pollutants
- Setting technology standards
- Setting effluent limits
- Setting performance levels
- Standardising products (see Shelton 1996)

TC207 has six sub-committees focusing on organisation related issues, product related issues, and terms and definitions. The three organisation related sub-committees are

1. Environmental Management Systems, based in the UK
2. Environmental Auditing, based in the Netherlands
3. Environmental Performance Evaluation, based in the USA

The three product related work-groups are

1. Life Cycle Analysis, based in France
2. Environmental Labelling, based in Australia
3. Environmental Aspects in Product Standards, based in Germany (see Shelton 1996)

Each sub-committee has a number of work-groups which are each developing one or more standards, as shown in Table 2.
### Table 2: Activities of TC 207 Sub-Committees 1, 2 & 3 (based on Barthel 1996 and Hunt & Johnson 1995)

<table>
<thead>
<tr>
<th>Standard</th>
<th>Area</th>
<th>Description</th>
<th>Committee/ Working Group</th>
<th>Status</th>
</tr>
</thead>
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<td>Environmental management systems</td>
<td>Specification with guidance for use ISO 14001 published 1st September 1996</td>
<td></td>
<td></td>
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<tr>
<td>ISO 14002</td>
<td>Environmental management systems</td>
<td>Guidelines on special considerations affecting small and medium enterprises Preliminary stage - Evaluation of market need currently in progress</td>
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<tr>
<td>ISO 14004</td>
<td>Environmental management systems</td>
<td>General guidelines on principles, systems, and supporting techniques ISO 14004 published 1st September 1996</td>
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<td>ISO 14010</td>
<td>Guidelines for environmental auditing</td>
<td>General principles on environmental auditing ISO 14010 published 1st October 1996</td>
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<td>Audit procedures - Auditing of environmental management systems ISO 14011 published 1st October 1996</td>
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<tr>
<td>ISO 14015</td>
<td>Environmental site assessments</td>
<td>SC 2 / WG 4 Preliminary stage. Scope, content and market need currently being evaluated by WG 4 which meets in October and December 1996.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ISO 14020</td>
<td>Environmental labels &amp; declarations</td>
<td>General principles Committee draft. Publication mid 1998</td>
<td></td>
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</tr>
<tr>
<td>ISO 14021</td>
<td>Environmental labels &amp; declarations</td>
<td>Environmental labelling - self declaration environmental claims - terms &amp; definitions Committee draft. Possible publication early 1998.</td>
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<tr>
<td>ISO 14022</td>
<td>Environmental labels &amp; declarations</td>
<td>Environmental claims - self declaration environmental claims - symbols Working draft. Due to be published 1999.</td>
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<tr>
<td>ISO 14023</td>
<td>Environmental labels &amp; declarations</td>
<td>Environmental claims - self declaration environmental claims - testing &amp; verification methodologies Working draft. Due to be published 1999.</td>
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<tr>
<td>ISO 14024</td>
<td>Environmental labels &amp; declarations</td>
<td>Environmental labelling TYPE 1 - guiding principles and procedures Committee draft. Due to be published mid 1998.</td>
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</tbody>
</table>

The remaining standards are shown in Table 3

### Table 3: Activities of TC 207 Sub-Committees 5 & 6 (based on Sasaki, 1995)

<table>
<thead>
<tr>
<th>Standard</th>
<th>Area</th>
<th>Description</th>
<th>Committee/ Working Group</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISO 14040</td>
<td>Life Cycle Assessment</td>
<td>Principles &amp; practices SC 5 / WG 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ISO 14041</td>
<td>Life Cycle Assessment</td>
<td>Life cycle inventory analysis SC 5 / WG 2 SC 5 / WG 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ISO 14042</td>
<td>Life Cycle Assessment</td>
<td>Life cycle impact assessment SC 5 / WG 4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ISO 14043</td>
<td>Life Cycle Assessment</td>
<td>Life cycle improvement assessment SC 5 / WG 5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ISO 1405x</td>
<td></td>
<td>Guidelines for the inclusion of environmental aspects in product standards</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ISO 14060</td>
<td>Terms &amp; definitions</td>
<td>Guide on the principles for TC 207 terminology SC 6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
ISO 14001, the environmental management systems specification standard, is the only standard to which external certification and registration can be sought. The other standards provide guidance to support the environmental management system.

3.3.2 The Objectives of ISO 14001

The ISO 14001 specification discusses a number of reasons why it feels that organisations may increasingly wish to achieve sound environmental performance and demonstrate that achievement to others:
1. They wish to control the impact of their activities, products or services
2. They face increasingly stringent legislation and economic policies to foster environmental protection
3. They face increasing concern from interested parties, including concern for sustainable development.
4. Reviews and audits may not be enough to show the organisation that it meets, and will continue to meet, legal and policy requirements. (see International Organisation for Standardisation 1995)

ISO 14001 also explains what the international environmental management system standards are intended to be, and what they are not intended to be. Specifically, ISO 14001 is not intended to be used for non-tariff barriers or to change the legal obligations of an organisation; it is not intended to establish absolute requirements for environmental performance, beyond a policy commitment to compliance and continual improvement (in other words, two organisations with similar activities but different performance could both become registered to ISO 14001). ISO 14001 is not intended to guarantee optimal environmental outcomes, it merely states that the implementation of a formal environmental management system encourages organisations to implement the BATNEEC. Also, ISO 14001 does not address occupational health and safety (see International Organisation for Standardisation 1995).

ISO sets out five objectives which ISO 14001 is intended to achieve:
1. It is intended to provide organisations with elements of an effective environmental management system which can be integrated with other management requirements
2. It is intended to assist organisations to achieve their environmental and economic goals.
3. It is intended to be applicable to all sizes and types of organisation
4. It is intended to accommodate diverse geographical, cultural and social conditions
5. It is intended to enable an organisation to establish and assess the effectiveness of procedures to set the environmental policy and objectives, achieve conformance with them, and demonstrate conformance to others (International Organisation for Standardisation 1995). ISO 14001 contains a number of requirements which are designed to help meet these objectives.
3.3.3 The Components of ISO 14001

An overview of the requirements of ISO 14001 will be discussed here. ISO 14001 is driven by the principle of continual improvement, with an environmental policy as a starting point, planning an environmental management system, implementing that system, carrying out checking and corrective action, and holding a formal management review of the system as the elements which can be linked together into a cycle of continual improvement, as shown in Figure 5:

Figure 5: ISO 14001 System Principles

Each section within this cycle has a number of requirements:

- **Policy:**
  1. Must be defined by top management
  2. Must be appropriate to nature, scale and environmental impacts of the organisation
  3. Must include a commitment to comply with legislation and voluntary commitments
  4. Must provide the framework for setting and reviewing environmental objectives and targets
  5. Must be documented, implemented and maintained, and communicated to all employees
  6. Must be available to the public

- **Planning**
  1. Must address the environmental aspects of an organisation
  2. Must address legal and other voluntary requirements to which the organisation subscribes
  3. Must address the mechanisms whereby objectives and targets are set and reviewed
  4. Must address the mechanisms whereby environmental management programmes are implemented and reviewed.
• Implementation and Operation
  1. Must address the establishment of the management structure and the allocation of responsibilities within the environmental management system
  2. Must address the systems for training, awareness and competence of employees and contractors
  3. Must address internal and external communication mechanisms
  4. Must address documentation of the environmental management system
  5. Must address document control procedures
  6. Must address the mechanisms whereby operational control procedures are established, implemented, communicated and reviewed
  7. Must address systems to ensure emergency preparedness and response systems are effective.

• Checking and Corrective Action
  1. Must establish and maintain systems for monitoring and measurement
  2. Must establish and maintain systems for resolving non-conformances and checking and corrective action
  3. Must establish and maintain procedures for management of environmental records
  4. Must carry out regular environmental management system audits

• Management Review
  1. Must review the appropriateness of the environmental management system
  2. Must consider need for changes in the system based on audit results, monitoring results compared with targets, incidents, costs of the programme, stakeholder feedback.
3.4 The Similarities and Differences Between the Systems

As the previous sections have shown, the three standards have much in common. They all require an environmental policy which makes a commitment to continual improvement. However, ISO 14001 is more focused on improvement of the management system rather than actual environmental performance per se, the intention being that improvement in management will bring about improvement in performance. All of the standards stress the need for involvement by senior management and that roles and responsibilities are clearly defined.

The use of objectives and targets is to be found in all three standards, as is the implementation of a management programme to help realise the targets. Operational control procedures are seen as vital to environmental management to help reduce the risk of adverse environmental impacts due to the lack of effective control. Good record keeping is required by all the standards, and training and involvement of the entire workforce are seen as essential. Internal audits are the means of checking the position of an operations and their progress towards targets.

There are however, a number of key differences in the standards which will be discussed here. The first issue concerns the eligibility of organisations to join the schemes. ISO 14001 and BS 7750 are designed to be open to any business sector and allow organisations to decide whether to implement their standard on a site-by-site basis or use the entire organisation as the business unit. EMAS insists that individual sites apply to join the scheme and set up their own management systems, public statements, and certification programmes. EMAS is restricted to the industrial sector, although may be widened in scope at a future date.

All three standards insist upon a policy level commitment to compliance with relevant environmental legislation as a minimum, but BS 7750 also requires a full register of the regulations which apply to the activities of the organisation. ISO 14001 simply requires that a system exists which allows an organisation to keep up to date with legislative requirements.

A major difference between ISO 14001 against EMAS and BS 7750 concerns the documentation of environmental effects. ISO 14001 requires that the organisation set up a system for identifying its 'significant environmental aspects'. In other words, under ISO 14001, organisations must determine which of its environmental aspects could have a significant impact upon the environment, the intention being to focus effort on those environmental aspects which are significant in the first instance, since most environmental benefit would be gained this way.

Under BS 7750 and EMAS, however, organisations must have a full inventory of their environmental effects. BS 7750 defines an environmental effect as, "Any direct or indirect impingement of the activities, products and services of the organisation upon the environment, whether adverse or beneficial."
EMAS makes no reference to indirect environmental effects, but does discuss contractors and communicating with customers on product disposal.

The effects register required by EMAS must consider the following where applicable:
1. Emissions to the atmosphere both controlled and uncontrolled.
2. Discharges to water or sewers both controlled and uncontrolled.
3. All wastes including hazardous waste.
4. Land contamination.
5. Natural resource use including the use of land, water, fuels and energy.
6. Visual impact and the discharge of thermal energy, noise, odour, dust and vibration.
7. Effects on specific parts of the environment and ecosystem.

These effects must be considered under the following conditions:
- Normal operating conditions.
- Abnormal operating conditions.
- Accidents and potential emergency situations.
- Past, current and planned activities.

The second critical difference between the standards concerns external reporting. A core component of EMAS is the environmental statement. The specific requirements of the statement have already been discussed, but to reiterate the principle: The site must produce a public environmental statement upon the completion of the initial environmental review and establishment of the environmental programme, and thereafter upon the completion of each audit cycle, with simplified statements every year where necessary. These statements must be externally verified. BS 7750 has no requirement for formal external reporting but ISO 14001 leaves the decision as to whether or not to report up to the organisation, saying: “The organisation shall consider processes for external communication on its significant environmental aspects and record its decision.”

In other words, the organisation can decide what, if anything, it is going to report externally, so long as it makes a formal decision on the issue.

External verification is a key objective for the eco-management and audit scheme, with both the external statement and the management system requiring verification by an accredited competent authority. Also, EMAS requires certification by a designated National Accreditation Body. Both BS 7750 and ISO 14001 allow self verification of the management system through internal audit and self declaration to conformance with the requirements of the standards, although for full certification the organisation must register their system to the National Accreditation Body, and have their system externally verified to conformance with the chosen standard.
The following table is reproduced from a report in Environment Business Magazine, published in 1995, and provides a summary of the similarities and differences between a number of environmental management systems standards.

**Figure 6: Summary of Components of EMS Standards**

<table>
<thead>
<tr>
<th>MANAGEMENT SYSTEM COMPONENT</th>
<th>ISO 14000</th>
<th>EMAS</th>
<th>BS 7750</th>
<th>ICC</th>
<th>PERI</th>
<th>US CMA</th>
<th>KEIDANREN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Company Policy</td>
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<td>Senior Management Involvement</td>
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<tr>
<td>Review of Impacts</td>
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<tr>
<td>Register of Regulations</td>
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<tr>
<td>Register of Significant Impacts</td>
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<tr>
<td>Allocated Responsibilities</td>
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<td>Objectives and Targets</td>
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<td>Audits (Internal)</td>
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<tr>
<td>Public Statement / Reporting</td>
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<tr>
<td>System Verification</td>
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<tr>
<td>Statement / Report Verification</td>
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<tr>
<td>Commitment to Continuous Improvement of System</td>
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</tbody>
</table>

**KEY**
- 1 Review
- 2 Assess
- 3 To Competent
- 4 By Internal Audit

- Regulation
- Principle
- Compliance
- Requirement
- Authority
- Guideline / Good Practice
3.5 The Response to the Environmental Management System Standards

The response of industry to the introduction of the environmental management system standards has focused on a number of key issues:
1. Which is the best format for the environmental management system
2. Will the introduction of a formal EMS bring about regulatory relief
3. Can environmental management systems be integrated with other systems, such as ISO 9000 / QS 9000 and occupational health and safety.

3.5.1 The ‘Best’ Standard Format for an EMS

There has been much debate on the ‘best’ format for an EMS, with a consensus emerging that EMAS is the more stringent of the three main standards, (see Roberts 1995a, 1995b, 1996; Thayer 1996; Lucas et al 1994; Anon 1995) requiring both a register of environmental effects and an externally verified public statement, whereas ISO 14001 requires neither and BS 7750 only requires the effects register. However, in the USA in particular, the publication of an external statement on environmental performance has caused concern among legal experts that disclosure may expose organisations to litigation.

TC 207 has deliberately avoided contentious issues such as specifying technologies, or insisting upon environmental statements and effects registers, in order to make ISO 14001 more accessible to organisations, but this has exposed the standard to accusations of weakness. A recent article in ENDS articulated concern that many non-government organisations, such as the World-Wide-Fund for Nature, had found the cost of participation in the many technical committees set up under the ISO 14000 series prohibitively expensive. (Environmental Data Services 1996c)

A similar concern was voiced by less wealthy developing countries, with the fear that,

“Supply chain pressures will force them [developing countries] to comply with standards on environmental management and labelling which they had little influence in producing and may not be appropriate for them, and will thus become a barrier to trade with industrialised nations.” (Environmental Data Services 1996c)

Robert Jones, UK Environment Minister was quoted in the same issue of ENDS as saying that standards such as ISO 14001,

“Must be seen to be serving the public and government interest ... It is particularly important that standards are credible and effective. You cannot afford weak standards: that will undermine the case for the voluntary approach.” (Environmental Data Services 1996b)

3.5.2 Deregulation

Much discussion has centred around the possibility for using formal environmental management systems as a basis for industry deregulation, an issue introduced in the opening
section. In Europe, the German Government is advocating the implementation of EMAS, with Sissel & Mullin (1995) reporting that,

"In Germany, many companies are initially focusing on EMAS instead of ISO 14001 because the German government has suggested that rigorous implementation of EMAS could lead it to relax its regulation of industry. It "will give us greater freedom of action with respect to the approval and inspection of our production plants. This opportunity must not be wasted", says Dieter Becher, Bayer’s management board member responsible for the environment." (Sissel & Mullin 1995, page 39)

At the present time it is not known whether or not the environmental management standards will be used as a means for deregulation, or the extent to which EMAS will be adopted as formal legislation within Europe. It is possible that national governments, such as Germany and Holland, may choose to incorporate mandatory environmental management systems into legislation even if the European Union does not.

The choice of environmental management system standard will depend very much on the nature of the business considering a system, but it appears that ISO 14001 will have a greater international appeal whereas EMAS may be advantageous to those industrial organisations which do most of their business within the EU. While EMAS is generally accepted as a more demanding system than ISO 14001, there remains concern over accreditation Councils. Recently, complaints have been made regarding the credibility of verifiers in Germany, with ENDS reporting that,

"While most Member States are said to have adopted similar approaches to both these stages, Germany is claimed to have taken a different route. This, coupled with the rapid uptake of EMAS by German firms, has fuelled concern about its approach." (Environmental Data Services 1995b, page 7)

The main allegations are based on the fact that German verifier examinations focus on theoretical knowledge, rather than a witnessed site inspection as required in the UK, that some German verifications have taken a quarter of the average time required in other countries, and that some individuals accredited in Germany have claimed a greater scope of expertise than entire teams of verifiers in the UK (see Environmental Data Services 1995b).

3.5.3 Systems Integration

There has been much discussion regarding the extent to which environmental management systems could be integrated with existing systems, especially quality systems such as ISO 9000. Sissel and Mullin (1995), suggested that in the USA, organisations in the chemical industry,

"Want to see ISO 14000 integrated as much as possible with ISO 9000 and Responsible Care. In Europe, the proliferation of management programmes and standards in particular, is problematic. In addition to the European Union’s environmental management system standards, individual countries, including the UK and Ireland, have issued their own separate standards. Hopes are high that ISO 14000 will serve as a vehicle for third-party verification under Responsible Care and that it
will evolve into a single standard for a range of management practices that will include health and safety.” (Sissel & Mullin 1995, page 39)

3.5.3.1 Integrating Quality Systems with an EMS

ISO 9000 is a quality assurance system driven by management systems, designed to help firms deliver consistent quality of product or service, through documented procedures and systems. It does not aim to assure consistently high quality, so one could produce concrete life-jackets if one desired, but it does aim to assure a consistent quality of product or service. ISO 9000 has become the international quality standard of choice for many customers and suppliers of goods and services, and many firms appear to be looking for synergy between their existing quality management systems and any environmental management system they may introduce.

Of the three main EMS standards, ISO 14001 is the closest in format to ISO 9000. As Theissen (1995) explains,

“The ISO 14000 EMS standards are analogous to 9000 series in that they are management systems focused, and, while intending to improve environmental results, do not measure or require environmental performance improvement.” (Theissen 1995, page 24)

This is in marked contrast to EMAS, which specifies improvement in actual environmental performance as the goal. In fact, the ISO 14001 specification includes an Appendix which outlines the interaction of the sub-clauses within ISO 14001 with those within ISO 9001, regarding such matters as management responsibility, document and data control, process control, inspection and testing, control of non-conformances, internal quality audits, training, among others.

Arco Chemicals’ executive advisor for EHS, John Master, who serves as the US Chemical Manufacturers Association (CMA) representative on the ISO 14000 technical committees, has been quoted as saying,

“We’ve found that companies that practice both Responsible Care and Total Quality Management are probably 90% to 95% in compliance with ISO 14001.”(Lucas et al 1994, page 33)

DuPont have carried out feasibility work in the integration of environmental management systems with quality management systems. Having spent time examining parallels between ISO 9000 and ISO 14000, Du Pont found that regulatory aspects of ISO 14000 prevent some direct parallels, but that,

“The system elements tend to be similar, and there is opportunity to use or possibly adapt [ISO 9000 systems to ISO 14000 requirements]” (Begley 1995, page 45)

Despite the similarities in format between existing quality management systems such as ISO 9000 and the environmental management systems, particularly ISO 14001 it is essential that a key difference between the systems remains the driving force for implementation, with ISO 9000 driven almost exclusively by customers. The environmental management systems have been driven through by a much wider constituency which, though including customers, is also
strongly influenced by government pressures, lender and insurance pressures, shareholder pressures, pressures from the media and pressure from the local community and the wider community with a stakeholding in the environmental performance of an organisation.

3.5.3.2 Integrating Occupational Health & Safety Systems with an EMS

None of the standards include provisions for occupational health and safety, yet many organisations organise their management in such a way that health, safety and environment matters frequently fall under the remit of one person, with the function often known as an arrangement of the initial letters: SHE, EHS, or HSE. There are frequently benefits from so doing, since issues which relate to the environment are often difficult to distinguish from health and safety issues. Is a toxic release, for example, an environmental or an occupational health and safety issue? After all, the toxin will probably not distinguish between workers and non-workers, or between humans and non-humans. Therefore, it will often make sense for these matters to be managed together. Having separate systems for managing these matters could be highly inefficient, with many overlaps, and the need to audit the systems individually will be much less cost effective than auditing them under a single unified system.

British Standards have launched a guidance standard, BS 8800 : 1996, which explains how to organise an occupational health and safety management system based on two possible approaches: HS(G)65, a guidance publication from the UK Health and Safety Executive on ‘Successful Health and Safety Management’; and ISO 14001. The document discusses risk assessment in the place of environmental impact assessment, for example, using the ISO 14001 format and clauses but applying them to health and safety issues. (see British Standards Institution 1996)

What becomes clear is that although ISO 14001 has excluded occupational health and safety from its scope, there is little in the standard to prevent integration with occupational health and safety management systems. However, there is an issue concerning certification which an organisation must address if deciding whether or not to pursue third party certification of their ISO 14001 based system. This concerns non-conformances within health and safety. Would health and safety management non-conformances, if integrated with an environment management system, put the EMS certification at risk? At this time the position of the National Accreditation Councils on this issue is not known.
3.6 Summary Findings on Environmental Management System Standards

All three of the main standards available to organisations offer a genuine opportunity to improve both environmental management and environmental performance. The benefits will arise in two ways. Having a system up and running will present the clear benefits outlined in the standards, such as better control over activities likely to have an environmental impact, formalised communication systems to ensure information is effectively utilised, monitoring systems to track performance, objectives and targets to provide goals, and a policy which puts into words the role the organisation feels it has in protecting the natural environment.

But there is also benefit to be gained in actually carrying out the processes of review and implementation themselves. This makes people focus on their activities and the gaps in their management of their activities. While it is clear that continuing to implement and operate a system once this is done will help performance improve, it may well be that many improvements in practice arise as a direct result of carrying out an initial review.

Which of the three systems is the ‘best’ is very much a moot point. While being broadly similar in their goals, the standards each have unique features. EMAS, thus far, is restricted to the industrial sector, and its reporting requirements, while appealing to governments and organisations keen on full participation in the management of their activities through complete openness, will not appeal to those organisations keen to avoid providing customers with competitive data, such as energy figures, which will allow the cost of making the product to be compared to the price they are being charged. Furthermore, reporting and external verification will not appeal to those organisations anxious to avoid exposing themselves to litigation through breaches in legislation.

BS 7750 has been accepted by the EU as fulfilling the environmental management system requirements of EMAS, but has no requirements for environmental reporting. It is likely that multinational organisations will simply miss out BS 7750, choosing to register instead to ISO 14001, and may consider EMAS in Europe if it is decided that there is commercial benefit in so doing.

ISO 14001 is likely to emerge as the dominant standard for a number of reasons. Firstly, it is an international standard to a greater extent than EMAS. During the development of the standard, TC 207 included delegates from 41 participating and 14 observer nations (Litvin 1996). This will appeal to multinational organisations keen to implement common systems throughout their operations wherever possible. It also appeals to firms anxious to prove their environmental credentials in an international context.

Secondly, ISO 14001 comes from a successful ‘stable’ of international standards, following the global recognition of ISO 9000, which has become the most widely adopted standard for quality systems. Thirdly, ISO 14001 is generally felt to be the most straightforward of the
standards to implement, given the absence of difficult issues such as the environmental effects register and the external environmental statement.

There are a number of factors, however, which must be considered. Most significant, from the point of view of industry perhaps, will be the response of legislators and regulators to the standards. The extent to which the different standards lead to relaxed environmental legislation may prove critical to business. Likewise, if certification leads to more co-operation from enforcement agencies on non-compliance issues, then this will encourage adoption.

If the EU, or any of the member states, decide to make mandatory adoption of EMAS a requirement, then this will encourage adoption, whether it leads to deregulation or not. It is possible that the environmental system standards could also become non-tariff trade barriers. Firms may find themselves unable to do business in certain countries without certification to one of the environmental management system standards.

The extent to which the standards become necessary for doing business must also be considered. The reaction of customers will be critical. At the present time, it is not clear that consumers are influenced by the presence of standards to a great extent. With the high profile that the systems are currently experiencing, however, it must be accepted that this is unlikely to remain the situation.

ISO 14001 remains vulnerable to accusations of lack of stringency. Its future will depend on the extent to which it gains credibility among non-government organisations and other opinion shapers as this will influence the credibility it gains within business.
4. Review of Existing Company Structures

A key requirement of the project brief is to,
“Review existing company structures, environmental policy and targets...”

It would be possible to carry out this activity from Guildford, by sending requests for information to the various Group companies and then interpreting the results given. However, it has been agreed that this would be unlikely to provide the depth of information required by the project, nor would it give the project the level of understanding of the nature of the Group’s operations which would be required for the formulation of a proposal for an environmental management system which would be acceptable to the Group companies.

Therefore, a site visit programme has been drawn up to enable all of the site operations to be visited and, critically, to allow all of the environmental, health and safety operatives of the Group to have an input into the review process and to ensure that all of the operations were fairly represented. Also, the valuable input of the parent company of Borax, RTZ-CRA would be needed and so their opinions were sought also in a direct interview. The following site visit plan was organised:

15th May 1996: Visit to RTZ Head Office to meet James Stevenson, RTZ Group Environmental Advisor to gather the views of Borax’ sole shareholder.

5th June 1996: Visit to Borax Micro-Milling (UK) to review operations and discuss environmental management practices with Paul Murray, Managing Director, and David Wray, Production Manager in Widnes and Runcorn.

17th June 1996: Visit to Borax Français to review operations and discuss environmental management practices with Jean-Louis Vallin, Operations Manager, Regis Thyot, Environment Manager, and Jean Dufour, Quality and Health and Safety Manager in Coudekerque.

18th June 1996: Visit to Borax Rotterdam to review operations and discuss environmental management practices with Hans Sjouke, Managing Director, and Ron Kouwenhoven, Quality and EHS Manager.

25th June 1996: Visit to Borax España to review operations and discuss environmental management practices with Francisco Torres, Quality and EHS Manager in Valencia and Nules.

11th August 1996: Visit to US Borax to review operations and discuss environmental management practices with Preston
Chiaro, Vice President - Boron Operations, Gerry Pepper, Head of Environmental Affairs, Mike Kirby, Art Beckerman, Dave Parker, Joe Sifke, Dara English, Environmental Affairs Team in Boron (Calif.) and Wilmington (Los Angeles) and Mark Reece, Laboratory Services Manager in Valencia (Los Angeles).

24th August 1996: Visit to Borax Argentina to review operations and discuss environmental management practices with Jorge Rodriguez-Lascano, Managing Director, Ramiro Cornejo-Torino, Regional General Manager, and Pablo Mario Vago, EHS Manager in Buenos Aires, Campo Quijano, Tinclayu, Sijes, Porvenir.

The fieldwork provided a background into the nature of activity at each of the operations, investigated the results of environment, health and safety audits at the group companies, and then looked at the position of the group companies in the following areas:

1. Environmental Policy
2. Environmental Planning
   2.1 Environmental Aspects
   2.2 Legal and Other Requirements
   2.3 Objectives and Targets
   2.2 Environmental Management Programmes
3. Implementation and Operation of Management Control Systems
   3.1 Structure and Responsibility
   3.2 Training, Awareness and Competence
   3.3 Communication
   3.4 Environmental Management System Documentation
   3.5 Document Control
   3.6 Operational Control
   3.7 Emergency Preparedness and Response
4. Checking and Corrective Action
   4.1 Monitoring and Measurement
   4.2 Non Conformance and Corrective and Preventative Action
   4.3 Records
   4.4 EMS Audit
5. Management Review.

These are the five key areas which need to be addressed under ISO 14001 and, as has been discussed in the Environmental Management Systems Standards Section, ISO 14001 is likely to emerge as the system of choice for international organisations such as Borax reviewing an external standard for their EMS. This presented an opportunity to introduce the EHS teams to environmental management systems and to gather their input into the review process for environmental management systems in Borax.
The specific reviews for each of the operations are included as Appendices 6 to 11 (see APD6 to APD11 in Vol.4). The findings from each site review applicable to the Borax Group as a whole are discussed in the next section.
5. Summary of Environmental Management System Components for The Borax Group

The objective of this section is to draw together the observations made relating to individual Group companies into a single summary. Individual Group companies will not be referred to directly in this section, with the exception of Section 5.4.4, which explains that a different methodology for environmental auditing adopted by US Borax operations and Borax Europe operations. The emphasis will be on drawing out the broad patterns which best represent the Group as a whole rather than individual companies specifically. Nonetheless areas where there is a high dissonance between the companies in the Group will be highlighted.

5.1 Environmental Policy

The Borax Group has a comprehensive environment health and safety policy, with a number of clear commitments, including the mission to build from a foundation of legal compliance as a minimum towards continuous improvement in performance. These provide a useful framework to all the operating companies. However, there is no mention of the parent company, RTZ-CRA, nor is there any mention of the Berlin Guidelines, nor any mention of the Rio Declaration.

An ideal policy structure would look something like the following:

1. Operating Site / Company Policy:
   - Sets specific Commitments which provide meaningful guidance to the site specifically for setting specific objectives and targets.
   - Includes a Commitment to observing the principles of the Borax Group environment, health and safety policy.

2. Borax Group Policy
   - Sets specific Commitments which provide a meaningful framework for objective setting within the Borax Group
   - Includes a Commitment to observing the principles of the RTZ-CRA health and safety policy.

3. RTZ-CRA Policy
   - Provides a framework of guiding principles which are relevant to all companies within the RTZ-CRA Group
   - Includes a Commitment to observe the guidelines established in the Berlin Guidelines and/or the Rio Declaration

4. Berlin Guidelines
   - Provides a set of principles which are relevant to all companies in the mining industry specifically
   - Explains the Commitment of the mining industry to implementing the principles of the Rio Declaration.

5. The Rio Declaration
Establishes the Commitment of the United Nations of Earth to pursue policies and practices consistent with sustainable development, among other goals (The Rio Declaration is included as Appendix 14, see Vol.4 APD14)

Any policy which is set at an operational level anywhere within the Borax Group must be consistent with the principles of the Rio Declaration. If not, then it defeats its own objective, i.e. to provide a framework for setting objectives which can be measured to show progress towards meeting the challenges of improved environmental performance, consistent with the twenty-seven principles which form the Declaration at Rio de Janeiro.

There is only one site specific environmental policy at this time, that adopted by Boron Operations in the USA. However, the Group policy used throughout the Borax Group meets most of the requirements of an environmental management system such as ISO 14001 in that:

1. It is appropriate to the nature, scale and environmental impacts of Borax Activities, products and services
2. It includes a commitment to continual improvement and the prevention of pollution
3. It includes a commitment to comply with relevant legislation and regulations, but does not include a commitment to comply with other requirements, such as The Chemicals Industries Association’s Responsible Care Programme in Europe, to which Borax subscribes.
4. It provides a framework, at a Group level, for setting and reviewing environmental objectives and targets
5. It is documented and maintained, but is not fully communicated to all employees in a manner that can be verified.
6. It is available to the public, in so far as it is on public display in administration and visitor centres throughout the Group.
5.2 Planning

5.2.1 Environmental Aspects

Borax does not have a fully documented procedure to identify the environmental aspects of its activities, products and services in order to determine those which have or can have significant impacts upon the environment. In practice, the Group tends to follow legislative direction and the findings of the environmental, health and safety audits. This does not mean that the Group is not aware of the impacts of its activities, nor that these aspects are not considered in setting environmental objectives, merely that the procedures to identify the aspects are not established or maintained.

5.2.2 Legal and Other Requirements

In the most part, the Borax Group is very well positioned in regard to identifying and having access to legal and other requirements directly applicable to the environmental aspects of its activities, products and services. Membership of local and national industry bodies and groups, as well as subscribing to organisations which provide updates and advice on forthcoming legislation are important mechanisms, and the Borax Group companies, as well as the Group itself, participate fully.

5.2.3 Objectives and Targets

The management of objectives and targets in the Borax Group is a key issue. Objectives and targets are set at a corporate level within the Borax Group, based upon legal requirements, significant recommendations for action arising from the environmental audits, and the corporate environmental, health and safety policy. Objectives and targets are also set at a group company level, based upon similar drivers. The key challenge is to ensure effective communication between the Group Centre and the Group companies to make sure that all objectives and targets are effectively set, agreed, and communicated in the first instance, and then effectively monitored, reviewed and revised thereafter.

5.2.4 Environmental Management Programmes

A number of programmes are in place to meet objectives and targets across the Borax Group. Usually these are established in the business plan for each operating company and for the Group, reviewed and revised on an annual basis. They include designation of responsibility for achieving the targets and objectives, and the means and time frame by which they are to be achieved. The range of programmes in place may need to be extended in order to facilitate improved progress towards regulatory compliance in some areas, and towards better or best practice in others.
5.3 Implementation and Operation

5.3.1 Structure and Responsibility

At a Group level roles, responsibilities and authorities are defined, documented and communicated through the Borax Group EHS Management Structure and Responsibilities Memorandum, issued August 1st 1995 (see Appendix 15 - Vol.4 APD15). This sets out exactly how the management of EHS matters across the Borax Group is to be structured, including functional and 'dotted line' relationships.

Individual roles and responsibilities in the individual companies are defined and documented to varying extents. In some companies there is a memorandum following a similar format to the Group Memorandum, outlining the position that all employees have a responsibility for environmental matters and explaining the roles and responsibilities of individuals with specific functional responsibility for environmental affairs.

If a decision is made to implement environmental management systems across the Group then the Group and Group companies must,

"Appoint a specific management representative(s) who, irrespective of other responsibilities, shall have defined roles, responsibilities and authority for:

1. ensuring that environmental management system requirements are established, implemented and maintained in accordance with this standard;
2. reporting on the performance of the environmental management system to top management for review and as a basis for improvement of the environmental management system"

at a Group level and at a Group company level.

5.3.2 Training, Awareness and Competence

The extent to which the Borax Group companies fulfil the requirements of this section of the standard ISO 14001 vary widely.

In essence, companies must,

"Establish and maintain procedures to make its employees or members at all relevant levels aware of:

- the importance of conformance with the environmental policy and procedures and with the requirements of the environmental management system;
- significant environmental impacts, actual or potential, of their work activities and the environmental benefits of improved personal performance;
- their roles and responsibilities in achieving conformance with the environmental policy and procedures and with the requirements of the environmental management system; including emergency preparedness and response requirements; and
- the potential consequences of departure from specific operating procedures.

Despite having documented training procedures in place for ISO 9002 which could be utilised to incorporate environmental training, the emphasis thus far in the Group has been on training
regarding occupational health and safety related matters. As will be discussed later, training is critical to the successful implementation of environmental management systems, but is also essential to improved performance in environmental matters. A number of initiatives are underway at various Group companies to build environmental training into the training programmes for the sites.

5.3.3 Communication

Internal communication systems throughout the group companies themselves are, broadly, well established. Most all of the Group companies carry out regular documented site tours to identify significant environmental and health and safety issues by observation and discussion with operators. Regular management meetings are carried out at all sites, with EHS on the agenda at intervals varying between weekly and monthly.

Staff meetings are also utilised at most of the Group companies to raise environmental concerns and to report on progress to the work-force. Most, but not all, of the operating companies have formal EHS committees, but some have yet to incorporate environmental issues into their health and safety committees. It is important that all such review meetings are properly minuted and documented to provide a means of confirming any actions which were identified or agreed upon.

A key issue which came out of the discussions with the Group companies concerned communication with the Centre of the organisation. It is essential that the reporting requirements and frequencies, together with reporting timings are established, documented and communicated to all relevant function levels. How much information is required by the Centre will depend upon two factors

1. The level of involvement in the management of environmental issues at the Group companies that the Centre wishes to have.
2. The level of involvement in the management of environmental issues at Borax the RTZ-CRA administration wishes to have.

Regarding external communication, it did not become clear during the review process exactly how the Borax Group manages the receipt, documentation and response to relevant communication from external interested parties. The emergency plans clearly describe the roles and responsibilities of various individuals regarding communication during emergency situations and some of the Group companies apply these procedures to all external communication, others do not.

5.3.4 Environmental Management System Documentation

Borax does not have any formal environmental management systems in place at any of its sites and as such there is no specific description of the requirements of the management system and their interaction, nor is there direction to related documentation.
5.3.5 Document Control

The standard of document control across the Borax Group did vary from company to company, but was broadly satisfactory throughout the Group. The document control procedures required by ISO 14001 follow the same principles as those specified for the ISO 9000 quality assurance series of standards. That is to say,

1. Documents must be easy to locate
2. Documents must be periodically reviewed, revised as necessary and approved for adequacy by authorised personnel
3. The current versions of documents must be available at all locations where they are needed to ensure that the management system functions effectively
4. Obsolete documents must be removed from all points of issue and points of use promptly
5. Any obsolete documents retained for legal or knowledge preservation purposes must be suitably identified.

The Group companies have already implemented such document control systems for their ISO 9000 registrations. Such documents as policies, objectives and targets, roles and responsibilities, emergency procedures, operational control procedures, training records, measurement and monitoring documentation, audit protocols, for example, must all be managed in a controlled fashion. Any aspect of the environmental management system which requires a procedure to be established and maintained must be documented and then controlled through these means.

5.3.6 Operational Control

This is an area where there is opportunity for improvement throughout the Borax Group. According to ISO 14001, companies such as Borax must,

"Identify those operations and activities that are associated with the identified significant environmental aspects, in line with its policy, objectives and targets. The organisation shall plan these activities, including maintenance, in order to ensure that they are carried out under specified conditions by:

1. Establishing and maintaining documented procedures to cover situations where their absence could lead to deviations from the environmental policy and the objectives and targets,
2. Stipulating operating criteria in the procedures,
3. Establishing and maintaining procedures related to the significant environmental aspects of goods and services used by the organisation and communicating on of relevant procedures and requirements to suppliers and contractors."

This area is extremely important for effective environmental management and control of risks. At the present time, this is an area where Borax does not perform strongly throughout the Group. An example would be the disposal of hazardous wastes. The first stage is to identify those areas where an operational procedure is needed to safeguard against environmental risk. Waste oil, for example, must be disposed of in a controlled fashion to safeguard against the risk of pollution. Once done, the next stage is to determine what the
procedure should be for disposal of such wastes. The third stage is document, communicate and implement the procedure and to review the disposal of waste oil periodically to determine whether or not the procedure is being followed and whether or not the procedure ought to be changed.

In large part, Borax companies have identified most of the areas where operational control procedures are needed, and, for many of these areas operational best practice has been decided upon. What has not been done consistently across the Group and across individual companies, is the documentation, communication, implementation and review of such procedures.

5.3.7 Emergency Preparedness and Response

This is an area where, for the most part, the Borax Group is well organised and well prepared. According to the supporting guidance notes for ISO 14001 a good emergency plan can include:

1. emergency organisation and responsibilities
2. a list of key personnel
3. details of emergency services (e.g. fire department, spill clean-up services)
4. an internal and external communication plan
5. actions taken in the event of different types of emergencies
6. information on hazardous materials, including each material's potential impact on the environment, and measures to be taken in the event of accidental release
7. training plans
8. testing for effectiveness

Most of the Borax emergency plans cover these issues. Where there is a gap, such as covering only fire type emergencies, or where thought needs to be given to expanding the number or scope of emergency practice drills, the recent audit programmes for US Borax and Borax Europe have picked these up and made recommendations to local management.
5.4 Checking and Corrective Action

5.4.1 Monitoring and Measurement

This is the area with the greatest variation across the Group. Throughout the Group monitoring appeared to be very much with a view to achieving regulatory compliance, rather than with continual improvement as the goal. As regulatory regimes vary widely across the countries and regions in which the Group operates, there was a wide variation in the extent to which monitoring programmes have been developed. Even with this caveat, it was not clear that even the goal of regulatory compliance could be assured given the quality and quantity of information generated by some of the specific monitoring practices.

One of the requirements of a monitoring programme, regardless of whether it is part of a formal environmental management system or not, is to provide sufficient data to provide information which will allow regulatory compliance to be verified. This is a minimum requirement for any monitoring programme in order to provide information which will allow Group companies to verify or initiate corrective action to demonstrate compliance with the Group Policy objective of achieving regulatory compliance as a minimum level of performance.

5.4.2 Non Conformance and Corrective and Preventative Action

This section is linked very closely with the previous section on Monitoring and Measurement. One can only have a meaningful non-conformance action procedure if one has a non-conformance identification procedure, which depends heavily on monitoring operations in the first instance to provide information on whether practices and levels of emissions conform to those set out in the objectives and targets, which also consider legal requirements.

Management review systems throughout the Group are well developed, and the recent audit programmes in Borax Europe and US Borax presented local management with a number of actions, the vast majority of which are being carried out. This suggests that the management procedures to deal with non-conformances, once identified, are effective. There must be concern, however, that there may be some potential regulatory non-conformances which are not always being identified through extensive monitoring and measurement.

5.4.3 Records

The standard of record keeping throughout the Borax Group, for the most part, is of a high standard. Therefore, the development of procedures to cover the identification, maintenance and disposition of environmental records, including training records and audits and reviews has either taken place, is underway, or would not require an excessive amount of effort to initiate and complete.
5.4.4 Environmental Management System Audit

As there is no formal environmental management system in place at Borax at this time there is no audit of the environmental management system specifically. Nonetheless, there are already a number of environmental review procedures in place in the Borax Group. The first is the RTZ-CRA health, safety and environment review. The RTZ-CRA HSE review procedure is included as Appendix 16 (see Vol.4 APD16). Secondly there is the internal audit programme in operation at US Borax. This is a comprehensive programme, fully documented, and the audit programme (Appendix 17 – see Vol.4 APD17) sets out the scope, frequency, methodologies, responsibilities and requirements as required by ISO 14001.

Borax Europe have an audit programme utilising internal resource and external consultants, ERM. These audits have focused on compliance and potential risk of liability issues in the first instance. It has been acknowledged at most sites that the scope of such audits would need to be broadened to bring Borax Europe in to line with the requirements of auditing the EMS with a view to pursuing continuous improvement rather than regulatory compliance alone.
5.5 Management Review

The final step in each revolution of the environmental management cycle is the review of the system. Top management must review the system to ensure that the EMS continues to be suitable, adequate and effective. The review is also used to review the results of audits to determine whether or not changes to policy, objectives, or specific components of the management system are needed to respond to changing circumstances and to strive towards continual improvement. The intervals at which environmental reviews take place vary across the Group companies, but one would suggest that there should be some form of review at least quarterly at the Group company, with a formal review of the environmental management system for each site on an annual basis, consistent with the timing of environmental audits and the annual business reviews.

At a Group level there should be some form of progress review at least bi-annually, with a full review of the environmental management systems and practices on a four yearly basis.
6. Environmental Performance Reporting Requirements

A key objective of any environmental management system is to bring about continual improvement in environmental management, which will provide the framework to bring about improvement in environmental performance. One of the tasks associated with this work is to evaluate the environmental reporting needs of the Group and its parent, RTZ. This aspect of environmental management is critical to the process of continual improvement. The management system must be reviewed for effectiveness at regular intervals.

For senior management to review the systems in place they will require sufficient information about the running of the system and the environmental issues being faced and addressed by the operations to make an informed evaluation of the current situation, and bring about changes designed to move performance towards future objectives and targets. Such information may include audit results and recommendations, comparisons of performance versus targets, any significant environmental incidents, the operating cost of running the programme, and feedback from stakeholders.

It is worth observing that RTZ, the parent company of Borax, will have its own objectives and targets. Just as individual operations must integrate Borax Group goals into their environmental strategies, Borax Group must comply with RTZ needs. This requires good communication. In the setting of objectives, the operations must be made fully aware of any Group level considerations which they may need to make in formulating their business plan. In the reviewing of progress, the accomplishments and challenges of the individual operations must be considered when setting new targets and goals.

The reporting requirements, therefore, go in two directions: operating company to Group (and Group to RTZ), and to operating company from Group (and to Group from RTZ). As far as possible, key individuals from each of these areas should be involved in this communication process, and any objective setting should be made in full consultation with those individuals who are likely to be responsible for implementing the programmes to achieving the objectives.
6.1 RTZ-CRA Drivers

RTZ is driven by a number of factors. Community relations is an important consideration when setting goals for the RTZ Group, since the communities local to the operating sites will be among the first and most heavily affected by any negative environmental practices employed by the sites. RTZ as a group must be in a position to educate interested parties into the lengths the Group companies are going to in order to safeguard their local environment and to contribute to the well-being of their local communities.

Issues of product safety are also important to the RTZ Group, since the Group must be able to reassure interested parties that their products are safe, and where there is any doubt over product safety, all possible measures are being taken to address these issues. Such measures will include working with the scientific and regulatory communities to understand fully the properties of the products and the levels to which precautions may need to be taken in their handling, use, and disposal.

Technical innovation is a mechanism through which environmental performance and operational efficiency in the Group can be improved, and RTZ must strive to employ the best available technology across the Group. Good communication with and between the operating companies will facilitate this process, through sharing of experience beneficial to the rest of the Group. RTZ must also be in a position to respond to institutional pressures from finance institutions and shareholders (and frequently the finance institutions are major shareholders) who are becoming increasingly aware of environmental issues and concerns. RTZ must have the information it needs to ensure any interested parties are reassured of the Group commitment to the environment and the steps being taken to demonstrate that commitment.
6.2 Borax Group Drivers

To a great extent, the Borax Group is faced with exactly the same pressures and drivers as RTZ. Certain environmental issues will be unique to Borax, and there will be other issues faced by other parts of RTZ which are not relevant to Borax, but to a large extent the areas which need to be addressed regarding environmental reporting will be the same. Borax must reassure its shareholders (RTZ) that their environmental commitment and practices justify continued support from the Group. Borax must seek to employ best practices throughout the Group and must ensure reporting systems facilitate this. Borax must be able to reassure local communities and interested parties that they will strive to safeguard their local environments and maintain product safety.

Management review takes place at a number of levels. At each level a different amount of detail will be required to enable effective decision making. It is up to each Group company to determine the amount and type of information it requires about its environmental management system to review its effectiveness properly, this report will focus on the needs of Borax at a Group level.

Senior management at a Borax Group level are becoming increasingly integrated into the executive boards of the operating companies, and with this integration comes an increasing level of personal responsibility for the environmental performance of these companies. For example, Mr. Peter Edbrooke, the deputy chief-executive of the Borax Group, is on the board of directors for Borax Français. This means he is now part of the group ultimately responsible for environment, health and safety at Borax Français. This means that senior managers are becoming increasingly interested in ensuring that there is effective communication and reporting within the Group, and that this communication takes place frequently and regularly.

6.3 Sources of Reportable Information

The establishment of a formal environmental management system at each of the Group companies should assist this process. With the introduction of formalised systems come regular environmental audits of the operating companies, both internal audits and less frequent external audits. At a Group level this information can be utilised to help frame environmental strategy. A full breakdown of all the environmental audit findings may not be helpful to the Group. What would be useful, however, would be a breakdown of any non-conformances identified by audits, plus an action list of how each non-conformance will be addressed.

If the entire Group adopts a formal environmental management system, then this will be of benefit. Audit non-conformance reports will show the areas which the Group is managing successfully, as a whole, and those areas which may be challenging many of the operating companies. It may be that Group level intervention is needed, by organising training programmes or providing resource to help the companies overcome these challenges. The
Group has a responsibility here to ensure that the experience of one company in overcoming challenges within their EMS is shared with other companies should they come to encounter similar challenges.

The other source of information useful here is performance data showing progress towards targets. The benefit of reporting this information is similar to the non-conformance issue: best practice can be communicated and past experience utilised to assist group companies overcome challenges in meeting their environmental objectives if performance data from individual companies shows areas of interest to the Group collectively.
6.4 Integrating the Reporting Systems

The most significant challenge, perhaps, lies in integrating the reporting mechanisms and communication structures for the operating companies, the Borax Group, and the RTZ Group. What is absolutely not required is three different reporting systems, each requiring entirely different information, at different times of the year. A recommended information system would work, perhaps, along the following lines:

Operating companies carry out internal audits every year under a formal environmental management system. There are already quarterly reviews at most of the operating companies for environment, health and safety, together with an annual review which provides the mechanism for helping specify the business plan for each operating company. Monitoring data is gathered on an ongoing basis to track progress against targets. Information regarding actions arising from audits together with an analysis of performance versus targets from the monitoring data are used to draw out possible changes in the environmental programme.

A summary report of any non-conformances, planned remedial actions, key monitoring data, and significant achievements will be made and sent to the Borax Group for review. Significant achievements could include technical initiatives which have helped achieve reductions in energy consumption or emission levels, for example. Other initiatives by the company which are worthy of recognition, such as the production of a company educational or training tool which helps raise environmental awareness at the company, awards by local or national agencies for achievements in environmental, health or safety performance, as examples, could be included in such a report. As stated earlier, the benefit of this is that it helps the Group fulfil a facilitating role in sharing best practice and addressing common challenges.

The Group could then provide advice to the operating company to help the company in its internal review of its environmental performance and the formulation of its strategy to go into its next business plan. The business plan provides the overall framework for environmental objectives and targets, and the programmes which will be introduced to achieve them.

At a Group level Borax would use the information gathered from the summary reports from each company to review progress towards Group objectives and targets, and the effectiveness of the Group management system in achieving them. Information on progress could be provided to RTZ-CRA who could fulfil a similar advisory role for the RTZ-CRA Group companies for the formulation of business plans. RTZ-CRA have their own health, safety and environment review process and any changes made to the Borax Group plans would need to be consistent with any revised RTZ-CRA plan. In turn, once the Borax Group has formulated its proposal for a Group plan, the operating companies can review their proposals for consistency with the Group plans.
6.5 The Need for A Borax Group EHS Function

The critical issue in determining reporting requirements at a Group level for Borax is understanding the actual role the corporate level of environment, health and safety function fulfils. If all the corporate function does is act as a messenger ferrying information between RTZ-CRA and the Group companies, then it is serving no purpose beyond draining resources. Similarly, if a great deal of information on environmental performance is reaching the corporate function but nothing is done with this information, then the corporate function is wasting the time of others in addition to draining resources. The corporate EHS function of a major automotive components group has recently been identified as surplus to requirements, through providing none of the valuable feedback necessary, and is being disbanded as a result (Lawrence 1996).

In fact, the corporate level EHS function has critical role to play in adding value to the Group companies through providing positive feedback into their environmental review process. The corporate function has a role in acting as facilitator for the wider Group. Many environmental issues may affect all of the Group companies, such as the forthcoming EC packaging waste Directive, the advent of a raft of environmental management system standards, benchmarking, performance indicators, for example.

The corporate function should strive to provide advice to the Group companies on the implications of these new challenges and provide technical advice to the Group companies on how best to address them. If technical advice cannot be provided, the corporate function should seek to put the Group companies in touch with experts on the subject. In some cases this expertise may exist outside the Group, and in other cases this expertise may be found in other Group companies, and it should be the role of the corporate function to facilitate exchange of this expertise, where the individual Group companies may not have the resource to devote effort to researching forthcoming challenges to the same extent.

The day to day management of environmental affairs at each operation must be handled locally and the role of the corporate function should not be seen as interfering with this process. If Group companies do see the corporate function as being an obstacle to effective management of their environmental challenges then there is clearly a need for change in the focus of the corporate effort towards facilitating and advising the Group companies in their pursuit of excellence for the Group.
6.6 Proposed Environmental Reporting Structure

With the above in mind, then, the reporting system for the corporate level of the Borax Group should be designed to assist the corporate function in providing positive feedback to the operating companies. As discussed earlier, this would include a comparison of performance against targets: this should aim to show where there are significant deviations between desired performance and actual performance and thus where attention needs to be focused. There should also be a breakdown of the key findings from the internal audits, especially any non-conformances identified and action plans to remedy these non-conformances.

Each operating company will put together a strategy for the following year based on their experiences from the previous twelve months and taking into account any internal and external factors, such as legislative pressures and market pressures, which may encourage a change in focus within the environmental management programme. The corporate EHS function must assist this review process by providing advice concerning long-term changes in strategic environmental issues which they have a responsibility to investigate and disseminate throughout the Group.

Figure 7 illustrates the reporting routes proposed within the RTZ-CRA Group organisations.

Figure 7: Reporting Schematic for EHS Management within RTZ-CRA Group
As the schematic shows, each area has its own management system. The RTZ-CRA Group has a business plan, within which the environmental programme for the year is specified. This programme would be a series of activities at the RTZ-CRA level, which might include assessing the implications of the Basel Convention on transfrontier shipment of waste for the metals industry and disseminating this knowledge throughout the RTZ-CRA Group companies, as a possible example.

Input from the Group companies would come through queries on an ongoing basis, and a formal report, including the 'RTZ-CRA Questionnaire on HSE Performance' for the year, which would provide RTZ-CRA with an understanding of the progress towards objectives being made across the Group and the programmes in place to improve performance. This information would assist the RTZ-CRA Group in providing advice to the Group companies and in formulating any revisions to the subsequent business plan.

The Borax Group would also have an annual plan, consistent with the overall objectives of the parent Group, and which would establish the environmental programme to be adopted at a corporate level. This programme would be specific to issues relating to Borax, such as forthcoming legislative issues, and strategic initiatives such as the investigation of environmental management systems, providing resource to co-ordinate or provide technical expertise to assist with dust studies or audits, as examples. The corporate function would provide input into the Group company environmental programmes by disseminating their findings and responding to ongoing enquiries from the Group companies.

At an operating company level the same management system principles are implemented. The environmental programme helps move the company forwards towards its targets and objectives, and technical advice and assistance should be fed into these programmes from the corporate function. Internal audits and monitoring programmes will provide the operating company with valuable information for its internal review of its management programme, to be included with stakeholder considerations when formulating the subsequent annual plan. Key information on progress together with outline initiatives for the annual plan could be provided to the corporate function. The corporate function would then be in a position to provide advice to the operating companies and to identify areas for action within the corporate environmental programme to add benefit to the operating company programmes.

As mentioned earlier, RTZ-CRA have their own reporting conditions for RTZ-CRA Group companies, with each of the Borax operating companies required to complete a 20 to 30 page EHS questionnaire each year. This questionnaire asks for quantitative data on energy consumption, water management, hazardous waste management, for example, as well as qualitative data on environment, health and safety management practices at the operating companies. In addition, the questionnaire asks for a short report to expand upon any answers provided in the questionnaire, where desired. As far as possible, any Borax Group reporting must incorporate the requirements of RTZ-CRA so as not to overburden the Group companies with demands for reports.

A summary copy of the RTZ HSE questionnaire is included as Appendix 18 (see Vol.4 APD18). The areas shaded in grey are areas which could be added to the existing format to
add value to the information. I.e. annual targets and deviation from targets, rather than just values, and historical data wherever possible to allow progress to be compared with past performance. The questionnaire includes a number of areas which would be duplicated with any internal auditing process for a formal EMS, such as policy, training, managerial responsibilities, etc., which would all be tracked with an internal audit. However, the RTZ questionnaire does not request data on atmospheric emissions such as dust, and data on occupational dust and noise exposure. These could be included in the questionnaire for the Borax Group.
7. Recommendations - Where Should Borax Go From Here?

(see Internal Paper 1 – Recommendations to Borax on the Selection and Implementation of a Formal Environmental Management System – Vol.4 IP1)
8. Discussion on Environmental Management Systems

The activities carried out thus far in this work have fallen into four broad areas:

1. Review why Borax may need to implement an environmental management system (see Section 2)
2. Review the options available to the Group regarding the choice of management system (see Section 3)
3. Review the current situation at Borax (see Sections 4 and 5)
4. Recommend the strategy needed to respond to the Group needs (see Sections 6 and 7).

RTZ has suggested that ISO 14001 could be the favoured system of the parent company, but Borax determined that they must do what is best for their operations, and so recommended a review of the other management system standards.

The review stages of the work determined a number of key issues for an industrial minerals operation such as Borax. Firstly, there is ever increasing external pressure to demonstrate sound environmental performance and management. There is also evidence that industry is acutely aware of these pressures and the need to show consistency in approach, as illustrated by the rise of the environmental management system standards in a relatively short space of time. There is also increasing internal pressure to respond to these pressures in a systematic way. If the Borax Group is to respond to the external pressures it faces, it is finding it needs to organise itself systematically to plan its response and to be able to communicate progress effectively across the Group.

It became clear during the standards review that for an international organisation operating under a variety of legislative regimes regulatory compliance, while essential, is no longer a guarantee of sound environmental performance. It has become clear that some form of international recognition system is required. The most effective system for Borax is ISO 14001, a system which is compatible with its existing ISO 9000 quality system, and one which has been designed to be as flexible as possible specifically with multi-national operations in mind.

A full review of the existing structures for environmental management was carried out through site visits to every operating location across the Group. There was wide variation in the extent to which management of environmental affairs was formalised across the Group, but many key features of sound environmental management were already in place.

The findings of the environmental reviews were circulated to the respective EHS managers and company managing directors of the operating companies and then a formal review meeting was held in Holland. At this meeting the findings of the review were presented, together with recommendations for the implementation of a formal environmental management system across the Group. The delegates, who included representatives of the Borax Europe corporate EHS team, EHS representatives from all of the operating companies, managing directors from the European Group companies, and the European director of operations and logistics, were asked to consider:

- Whether there was a need to implement a formal EMS
• Which of the available standards, if any, was the best format for the Group
• Whether formal certification of any system should be sought
• How the Group should implement any system
• Who would be actioned to carry out implementation

This meeting was critical to the successful completion of this project. The recommendations phase of the project would be evaluated by those in the best position to determine the feasibility of the recommendations: those responsible for EHS at the operating companies.

To revisit the specific tasks associated with the recommendations phase:
1. Design an appropriate environmental management system for the Group
2. Identify what needs to be done to implement the system
   • Identify stages in the process
   • Propose a logical phased implementation programme
   • Evaluate timing and time-scale for implementation

As determined during the review of environmental management system standards and the recommendations for implementation, any EMS design should be compatible with those used internationally, so any self-designed EMS would hinder this objective. Therefore, the system should be ISO 14001 itself.

The key stages for effective implementation of the system are as follows:
1. Review the need for a system
2. Determine the options available
3. Review existing structures
4. Determine proposed strategy for implementation
5. Gain local commitment to the strategy
6. Ensure consistent approach to implementation
7. Implement the system
8. Review progress
9. Determine need for verification based on review

The following decisions and actions were determined through presentation and discussion at the meeting in Holland, 5th-6th November 1996:
1. Borax will implement a formal environmental management system
2. This system will be compatible with ISO 14001
3. The ultimate objective of implementation will be to seek certification, although the current priority is to achieve full implementation of the system.
4. The Group will form an ISO 14001 committee by the end of November 1996 to ensure a consistent approach to implementation
5. The Group companies will assume responsibility for implementing the system at their own operations.
6. External consultants will be used to assist this process. The local companies will contact their own consultants accordingly.
7. Board of Director's commitment to the strategy will be sought at a senior management committee meeting on 5th December 1996.
8. A Group work-shop will be held to finalise the approach to implementation, facilitated by Environmental Resources Management, to be held in the UK on 18th December 1996.
10. Full implementation of the system to be achieved by 31st December 1997.
11. A review of progress and a final decision on the need for full certification to be made at year end 1997.

The meeting in Holland was designed to secure commitment from the operating companies through open discussion and the involvement of all in the decision process. This decision process has enabled timing and time-scales for implementation to be determined.

The reporting needs of the Group and its parent RTZ are much clearer with a formal environmental management system in place than previously. With formal environmental management system come a number of key requirements for environmental policy, planning, impact assessment, regulatory requirements, objectives and targets, responsibility allocation, communication, training, operational control procedures, emergency procedures, monitoring and measurements and internal review, just as examples.

The presence of a formalised auditing programme as part of this management system will provide information on environmental management system performance and highlight non-conformances to be addressed. Key information from this review will provide assistance to the Group in the setting of Group objectives and programmes to support the Group companies. RTZ already has a reporting programme in place which overlaps with the internal audit system needed for ISO 14001 but must be incorporated into the internal reporting system for Borax. The implementation needs and stages and a logical phased implementation programme have been determined through consultation with the Group companies themselves. This has included an evaluation and determination of the timing and time-scales for implementation.

However, there is a fundamental issue which must be addressed in the next stage of this project. Formalised environmental management systems such as ISO 14001, a priori, are concerned with environmental impacts and management. The risk inherent in the use of formalised environmental management systems, however, is they will inevitably bias attention towards those impacts which can be managed, rather than those which are significant. As was seen during the Case Studies of Borax and Rio Tinto in Project Document 2, on-site performance can improve at the expense of off-site performance relating to a particular environmental theme, energy being a case in point. The extent to which environmental management systems alone may not necessarily move operations in a more sustainable path, using the example of energy consumption, will be examined in Section 9.
9. Case Study on the Potential Dissonance Between 'Management' and 'Significance' – Energy Use in Borax Europe Operations

9.1 Context

As the ISO 14001 systems being implemented across the Borax Group develop, it is becoming clear that effective environmental control and improvement is, in great part, dependent on focusing effort on those areas where most environmental benefit can be, i.e. on the 'significant environmental aspects.' As development of the systems has progressed it has become increasingly apparent that a number of issues are significant across the Group.

The significance of different environmental aspects will vary from industry to industry. For example, Lane et al (1994) suggest that for the automotive industry, the most significant environmental priorities will include atmospheric emissions, water use, water discharges, and legislation, whereas for the mining and chemicals industries issues such as the natural environment, solid waste, accidents and emergencies would also be high priority areas.

In the case of the Borax Europe operations there are four main areas of activity that would need assessing for environmental significance. The majority of chemical processing within Borax Europe takes place at Borax Français, which produces boric acid using borate mineral and sulphuric acid. The rest of the European operations are concerned with receiving bulk shipments of borate from either the US mine or the Argentinean mines and then carrying out materials processing in the form of milling, grinding or granulating. Thence the product is packed and shipped on to customers or secondary stock-points.

The environmental aspects connected with these operations include: energy consumption, the use of packaging and any subsequent recovery or re-use, the environmental burden associated with the European logistical activities, noise exposure, dust production and dust exposure. These are the environmental issues that are relevant to all the European manufacturing activities.

However, the relative significance of these aspects has not been determined quantitatively, nor has the relative significance been considered site by site. For example, energy consumption may emerge to be the most significant environmental aspect at a European level, and this would enable targets and objectives to be set and programmes to be put in place to reduce energy consumption across Borax Europe. By contrast, it may emerge that, although energy is the most significant issue for Borax Guildford, for Borax España the most significant issue at their operation is dust.

9.1.1 An Holistic View

It may not be helpful to look at any of these issues in isolation. During the scoping of this work projects related to environmental aspects were reviewed. Currently, a team within the organisation is reviewing packaging. Dust and noise are already issues under review by a
separate team. Logistics is being reviewed, but not on environmental criteria. Energy has been assessed at US Borax, but has not been the subject of a study, on environmental grounds, in Borax Europe.

It may yet emerge that this approach will yield difficulties in terms of optimising environmental performance. For example, changing the packaging material may produce a more environmentally ‘friendly’ package, in terms of using a material which is more easily recycled or used for energy recovery, but this may have knock-on effects for the energy consumption during production or pollution due to a greater reliance on one transport mode.

Nonetheless, the priority for this case-study will be to assess the environmental effects associated with the use of energy and logistics in Borax Europe.
9.2 Objectives

This work aims to determine a baseline for energy consumption and distribution in Borax Europe and the environmental burden associated with these variables. This will require the following:

9.2.1 Issues Overview

An overview of the environmental and policy issues associated with energy consumption and transportation in Europe. Different energy systems have different associated burdens, as will different transport modes, and will be necessary to understand these. Furthermore, it will be helpful to consider policy directions in the European Union that may influence any decisions on internal policy on energy and logistics.

9.2.2 Quantitative Data

9.2.2.1 Requirements

The first step in any decision on possible environmental improvement options is to gather baseline data. In the case of Borax Europe this will require data on energy consumption characteristics at each of the sites (how much energy, of what type, by which source, used in what tasks), the nature of the logistics activity (how much product, what transport media, over what distance, at what utilisation) as a starting point.

9.2.2.2 Existing Data

Some information sources are better developed than others:

9.2.2.2.1 Energy Management

In the case of energy management, the Guildford facility, commissioned in 1994, has an energy management system that monitors electricity and gas consumption across the facility. This system has the capability to monitor consumption in each geographical activity area and each functional activity area, with measurement and analysis every fifteen minutes. By contrast, some of the older systems in Borax Europe will only monitor site consumption in aggregated form.

9.2.2.2.2 Logistics

Information regarding the type of material shipped, the final destination of the material, and the volume of material shipped is currently documented and is available through the logistics functions from the Borax Europe companies.
9.2.2.3 Additional Data Needed

9.2.2.3.1 Energy Audit
There is no functional breakdown of power consumption patterns for all facilities so a physical energy audit will be required to determine the relative energy demands of the cranes, conveyors, boilers, dust filter systems, mills, packing machines, domestic systems, as examples. This will enable attention to be focused on those areas where the greatest proportion of power is consumed.

9.2.2.3.2 Logistics Audit.
Information regarding the exact route taken to arrive at a particular location (in so far as a shipment from Rotterdam to Dublin might go via Liverpool) and the transport mode(s) used will be determined through consultation with logistics personnel at the Group companies.

In the case of road transport, if the location and intermediate destinations are known for a particular customer, then a software package such as AutoRoute Express becomes extremely useful as this software can determine the distance travelled and the breakdown of road-types: motorway/ primary, main, local. Information regarding the actual utilisation achieved by lorries might be more difficult to determine since customers often collect material rather than Borax delivering it. Nevertheless, it should be possible to consult with Borax Europe’s logistics function together with site management to generate a figure that could be used.

9.2.3 Analysis
Once information gathering has been carried out, it will be essential to carry out an analysis that allows the environmental burden of the energy consumption and logistics patterns to be calculated. Hereafter, objectives and targets can be set which provide the greatest scope for reducing the total environmental burden associated with these aspects of the operations. Ideally, any analysis should allow for issues that are being addressed by different projects, such as packaging, to be incorporated into the overall burden calculations at a future date.
9.3 The Environmental Effects of Energy Consumption and Logistics

9.3.1 Energy

"The production and use of energy in all its forms is one of man's key impacts on the environment. Almost all of our energy is currently obtained from non-renewable resources (oil, gas and coal). Energy production and consumption leads either directly or indirectly to emissions of CO₂, SO₂ and NOₓ which contribute to global warming and acid rain. Reduction in energy consumption by industry and commerce will help address these problems." (Lane et al 1994, Annex V)

9.3.1.1 Energy Consumption in the European Union

The European Union uses fossil fuels in the form of coal, oil, and natural gas, plus natural power, as primary sources of energy. Of these fuels, some natural gas is used directly by consumers, but the majority is converted into other forms of energy. Crude oil is refined into a range of petroleum products; some oil is used in power stations to generate electricity, as is coal. Nuclear power stations use uranium to generate electricity via controlled nuclear fission. (UK Environment Agency 1997)

In 1992 European Union member states required 1302 million tonnes oil equivalent of fuel. This requirement is forecast to rise to 1429 million tonnes oil equivalent by the year 2000. The breakdown of sources is shown in Table 4.

Table 4: EU Energy Forecasts 1992 to 2000. All figures expressed as tonnes oil equivalent (from BP 1995)

<table>
<thead>
<tr>
<th>Fuel Source / Year</th>
<th>1992</th>
<th>2000 (forecast)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid fuels (coal / lignite)</td>
<td>319 million tonnes</td>
<td>313 million tonnes</td>
</tr>
<tr>
<td>Oil</td>
<td>628 million tonnes</td>
<td>675 million tonnes</td>
</tr>
<tr>
<td>Gas</td>
<td>247 million tonnes</td>
<td>314 million tonnes</td>
</tr>
<tr>
<td>Nuclear</td>
<td>64 million tonnes</td>
<td>70 million tonnes</td>
</tr>
<tr>
<td>Hydro</td>
<td>40 million tonnes</td>
<td>48 million tonnes</td>
</tr>
<tr>
<td>Geothermal / others</td>
<td>1 million tonnes</td>
<td>1 million tonnes</td>
</tr>
<tr>
<td>EU Total</td>
<td>1302 million tonnes</td>
<td>1429 million tonnes</td>
</tr>
</tbody>
</table>
In Europe, the majority of this fuel is used in the electricity production industry. Table 5 illustrates the breakdown in energy sources for electricity.

Table 5: EU Fuel on Power Sector Forecasts, 1992 to 2000. All figures are expressed in Terawatt hours (TWh) (from BP 1995).

<table>
<thead>
<tr>
<th>Fuel Source / Electricity Produced</th>
<th>1992</th>
<th>2000 (forecast)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>792 TWh</td>
<td>819 TWh</td>
</tr>
<tr>
<td>Oil</td>
<td>224 TWh</td>
<td>210 TWh</td>
</tr>
<tr>
<td>Gas</td>
<td>160 TWh</td>
<td>470 TWh</td>
</tr>
<tr>
<td>Nuclear</td>
<td>785 TWh</td>
<td>836 TWh</td>
</tr>
<tr>
<td>Hydro</td>
<td>465 TWh</td>
<td>504 TWh</td>
</tr>
<tr>
<td>Geothermal / Solar</td>
<td>6 TWh</td>
<td>17 TWh</td>
</tr>
<tr>
<td>Others</td>
<td>27 TWh</td>
<td>54 TWh</td>
</tr>
<tr>
<td>EU Total</td>
<td>2459 TWh</td>
<td>2910 TWh</td>
</tr>
</tbody>
</table>

The use of energy for materials handling, processing and packaging operations, in the form of electricity to run the cranes and conveying systems, gas to fire the boiler furnaces for the borax and boric acid production lines at Coudekerque and diesel oil to drive the forklift trucks used at Rotterdam, together with the gas and electricity needed for the domestic systems such as lighting and heating, could require significant quantities of electrical and direct fuel energy.

9.3.1.2 Environmental Consequences of Energy Production and Consumption.

As outlined earlier, the European Union derives its electrical energy from 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.

9.3.1.2.1 Resource Depletion from Energy Production

Energy sources can be divided into those that are renewable, and those that are non-renewable. Hydropower, solar power, wind power, and tidal power, for example, are all driven by energy sources that are renewable. However, coal, oil, and gas - the fossil fuels - and uranium are non-renewable energy sources and thus electrical generation systems that rely on these energy sources will contribute to resource depletion.

For example, according to UNEP (1997) figures, the majority of electrical power in the EU is derived from fossil fuels (e.g.: UK - 91%, Germany - 87%, Spain - 81%), with the majority of the balance coming from nuclear power. Thus, a key issue arising from energy consumption in Borax Europe will be resource depletion.

9.3.1.2.2 Atmospheric Pollution from Energy Production and Consumption

Whenever atmospheric conditions exist where substances exist in concentrations high enough to cause measurable effects in humans, animals, flora or materials, it is said to be polluted. (see Kiely 1997, page 335)
Power stations are a source for a variety of atmospheric pollutants during electricity generation. These include:

- Particulates
- Carbon Monoxide
- Carbon Dioxide
- Sulphur Dioxide
- Nitrous Oxides
- Volatile Organic Compounds
- Mercury

The environmental burdens of these pollutants will be discussed in detail in Section 9.3.3 - 'Environmental Burdens Associated with Energy and Logistics' - as many of them can also be associated with logistics.

9.3.1.2.3 Water and Land Pollution from Energy Production

Both oil and gas are produced primarily from offshore sites. Oil can enter the environment as a result of the disposal of spent drilling cuttings and from the discharges of contaminated water. Coal mining can involve contamination of water pumped from working mines and also produces large quantities of mining ‘spoil’ (see UK Environment Agency 1997). Nuclear energy production creates radioactive wastes that can have long-term effects on many parts of the environment, while the combustion of coal in power stations produces large quantities of ash.

9.3.2 Logistics

According to Kiely (1997),

"We have made transport vital to both our economic and social well-being since the production and distribution of goods and services are dependent on it. Economic development has always followed the lines of communication. In European Union countries about 10% of the GDP and 9% of employment are generated by the transport industry." (Kiely 1997, page 858)

However, the OECD estimate that the socio-economic cost of road transport, which accounts for over 80% of freight transport, could be as high as 5% of GDP (Organisation for Economic Co-operation and Development 1986).

This section will review the nature of energy consumption in the European Union and the attendant environmental effects associated with this consumption, together with the environmental effects of logistics.

9.3.2.1 Logistics in the European Union

More than six million people are employed by the transportation industry in the European Union (see Europa 1997). In terms of modal share of the different options in transportation: approximately 70% of all non-coastal shipping freight in the European Union is moved by
road, approximately 15% by rail, and 15% by inland waterway or pipeline (Department of Environment Transport and the Regions 1997; Stanners & Bourdeau 1995). There is some variation across member states: for example, in Britain: the road network carries approximately 85% of all freight, while in Germany the share of roads is only 50% (Department of Environment Transport and the Regions 1997), reflecting the varying extent to which alternatives to roads are either available or developed across the EU.

Even when coastal shipping from ports is included in the figures, road remains the dominant mode – at over 60% of all freight in the EU (Department of Environment Transport and the Regions 1997). The trends over the past twenty years or so have shown a dramatic increase in the amount of road traffic. In the case of Great Britain road traffic (including goods vehicles, light vans, buses, cars and taxis) has risen from under 200 billion vehicle kilometres in 1970 to over 400 billion vehicle kilometres in 1994 (UK Environment Agency 1997). The majority of the growth in road traffic has been attributed to increased car ownership (now at 426 cars per 1000 people in the EU) but the trends in road freight are also upward. Environmental Data Services (ENDS) reported the 1997 road traffic forecasts from the UK Government:

“Road transport is set to increase by 38% on current policies... HGV [heavy goods vehicle] traffic is forecast to grow strongly.” (Environmental Data Services 1997b, page 8)

Table 6 outlines the key environmental consequences of the operation of logistics systems.

9.3.2.2 Environmental Consequences of Logistics in the European Union.

The logistics activities of Borax Europe rely on four main modes of transportation: heavy goods road vehicle, inland waterway, rail, and coastal / container vessels. All these modes require hydrocarbon combustion fuels, either as a direct fuel source, or – in the case of the diesel/electric rail network – as a direct fuel source or as part of the fuel mix in the electrical energy supply system. Although the combustion systems used by the different modes will burn fuels differently, giving different proportions of the various environmental effects, the type of effects they will have remains broadly similar.

Table 6 outlines the key environmental consequences of the operation of logistics systems.
Table 6: Typical environmental impacts resulting from transportation operations (from Kiely 1997, page 859)

<table>
<thead>
<tr>
<th>Environmental Subsystem</th>
<th>Impact from Operations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ecosystem</td>
<td>Run-off from fuelling facilities</td>
</tr>
<tr>
<td></td>
<td>Ingestion of lead</td>
</tr>
<tr>
<td>Physical Environment</td>
<td>Vehicle exhaust emissions</td>
</tr>
<tr>
<td></td>
<td>Deposition in water or rain of exhaust emissions</td>
</tr>
<tr>
<td></td>
<td>Noise</td>
</tr>
<tr>
<td></td>
<td>Aesthetic impacts</td>
</tr>
<tr>
<td>Health</td>
<td>Spills of toxic fluids</td>
</tr>
<tr>
<td></td>
<td>HC, CO, NOx, SO2</td>
</tr>
<tr>
<td></td>
<td>Particulates</td>
</tr>
<tr>
<td></td>
<td>Photochemical smog</td>
</tr>
<tr>
<td>Safety</td>
<td>Spills of hydrocarbons</td>
</tr>
<tr>
<td></td>
<td>Traffic accidents</td>
</tr>
<tr>
<td>Socio-economic Environment</td>
<td>Maintenance costs</td>
</tr>
<tr>
<td></td>
<td>Enforcement problems</td>
</tr>
<tr>
<td></td>
<td>Impact on local employment</td>
</tr>
</tbody>
</table>

Many of these effects are similar to those seen in the breakdown in the environmental effects of energy – since they both involve hydrocarbon combustion systems. These will be discussed in greater detail in Section 9.3.3 - ‘Environmental Burdens Associated with Energy and Logistics’ - to avoid duplication. However, there are some aspects to logistics that are specific.

9.3.2.2.1 Lead

As a pollutant, lead is a systemic agent affecting the brain. According to Porteous (1993),

“It has been suggested that it [i.e. lead] is associated with mental retardation and hyperactivity in infants.” Porteous 1993, page 222)

Whitelegg (1988) adds that lead accumulates in persons who are exposed and the main source of lead pollution is the petrol engine motor vehicle.

9.3.2.2.2 Noise

According to Kiely,

“Traffic noise can interfere with speech communication, can disturb sleep and relaxation and interfere with the ability to perform complex tasks. Surveys in many countries have shown that traffic noise is one of the principal environmental nuisances in urban areas.” (Kiely 1997, page 861)

The disturbing features of traffic noise tend to be its general level and its variability with time, (see Porteous 1993, page 322) with the noise generated by a stream of traffic dependant upon:
1. traffic volume and speed
2. traffic composition (percentage of heavy goods vehicles)
3. road gradient
4. traffic flow conditions (free flowing or stop-start)
5. road surface type and irregularities (see Kiely 1997, page 862)

9.3.3 Environmental Burdens Associated with Energy and Logistics

9.3.3.1 Volatile Organic Compounds
These include hydrocarbons (approx. 50%), ethylene oxide, formaldehyde, phenol, phosgene, benzene, carbon tetrachloride, chlorinated fluorocarbons (CFCs) and PCBs. Many of these are highly reactive and can lead to the formation of photochemical oxidants. They can react with nitrous oxides and oxygen in the atmosphere with sunlight to produce smog and aerosol pollution (see Kiely 1997, page 348).

1992 figures from the European Community suggest that road transportation is responsible for 26.7% of VOC emissions, while solid fossil fuel mining accounts for 13.3% and combustion industries and heating systems for commerce, residential and institutional buildings accounts for under 4% (see Stanners & Bourdeau 1995, page 331). The gas distribution industry contributes a further 8.3%. Between them, then, logistics and energy systems of Borax Europe rely on services which could account for as much as 52% of European VOC emissions.

9.3.3.2 Carbon Monoxide
Carbon monoxide is a poison that can decrease the oxygen carrying capacity of the blood. Carbon monoxide concentrations of 30ppm for eight to twelve hours have been associated with impaired psychomotor performance and reduced visual acuity, and with increased physiological stress to individuals with heart disease (see Whitelegg 1988).

Carbon monoxide is a product of incomplete combustion of carbon based fuels - where CO is produced instead of CO₂. Approximately 70% of human based carbon monoxide comes from mobile sources; predominantly automobiles, with power stations and domestic heating systems being other sources (see Kiely 1997, pages 337 and 341).

According to Porteous (1993),

"In busy streets the carbon monoxide concentration can rise to 15 to 20 parts per million (PPM); over 100 PPM have been measured in London." (Porteous 1993, page 25)

9.3.3.3 Sulphurous Oxides
Sulphurous oxides such as sulphur dioxide (SO₂) are released from both anthropogenic sources (90%) such as power stations, traffic, oil refineries, waste incineration plants and from natural sources (10%) such as volcanoes, sea spray, rotting vegetation, plankton (see Blurden & Reddish, 1996).

Sulphurous oxides are synergistic in combination with smoke. Together they affect the respiratory tracts and about 1% of the population encounters bronchial spasms at
concentrations between 300 and 500 micrograms per cubic metre (see Porteous 1993, page 353). In addition to direct health effects, sulphurous oxides play an important role in the formation of acid rain, as will be discussed in Section 9.3.3.5.

The proportion of anthropogenic sulphur dioxide from various sources varies across the EU, Community figures from 1985 suggest that 66.3% of EU SO\(_2\) emissions were related to energy production, and a further 19.2% related to energy combustion processes, whereas only 2.9% of SO\(_2\) releases were related to road transportation (see Statistical Office of the European Community 1993, page 392).

9.3.3.4 Nitrous Oxides

Nitrous oxides react chemically with hydrocarbons to develop photochemical oxidants. Nitrogen dioxide is mainly a secondary pollutant, the majority of which is formed in the atmosphere as a result of the chemical interaction of nitric oxide - emitted from combustion processes - with ozone and other oxidants. Some nitrogen dioxide is emitted as a primary pollutant from vehicle exhausts. It is associated with increased incidence of acute bronchitis in infants and young children, and acute respiratory disease in all parts of a family. These are associated with nitrogen dioxide levels from 0.06 PPM to 0.08 PPM over a six-month period (see Whitelegg 1988).

In fact, transportation is the predominant source of nitrous oxide pollution, with 1985 EU figures suggesting that road transportation accounts for 53.6% of NO\(_\text{x}\) emissions, energy production accounts for 30.7%, and energy combustion 8.8% (see Statistical Office of the European Community 1993, page 392). As with sulphurous oxides - a significant environmental effect is acid rain.

9.3.3.5 Acid Rain

According to Porteous (1993),

"Most rainfall is slightly acidic due to the carbonic acid from the carbon dioxide content of the atmosphere, but ‘acid rain’ in the pollution sense is produced by the conversion of the primary pollutants sulphur dioxide and nitrogen oxides to sulphuric acid and nitric acid, respectively." (Porteous 1993, page 2)

Mannion (1992) describes the processes involved in the formation of atmospheric acids:

- Sulphurous and sulphuric acid

SO\(_2\) is emitted from natural and anthropogenic sources and dissolves in cloud water to produce sulphurous acid:

\[
SO_2 + H_2O \rightarrow H_2SO_3 \leftrightarrow H^+ + HSO_3^-
\]

Sulphurous acid can be oxidised in the gas or aqueous phase by various oxidants:

SO\(_2\) → oxidant → SO\(_3\)
Aqueous sulphur trioxide forms sulphuric acid:
\[ SO_3 + H_2O \rightarrow H_2SO_4 \leftrightarrow H^+ + HSO_4^- \leftrightarrow 2H^+ + SO_4^{2-} \]

- Nitrous and nitric acids
NO and NO\(_2\) are produced by combustion processes and lightning. They are involved in many chemical processes, some of which may generate ozone in the troposphere, causing photochemical smog:
\[ NO_2 \rightarrow \text{light} \rightarrow NO + O \]
\[ O + O_2 \rightarrow O_3 \]

In addition, nitric acid and nitrous acids may be produced:
\[ 2NO_2 + H_2O \rightarrow HNO_3 + HNO_2 \]

Porteous illustrates the acid rain cycle in Figure 8.

Figure 8: The Acid Rain Cycle (from Porteous 1993, page 3)

9.3.3.5.1 Effects of Acid Rain
Although the damage done by acid rain is complex, the main effects include the leaching or minerals such as 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.

A forecast reported in 1990 stressed that,
“Acid Rain will cost Europe 118 million cubic metres of wood - worth £16 billion - every year for the next century... If emissions of sulphur, nitrogen oxides, and ammonia are not reduced beyond targets agreed by the EU states, losses will equal thirty times the amount of British timber output per year.” (Bown 1990, page 17)

The University of East Anglia and Environmental Resources Group reported in 1991 that,
“In Eastern and Western Europe acid rain causes £200 billion to £600 billion worth of damage every year to lakes, forests, buildings and human health.” (Anon 1991, page 16)

9.3.3.6 Carbon Dioxide
Carbon dioxide is a normal component of the atmosphere, present at about 0.03%, and is essential for plant growth (see Kiely 1997, page 360). Thus it is not a pollutant in the same sense as other emissions discussed this far. It is produced by the complete combustion of carbon containing materials, by decay organisms such as aerobic decomposers, by fermentation, and by the action of acid on limestone. It is exhaled by plants and animals and utilised in photosynthesis in the carbon cycle. (see Porteous 1993, page 51)

Sources of carbon arising from human activity include fossil fuel combustion and deforestation - which account for an estimated 5.4 billion tonnes and 1.6 billion tonnes respectively per annum. (see Mason 1992) The UK Department of Environment, Transport and the Regions estimate that in 1995 transportation accounted for 25% of the fossil fuel related carbon dioxide emissions, an increase from 12.5% in 1970. (see Department of Environment Transport and the Regions 1997)

In fact, the volume of carbon mobilised by human activity is fairly small when compared with natural carbon processes. Figure 9 illustrates the global carbon cycle.
9.3.3.6.1 Global Warming

If anthropogenic sources of carbon dioxide represent such a small proportion of the total in the carbon cycle, why should they be classified as an environmental burden associated with Borax Europe activities? An explanation of the principles of global warming will be required in order to understand the significance of these carbon emissions.

9.3.3.6.1.1 The Greenhouse Effect

According to UNEP (1998),

"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." (UNEP 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 (Anon 1996). 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.

9.3.6.1.2 Man-made Enhancement of the Greenhouse Effect

Mason (1992) summarises the issue:

“The greenhouse effect is an essential key controlling factor in the climate of our planet. If there were no greenhouse gases, water vapour and carbon dioxide, the surface temperature of the planet, the average surface temperature, would be -19°C. It is actually +15°C, so there is 34°C of warming due to the greenhouse effect and without, this would be a frozen, lifeless planet. The concern, of course, is that man, by putting additional greenhouse gases into the atmosphere, may be enhancing the natural effect.” Mason 1992, page 8

According to Montague (1992),

“There are four kinds of greenhouse gases: CO₂, methane, nitrous oxide, and CFCs or chlorofluorocarbons. The main culprit is CO₂, and the greenhouse potential of the other gases is often expressed as ‘CO₂ equivalents’. When the warming effect of all four gases is added together today and translated into CO₂ equivalents, we have 425 PPM of CO₂ equivalents in the atmosphere, a 55% increase since 1750. Actual CO₂ is now 356 PPM and the remainder is other greenhouse gases.” (Montague 1992)

Table 7 illustrates the growth in greenhouse gas concentrations since 1765:

**Table 7: Global Warming by Greenhouse Gases in 1990 Relative to 1765 (based on Mason 1992, page 9)**

<table>
<thead>
<tr>
<th></th>
<th>CO₂ (PPM)</th>
<th>CH₄ (PPM)</th>
<th>N₂O (PPM)</th>
<th>CFC₁₁ (PPM)</th>
<th>CFC₁₂ (PPM)</th>
<th>HCFC₂₂ (PPM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1765 Concentration</td>
<td>279</td>
<td>0.79</td>
<td>0.285</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1990 Concentration</td>
<td>354</td>
<td>1.72</td>
<td>0.31</td>
<td>0.28 *10⁻³</td>
<td>0.48 *10⁻³</td>
<td>0.32 *10⁻³</td>
</tr>
<tr>
<td>Increased heat flux (W/m²)</td>
<td>1.5</td>
<td>0.42</td>
<td>0.1</td>
<td>0.06</td>
<td>0.14</td>
<td>0.08</td>
</tr>
<tr>
<td>% Contributions</td>
<td>66</td>
<td>18</td>
<td>4</td>
<td>12</td>
<td>12</td>
<td></td>
</tr>
</tbody>
</table>

The table highlights the differences in potency of the various gases, with CFCs being the most potent - giving them a 12% contribution to the increased heat flux effect despite their very low relative concentration.

Opinions vary greatly about the likely consequences of global warming, the rate at which it will happen etc., but it is not the purpose of this report to provide a critique of the entire global warming debate. Many feedback systems exist within the earth’s climate systems, which can make it difficult to predict exactly what will happen. However, it is possible that the relatively small contribution to the greenhouse system made by anthropogenic CO₂
emissions could be enough to move the energy balance away from equilibrium and cause mean temperatures on the earth to rise sufficiently to disrupt the atmospheric and hydrological systems upon which we depend.

9.3.4 Summary on Environmental Effects

It becomes clear that the use of the various energy sources in the processing operations at Borax Europe and the use of various modes of transport in the distribution of the processed product will have an environmental effect. The effects are likely to be felt at a local level and at a global level.

Local consequences from pollution such as lead, nitrous oxides, carbon monoxide, VOCs and sulphurous oxides will occur in both human and non-human environmental systems as the pollutants disrupt natural processes.

The global consequences of energy and logistics include global resource depletion and global pollution. The two major transboundary pollution issues that have been discussed here are acid rain and global warming, which are caused by a number of the pollutants discussed acting individually and synergistically.

These environmental effects provide a suitable justification for action within Borax Europe to ensure that the energy systems utilised in the processing operations are optimised. In this case this will require that:

- The total energy requirement is minimised
- The energy systems utilised to meet this minimised requirement are the least polluting option wherever possible.
9.4 Policy Issues

The wide ranging environmental effects associated with the use of energy and transportation provide a convincing case for action in their own right. Nonetheless, it must be recognised that there are a number of regulatory pressures that provide continuing impetus in the movement towards reduced environmental impact from energy and logistics. Many of these pressures will only be felt indirectly by Borax. For example, restrictions on emissions from power stations is an obligation which must be met by the electricity generating industry. However, as a customer of this industry Borax will recognise that any increases in costs at the utilities may be passed on to customers. In the case of logistics, however, some regulatory pressures will be felt more directly, since taxation on diesel will involve cost increases for purchasers.

As has been illustrated, there are a number of atmospheric pollutants released by the use of fuels in production and logistics activities. Effects can be felt both locally and globally.

9.4.1 Global Pollution Policy

The United Nations, through the UN Environment Programme (UNEP), is the planetary body responsible for global environmental issues. The European branch of this organisation is the UN/ECE Environment and Human Settlements Division. The major conventions and protocols on transboundary atmospheric pollution, in chronological order of convention, are as follows (see UNEP 1996):

   - The Protocol on the Reduction of Sulphur Emissions or their Transboundary Fluxes by at least 30 per cent, Helsinki, 1985.
   - The Protocol concerning the Control of Emissions of Nitrogen Oxides or the Transboundary Fluxes, Sofia, 1988.
   - Note: In 1995, the Executive Body for the Convention initiated the preparation of three new protocols on the following pollutants:
     - Nitrogen compounds and related substances
     - Persistent organic pollutants (POPs)
     - Heavy metals

2. The Convention on Environmental Impact Assessment in a Transboundary Context, Espoo (Finland), 25th February 1991

In addition to these conventions, The Intergovernmental Panel on Climate Change (IPCC), helps set the agenda for global environmental policy. The most recent addition to the global Protocol list is the Kyoto Protocol, December 1997. ENDS reported in December 1997 that, “The global community took its biggest step yet in responding to the threat of climate change by agreeing a Protocol to limit greenhouse gas emissions at a meeting in Kyoto, Japan, on 1st to 11th December. Developed nations must cut their emissions by 5% below 1990 levels, and by 30% below projected levels, by 2008-12. But it may be another two years before rules on issues which were set aside in Kyoto are finalised, the size of the loopholes in the Protocol becomes clear, and the strength of the signal to governments and businesses to introduce more energy-efficiency policies and products can be measured.” (Environmental Data Services 1997c, page 16)

9.4.2 European Union Policy

EU Policy direction is strongly influenced by global trends outlined above, and is coordinated through the Directorates General. In the case of policy relating to transport, energy and the environment, two Directorates General; DG VII for transportation, and DG XI for Environment, Nuclear Safety and Civil Protection, help set the agenda -in the form of the Environment Action Programmes - for European Community policy which is subsequently implemented by the Member States.

9.4.2.1 European Pollution Policy

According to DG XI (1998),

“In proportion to its size and population, Europe is one of the worst offenders when it comes to air pollution and climate change. The [European] Commission has already launched a number of initiatives to correct this situation, focusing particularly on the following areas:

- protecting the ozone layer (by CFC reduction)
- resisting emissions of acidifying substances (SO\textsubscript{2} and NO\textsubscript{x})
- resisting climate change and reducing emissions of greenhouse gases (CO\textsubscript{2}, CH\textsubscript{4} and N\textsubscript{2}O)
- reducing the concentration of lead, asbestos, VOCs and ozone in the atmosphere (see Directorate General for Environment, Nuclear Safety and Civil Protection 1998).

The Fifth Environment Action Programme was launched by the European Commission in February 1993, targeting the environmental impacts of agriculture, energy, industry, tourism and transport, to cover activities from 1992 to 2000.
Table 8, published by DG XI, summarises progress.

**Table 8: Objectives and Results on 5th Environmental Action Programme Efforts on Air Quality**

<table>
<thead>
<tr>
<th>Pollutants</th>
<th>Objective</th>
<th>Main Directives</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fine particles and heavy metals</td>
<td>70% reduction in emissions of cadmium, mercury and lead by 1995</td>
<td>IPC (Integrated Pollution Control Directive) Several Directives targeted at motor vehicles</td>
<td>North Sea States achieved 50% reduction by 1995. No data available for other states. Industrial particle emissions fell sharply, but emissions from road traffic rose.</td>
</tr>
<tr>
<td>VOCs</td>
<td>30% reduction by 1999 from 1990 levels</td>
<td>Directive (94/63) on oil storage and distribution</td>
<td>Objective unlikely to be achieved</td>
</tr>
<tr>
<td>Ozone</td>
<td>No infringement of WHO limits</td>
<td>Directive (92/72) on ozone pollution of the air</td>
<td>Objective unlikely to be achieved, but ozone concentrations could fall by 40-60% by the year 2000.</td>
</tr>
<tr>
<td>Dioxins</td>
<td>90% reduction by 2005 from 1985 levels</td>
<td>Directive (94/87) on the incineration of hazardous waste</td>
<td>Origin of emissions remains unclear Little Data Progress will depend strongly on quality of smoke cleaning</td>
</tr>
</tbody>
</table>

9.4.2.1.1 New EU Framework Directive

The EU has drafted a new framework Directive setting out a common strategy towards air quality to protect public health and protect eco-systems with a number of aims:
- To ensure the uniform evaluation of air quality
- To establish limits and warning thresholds for thirteen hazardous substances
- To tell the public which areas suffer from high air pollution and to notify them when safety limits have been breached.

This Directive (96/62 EEC), is expected to be followed by a series of sub-Directives for each pollutant class to replace existing legislation.

9.4.2.2 Policy Measures for the Transport Network

In addition to this work on pollution lead by the DG XI, the Directorate General for transport - DG VII- is examining policy measures aimed specifically at transport. DG VII has noted that since the present Commission took office in January 1995, it has put special emphasis on the need to create better balance between road and other means of transport so as to reduce pollution and congestion, accidents, and increase safety. It has published a Green Paper on Progress Towards Fair and Efficient Pricing, examining ways in which transport prices can better reflect the costs to society of pollution, congestion and accidents (Europa Information Service 1997b).

This discussion paper, published in December 1995, included the following suggestions to curb congestion, accidents, and pollution:
1. Adjusting existing Community legislation on road charges of Heavy Goods Vehicles in order to make progress towards fair and efficient pricing;
2. Electronic kilometre charges based on infrastructure damage and possibly other parameters (HGV);
3. Road tolls in urban areas;
4. Differentiated fuel taxes reflecting differences in fuel quality;
5. Differentiated vehicle taxes linked to a vehicle's environmental / noise characteristics (noisy, polluting vehicle pays more – the consumer can choose to drive a cleaner, quieter vehicle);
6. Insurance systems that cover accident costs and link risk and mileage to premiums paid by individual users;
7. The provision of information on the safety performance of vehicles.

The rationale behind the focus on road transportation was given by the European Transport Commissioner, Neil Kinnock:

“At the moment, some transport users pay too much, others too little; this system is both unfair and inefficient. Meanwhile, congestion is estimated to cost the Union some 2% of GDP every year; accident costs borne by other people as a society as a whole another 1.5% and air pollution and noise at least 0.6%. All in all this amounts to some 250 billion ECU per year throughout the Union: more than 90% of these costs are related to road transport. The available evidence suggests that road taxation falls far short of covering these costs.” (Europa Information Service 1997b)

In December 1996 the Official Journal of the European Communities published Notice 96/C 372/01, concerning the granting of aids for transport by rail, road and inland waterway, including a revision to existing legislation; extending for two years the existing mechanism for granting temporary aid to combined transport. The Journal stated that,

“The Commission considers that if proper competition between modes of transport is to be restored, aid for combined transport must continue to be authorised given that the inequality in distribution of infrastructure charges between modes of transport and the inadequate allowance made for external costs is operating against rail and waterway transport, and therefore against combined transport.” (Anon 1996, page 3)

A shift towards more effective combined transport systems is a key target for DG VII. According to the European Community's information service, Europa, the European Commission has prepared a design for a fully integrated Trans-European transport Network (TEN). It estimates the TEN will cost approximately ECU 400 billion (Over £300 billion) to make a reality by the year 2010. All of the projects in the design have been approved by the Member States concerned and several are already underway. The Commission's proposal envisages: 70,000 km of rail track; including 22,000 km of new and upgraded track for high-speed trains, 15,000 km of new roads; nearly half in regions on the outskirts of the Union, to complete a 58,000 km network; combined transport corridors and terminals, 267 airports of common interest and networks of inland waterways and sea ports (Europa Information Service 1997a).
9.4.3 Summary on Environmental Policy Measures

It can be seen that there is wide ranging legislation in place regarding the environmental effects of energy and logistics. Significantly, however, the policy measures outlined above demonstrate that the pressure on these areas will grow: legislation on atmospheric emissions is becoming more stringent, and a number of policy commitments towards global warming must be met.

In the United Kingdom, for example, meeting these commitments will involve significantly higher prices for energy. The following table, based on UK Department of Trade and Industry figures, illustrates the cost implications of a ‘Carbon Tax’ to help achieve CO$_2$ reduction targets:

**Table 9: Price increases needed to achieve CO$_2$ reduction targets in the UK** (from Environmental Data Services 1997a, page 30)

<table>
<thead>
<tr>
<th>Consumer Group</th>
<th>Energy Type</th>
<th>% change in prices for 10% CO$_2$ reduction</th>
<th>% change in prices for 20% CO$_2$ reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domestic</td>
<td>Gas</td>
<td>+50</td>
<td>+72</td>
</tr>
<tr>
<td>Domestic</td>
<td>Electricity</td>
<td>+21</td>
<td>+23</td>
</tr>
<tr>
<td>Industrial</td>
<td>Gas</td>
<td>+87</td>
<td>+125</td>
</tr>
<tr>
<td>Industrial</td>
<td>Electricity</td>
<td>+37</td>
<td>+41</td>
</tr>
</tbody>
</table>

Similar measures will have to be adopted throughout the EU if it is to meet its obligations under the Kyoto Protocol on Greenhouse Emissions.

Similar price increases are likely in the transport sector, as the EU seems committed to achieve a better balance between transport modes in the Union – with a greater reliance on combined transport. This will involve significantly higher fuel prices and costs in ensuring that HGVs meet emissions targets which continue to become more stringent.
9.5 Energy And Logistics Inventories

The objective for this section is to establish the data needs for the purposes of an evaluation of the environmental impact of energy and logistics in the European operations. Once this is complete the level of data of existing information within Borax Europe for these activities will be assessed and any data gaps highlighted. Thereafter, the work carried out to allow these gaps to be filled and hence generate inventories of energy and logistics patterns will be presented. This information will be carried forward into the analysis phase to generate an environmental burden inventory for Borax Europe energy and logistics.

The following table illustrates, in broad terms, the data requirements for the assessment

**Table 10: Data Requirements for Inventories and Assessment**

<table>
<thead>
<tr>
<th>Data Needed for Energy</th>
<th>Data Needed for Logistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inventory of operating sites and the types of energy utilised at each site</td>
<td>Inventory of operating sites and the modes of transportation utilised at each site</td>
</tr>
<tr>
<td>Process schematics</td>
<td>Shipment data (e.g. quantities of product shipped per annum)</td>
</tr>
<tr>
<td>Energy consumption rates at each node in schematic</td>
<td>Destination data (i.e. destination of shipment and distance travelled)</td>
</tr>
<tr>
<td>Production data (e.g. utilisation rates for process components) to allow total energy demand to be calculated for each site</td>
<td>Modes of transport utilised for each shipment</td>
</tr>
<tr>
<td>Sources of energy for each location (local supplier versus national / European grid)</td>
<td>Utilisation rate for each shipment (i.e. fully laden vessel, 75% laden, 50% laden, return loading)</td>
</tr>
<tr>
<td>Types of environmental imprint associated with energy production and consumption for each location</td>
<td>Types of environmental imprint associated with each of the transport modes used</td>
</tr>
<tr>
<td>Calculation of environmental imprint from energy demand and imprint per unit energy consumed</td>
<td>Calculation of environmental imprint from logistics by transport mode and by location.</td>
</tr>
</tbody>
</table>

9.5.1 Energy

9.5.1.1 Existing Data And Data Gaps for Energy

Table 11 provides a breakdown of needs, sources, gaps, and solutions for the data needed for an analysis of the environmental burden associated with energy in Borax Europe.
Table 11: Data Needs and Availability for an Energy Inventory

<table>
<thead>
<tr>
<th>Data Needed</th>
<th>Is the Data Already Available?</th>
<th>Source of Existing Data</th>
<th>Solution for Non-Existing Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inventory of operating sites</td>
<td>Yes</td>
<td>ERM Review, 1995†</td>
<td></td>
</tr>
<tr>
<td>Types of energy utilised at each site</td>
<td>Yes</td>
<td>ERM Review, 1995†</td>
<td></td>
</tr>
<tr>
<td>Process schematics</td>
<td>Yes</td>
<td>RTZ Technical Review, 1993‡</td>
<td></td>
</tr>
<tr>
<td>Energy consumption rates at each node in schematic</td>
<td>No</td>
<td>-</td>
<td>Site visit to discuss with technical / maintenance co-ordinators</td>
</tr>
<tr>
<td>Utilisation rates for process components</td>
<td>No</td>
<td>-</td>
<td>Site visit to discuss with production co-ordinators</td>
</tr>
<tr>
<td>Total energy demand for each site</td>
<td>No</td>
<td>-</td>
<td>Calculation from site visit data</td>
</tr>
<tr>
<td>Sources of energy for each location</td>
<td>Some</td>
<td>ERM Review, 1995†</td>
<td>Site visits to confirm with production / technical / maintenance co-ordinators</td>
</tr>
<tr>
<td>Types of environmental imprint associated with energy production and consumption</td>
<td>Some</td>
<td>Environmental Effects Review, Section 3</td>
<td>Life Cycle Analysis Software: PEMS 4.0</td>
</tr>
<tr>
<td>Total environmental imprint from energy demand by location and by Group</td>
<td>No</td>
<td>-</td>
<td>Life Cycle Analysis Software: PEMS 4.0</td>
</tr>
</tbody>
</table>

† Environmental Resources Management (1995a, 1995b, 1996a, 1996b, 1996c)
‡ RTZ Technical Services (1993a, 1993b, 1993c, 1993d)

9.5.1.1.1 Discussion

9.5.1.1.1 The Need for a Review

The use of energy for materials handling, processing and packaging operations, in the form of electricity to run the cranes and conveying systems, gas to fire the boiler furnaces for the borax and boric acid production lines at Coudekerque, and diesel oil to drive the forklift trucks used at Rotterdam, together with the gas and electricity needed for the domestic systems like lighting and heating, are understood to represent a significant environmental aspect for the Borax Europe Operations. The only available data for the entire Group dates back to 1995, when a risk and liability based audit was carried out for the Group by ERM (Environmental Resources Management 1995a, 1995b, 1996a, 1996b, 1996c).

This data showed that the combined activities of the European operations accounted for over 360 TJ of energy per year. However, production levels have changed at some of the operations, involving an increase in the annual running times of many of the activities. These factors, combined with the fact that in many cases such information that did exist was limited to the site, or a production line as a whole, rather than the components and activities of the
process in question, have made it desirable to carry out an energy review for the European operations.

The objectives for carrying out such a review are twofold. From the point of view of the engineering doctorate research undertaken, it ensures that the data used are current and complete. This cannot be overstated. There are five main operating locations in Europe: the four production sites at Runcorn/ Widnes, UK; Valencia/ Nules, Spain; Coudekerque, France; Rotterdam, Netherlands; in addition to the European technical and commercial centre in Guildford; UK.

Each of these operations measures energy in different ways, using measures such as kilowatt hours, metres cubed, and therms for gas alone. A fresh review would enable data to be gathered and represented in a common format. Initially the fundamental unit for energy, the joule, was used to represent energy usage. Subsequently, however, this was changed to the kilowatt-hour as it was found that this was a more meaningful measurement to the technical projects managers collaborating with this study.

Secondly, from the point of view of the Borax Group a specific energy review re-emphasises to the Group companies that energy efficiency is considered important by the Borax Group and provides an opportunity to discuss opportunities for improvements and best-practice sharing. This is best done face to face and direct contact with the information providers to secure involvement was felt to be beneficial to the study.

9.5.1.1.2 The Nature of the Operating Sites

In 1993 RTZ Technical Services carried out a technical review of all the operations in the Borax Group, including those at Coudekerque, Rotterdam (referred to as Botlek by RTZ Technical Services), Valencia and Nules in Spain (RTZ Technical Services 1993a, 1993b, 1993c, 1993d). These process flow-sheets were obtained and studied to determine the complexity of each of the operations.

9.5.1.1.2.1 Borax España

Borax España consists of a dockside materials handling facility at Valencia and a manufacturing site at Nules, 65km north of Valencia. The activities at Valencia consist mainly of truck loading and unloading equipment, storage, and dust extraction. The ship unloading activities are carried out by the Port of Valencia for Borax España. Nules consists of storage silos, warehousing, milling, drying, delivery systems for lorries, fork-lifts, a workshop, an administration building and a laboratory. The facility employs just over thirty people.

9.5.1.1.2.2 Borax Rotterdam

Borax Rotterdam carries out much of the bulk product handling for the European operations. Ocean going ships carrying borate in a series of holds arrive dockside where they are unloaded by cranes. Much of the plant at Rotterdam is associated with conveying, storing,
sieving, milling, drying and packaging this bulk material ready for shipment. Loading systems for barges, trucks and rail networks are present. Some production of agricultural products is carried out, but the vast majority of activity concerns bulk products. Warehousing and administration / laboratory facilities complete Borax Rotterdam, which employs 95 people.

9.5.1.1.2.3 Borax Français

Borax Français is the main chemical production facility for Borax Europe, producing boric acid by crushing and grinding colemanite ore, and then attacking the ore with a sulphuric acid mother liquor before drying. Borax decahydrate is produced by dissolving borax pentahydrate, settling the sludge and crystallising the product. Activities at Borax Français include bulk unloading and storage systems for the raw materials, chemical process equipment such as crushers, conveyors, reactor vessels, crystallisers, belt filters, cyclones, sieves, dryers, mills, packaging systems and product loading systems.

The process flowsheet for Borax Français is far more complex than any of the other European operations due to the nature of the production activities on a site which, including workshop, laboratory and administration functions, employs approximately 125 people.

9.5.1.1.2.4 Borax Europe Head Office, Guildford UK.

The central administration and technical functions for Borax Europe are based in Guildford, UK. The Guildford facility houses the European research group, with a number of dedicated laboratories for product R&D and for pilot scale process R&D. In addition to these research facilities, technical support in the form of chemical and optical analysis is present. Guildford also houses the administration for the European commercial functions, including the regional managers and central order processing and customer care functions. Also based in Guildford are the European information services and the European operations, logistics and environment groups.

9.5.1.2 Analysis

Analysis of the data will be discussed later in the report. At this juncture, it should be noted that the analysis will require tools that are not currently available within Borax Europe. Later discussion will outline how the data will be analysed.

9.5.1.3 Energy Review

9.5.1.3.1 Monitoring Equipment

Electric power monitoring equipment available to the Group consists mainly of electric power consumption meters located in the switch-rooms at each location. The number of electric power consumption metres varies across the Group, but none of the operating locations have more than three meters. On some of the larger installations, such as the mills at Coudekerque and the Shugi plant at Rotterdam, there are needle ammeters which indicate the current driving a plant at a given moment in time. Gas is also monitored through single meters,
although as there are fewer activities using gas (normally just the process and domestic boilers), this is not quite so problematic as having some hundreds of electric installations with only one or two meters between them.

After consultation with Gerry Pepper, Borax head of engineering based at Boron Operations, and an external consultant from the UK, it was decided to purchase a portable electric power meter. The device chosen was the LEM 2020P AC Power Meter, preferred on factors such as range of features, compatibility with voltages used in the European Operations, portability, and ease of use. Ease of use was particularly important since the assistance of technicians would be required at each location and operating instructions would need to be given verbally in more than one language.

9.5.1.3.2 Energy Review for Borax España

The energy review for Borax España was carried out during the week 28th April 1997 to 2nd May 1997. The review group comprised Peter Argust (Environmental, Borax Europe), Francisco Torres (Technical, Quality and Environmental, Borax España), and Miguel Galindo (Production, Borax España).

9.5.1.3.2.1 Electricity at Borax España

Based on appliance ratings, direct measurement, and conversion from previous measurements, it was possible to determine the electricity demand of the components of the production process. Process data allowed running times for installations to be included to provide an annual power demand for each installation. A breakdown, by area, of the findings of the review of electrical energy demand at Nules, is provided in Appendix 20 (see Vol.4 APD20).

The total electricity demand (calculated) for the operation can be determined by adding the activity totals together, as shown in Table 12

<table>
<thead>
<tr>
<th>Activity</th>
<th>Total Electricity Consumed (kWh/Year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milling &amp; Grinding</td>
<td>984382.56</td>
</tr>
<tr>
<td>Milling &amp; Grinding Delivery</td>
<td>30090.9</td>
</tr>
<tr>
<td>Agricultural Packing Plant</td>
<td>705.6</td>
</tr>
<tr>
<td>Neobor &amp; Boric Acid Packing</td>
<td>48009.024</td>
</tr>
<tr>
<td>Neobor &amp; Boric Acid Delivery</td>
<td>6423.9</td>
</tr>
<tr>
<td>General Services</td>
<td>31469.76</td>
</tr>
<tr>
<td>Boric Acid Silos</td>
<td>5439.0</td>
</tr>
<tr>
<td>Workshop</td>
<td>18000.0</td>
</tr>
<tr>
<td>Offices</td>
<td>10350.0</td>
</tr>
<tr>
<td>TOTAL</td>
<td>1134870.744</td>
</tr>
</tbody>
</table>

In fact, the metered total electricity demand in 1996 was approximately 1,100,000kWh.(Generallitat Valenciana 1996) The measured and calculated total of 1,134,871 kWh represents a deviation of +3.17% from the metered total. The installations
with the highest electricity demand were the fan for the Mill (355,622.4 kWh/year) and the 'selector' system, which ensures that the milled particles are within a certain size range (106,686.72 kWh/year). Between them, these two installations use 40% of the total electricity demand for the site.

9.5.1.3.2.2 Gas at Borax España

Natural gas is the second source of power for the processing operations at Borax España, used in the boilers which drive the heating systems for the dryers. Gas consumption at Borax España was metered at approximately 160,000 therms in 1996.

The following conversions, taken from Sharpe (1991) will be used:

Electricity (kWh) and Natural Gas (kWh) to energy (J)

\[
1 \text{ kWh} = 3.600 \times 10^6 \text{ J}
\]

Natural Gas (thermal units) to energy (J)

\[
1 \text{ therm} = 105.596 \times 10^6 \text{ J}
\]

Thus:

Borax España Gas consumption (therms) \* 105.596 \* 10^6 = Borax España Gas consumption (joules)

and

\[
\frac{\text{Borax España Gas consumption (joules)}}{3.600 \times 10^6} = \text{Borax España Gas consumption (kWh)}
\]

So

Borax España Gas consumption (therms) \* (105.596/3.6) = Borax España Gas consumption (kWh)

160,000 therms \* (105.596/3.6) = 4,693,155.56 kWh

Thus the gas for boilers is seen to be the dominant energy requirement for the operations of Borax España, consuming 80% of all energy used in operations.

9.5.1.3.3 Energy Review for Borax Français

The energy review for Borax Français was carried out during the week 14th April to 18th April 1997. The review group comprised Peter Argust (Environmental, Borax Europe), Bernard Petit (Maintenance, Borax Français) and Monsieur Laroye (Operations, Borax Français).

9.5.1.3.3.1 Electricity at Borax Français

Based on direct measurement and appliance ratings, it was possible to determine the electricity demand of the components of the production processes for borax decahydrate and boric acid. Process data allowed running times for installations to be included to provide and annual power demand for each installation. A breakdown, by area, of the findings of the
review of electrical energy demand at Borax Français is provided in Appendix 20 (see Vol.4 APD20).

A number of gaps exist for this information. In the borax decahydrate (10 mol) system; the vacuum unloading system was not in use at the time of the review, nor were the silo delivery systems for the 3,5 and 400 tonne silos, and the impurities removal system. The energy requirement for the vacuum system, in particular, is necessary for a full evaluation of the data. In the boric acid system; the 6 tonne per hour mill system, the pump from the dryers to the EM tanks, and the boric acid powder system, were not running. The 6 tonne per hour mill runs only 2-3 days per month, and the other systems only run periodically.

In 1996, Borax Français metered 7,494,929 kWh electricity, broken into the following areas:
Boiler: 300,215 kWh
Borax Decahydrate: 1,262,662 kWh
Boric Acid: 5,360,992 kWh
Domestic (lighting, computers, etc.) 600,000 kWh

According to the calculations from the review, 900,774.6 kWh out of a metered sub-total of 1,262,662 kWh in the borax decahydrate process were accounted for. It is estimated that the vacuum unloading system accounts for 90% of the electricity unaccounted for. In the case of the boric acid process, it is estimated that the demands of the systems unaccounted for (which run very rarely) do not account for more than 2% of the energy measured. Nonetheless, 5,361,894.12 kWh of a metered sub-total of 5,360,992 kWh were accounted for. In the case of the boric acid process, there is a deviation of +2.1%, assuming the non-measured systems account for 2% or less.

The largest components of this demand are the main dry mill, separator and cyclone system (2,054,052 kWh) and the 5 stage leach system (566,834.4 kWh). These two processes account for approximately 35% of all electricity required at Borax Français in 1996.

9.5.1.3.3.2 Gas at Borax Français

Gas is required for the following processes in the following quantities at Borax Français:

<table>
<thead>
<tr>
<th>Table 13: Gas consumption, by Activity, Borax Français, 1996</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>System using gas</strong></td>
</tr>
<tr>
<td>Boric Acid Dryer</td>
</tr>
<tr>
<td>Borax Decahydrate Dryer</td>
</tr>
<tr>
<td>Boiler</td>
</tr>
<tr>
<td>Factory Floor Heating</td>
</tr>
<tr>
<td>TOTAL</td>
</tr>
</tbody>
</table>

It can be seen that the gas installations are by far the heaviest users of energy at Borax Français, accounting for over 87% of all energy used at Borax Français in 1996.

9.5.1.3.4 Energy Review for Borax Rotterdam
The energy review for Borax Rotterdam was carried out during the week 21st to 25th April 1997. The review group comprised Peter Argust (Environmental, Borax Europe), Jack Rijsdijk (Technical Projects, Borax Rotterdam), and Kees de Kraaker (Maintenance, Borax Rotterdam).

9.5.1.3.4.1 Electricity at Borax Rotterdam

Based on appliance ratings, direct measurement, and conversion from previous measurements, it was possible to determine the electricity demand of the components of the production process. Process data allowed running times for installations for installations to be included to provide an annual power demand for each installation. A breakdown, by activity, of the findings of the review of electrical energy demand at Rotterdam, is provided in Appendix 20 (see Vol. 4 APD20).

The review has accounted for 2,522,118 kWh of electricity demand for Borax Rotterdam operations in 1996. However, some information is missing: at the present time annual running times for the compressor system, the vuilverwerking (recovery flow from conveyor C5), the stofzuiger (mobile vacuum cleaner) and the offices. The power requirement of Machine 8 was not established during the review. Jack Rijsdijk As in the case of Borax Français, these systems are infrequently used.

Furthermore the combined power requirement for majority of the machines whose annual usage is not known - the combined power requirement, when running, for the stofzuiger, vuilverwerking, canteen/offices/lab, and lift, is 46kW - is low in comparison with the more frequently used systems. However, the compressor system alone (108kW) has a heavier electricity demand when it is running, so it would be helpful to know the annual usage of this system.

Nonetheless, the major demands for electricity at Borax Rotterdam are in the bulk unloading and handling systems. The Stork Kraan and its filters and fans use 60,622.5 kWh per year for boric acid unloading and a further 41,922 kWh for Neobor unloading - an annual total of 102,544.5 kWh. The Man Kraan, used for Neobor unloading, uses 437,500 kWh a year. Like Borax Français, the mill at Borax Rotterdam has a high electricity demand. The Molen/Shugi system requires 208,000 kWh. Thus, the combined demand of the three systems with the largest electrical demand (748,044.5 kWh) represents approximately 30% of the electrical demand for Borax Rotterdam in 1996.

9.5.1.3.4.2 Gas at Borax Rotterdam.

Natural gas is used at Borax Rotterdam for the boilers, which are used predominantly for the Shugi system. The Shugi system has a drying process requiring heat. In 1996, Borax Rotterdam consumed 140,616 normalised metres cubed of natural gas in 1996. The following conversions, taken from Sharpe (1991), can be applied:

1 normalised metre cubed of natural gas = 38.62 * 10^6 joules energy
1 kWh (gas or electricity) = 3.6 * 10^6 joules

Therefore,
1 normalised metre cubed of natural gas = (38.62/3.6) kWh
140,616 normalised metres cubed of natural gas = 1,508,497.2 kWh

Thus, Borax Rotterdam’s natural gas consumption, in 1996, represents 1,508,497.2 kWh.

9.5.1.3.4.3 Diesel Oil at Borax Rotterdam

The third source of energy used at Borax Rotterdam is diesel oil, which is used by the forklift trucks. Forklifts play an important role at a materials handling facility, such as Rotterdam. At Borax Rotterdam, 61,000 litres of diesel were consumed in 1996. The following conversions, taken from Sharpe (1991), can be applied:

- Gross calorific value of diesel = 43.6 MJ/kg (approx.)
- Relative density of diesel = 0.84
- 1 litre diesel @ 0.84 * 43.6MJ = 36.624J * 106

If 1 kWh = 3.6J * 106, then:

61,000 litres diesel = 61,000 (36.624/3.6) kWh
= 620,573.33 kWh

Thus, Borax Rotterdam’s diesel oil consumption, in 1996, represents 620,573.33 kWh.

9.5.1.3.5 Energy Review for Borax Europe HQ, Guildford

The energy review for Borax Europe headquarters, Guildford, was carried out during the week 5th to 9th May 1997. The review group comprised Peter Argust (Environmental, Borax Europe) and Colin Ambler (Building Services, Borax Europe).

9.5.1.3.5.1 Electricity at Borax Europe, Guildford

Electricity use at Borax Guildford is metered as it enters the site. Beyond the meter power is split into:

- 10 circuits into the main building
- 4 external lines to sump pumps and car park lighting
- 6 lines to power and lighting in the workshops and stores
- 2 power circuits to the chiller systems
- Several ‘clean’ lines to the site computer room.

The 10 circuits into the main building are split into 73 distribution boards, which in turn are split into lighting and power circuits, which then go to other distribution boards. Each of the other main supplies is also similarly split at distribution boards. The building services manager felt that that the only method to gather sufficient data to understand the exact nature of power consumption at Guildford safely would be to rewire the entire building and meter each line. This was not a viable option during the review.

The total power metered for electrical consumption at Borax Guildford in 1996 was:
1,400,790 kWh
9.5.1.3.5.2 Gas at Borax Europe, Guildford

Natural gas is used at Borax Guildford for the heating systems and the staff canteen. In 1996 Borax Guildford consumed 182,417 normalised metres cubed of natural gas. The following conversions, taken from Sharpe (1991), can be applied:

1 normalised metre cubed of natural gas = $38.62 \times 10^6$ joules energy
1 kWh (gas or electricity) = $3.6 \times 10^6$ joules

Therefore,

1 normalised metre cubed of natural gas = $(38.62/3.6)$ kWh
182,417 normalised metres cubed of natural gas = 1,956,929.04 kWh

Thus, Borax Europe’s Guildford headquarters’ natural gas consumption, in 1996, represented 1,956,929.04 kWh.

9.5.1.3.6 Discussion

The results of the energy survey, which accounted for at least 95% of all energy consumption in the review, can be summarised for Borax Europe in order of magnitude, and in total, in Table 14.

Table 14: Borax Europe, Energy Inventory Summary, 1996.

<table>
<thead>
<tr>
<th>Location</th>
<th>Energy Type</th>
<th>Quantity of Energy Used (kWh/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Borax François</td>
<td>Natural Gas</td>
<td>52,335,422</td>
</tr>
<tr>
<td>Borax Français</td>
<td>Electricity</td>
<td>7,494,929 †</td>
</tr>
<tr>
<td>Borax España</td>
<td>Natural Gas</td>
<td>4,693,156</td>
</tr>
<tr>
<td>Borax Rotterdam</td>
<td>Electricity</td>
<td>2,522,118 †</td>
</tr>
<tr>
<td>Borax Europe HQ</td>
<td>Natural Gas</td>
<td>1,956,929</td>
</tr>
<tr>
<td>Borax Rotterdam</td>
<td>Natural Gas</td>
<td>1,508,497</td>
</tr>
<tr>
<td>Borax Europe HQ</td>
<td>Electricity</td>
<td>1,400,790</td>
</tr>
<tr>
<td>Borax España</td>
<td>Electricity</td>
<td>1,134,871</td>
</tr>
<tr>
<td>Borax Rotterdam</td>
<td>Diesel Oil</td>
<td>620,573</td>
</tr>
<tr>
<td>Borax Europe Sub-Total</td>
<td>Natural Gas</td>
<td>60,963,319</td>
</tr>
<tr>
<td>Borax Europe Sub-Total</td>
<td>Electricity</td>
<td>12,552,708</td>
</tr>
<tr>
<td>Borax Europe Sub-Total</td>
<td>Diesel Oil</td>
<td>620,573</td>
</tr>
<tr>
<td><strong>Borax Europe Total</strong></td>
<td><strong>ALL</strong></td>
<td><strong>73,866,600 †</strong></td>
</tr>
</tbody>
</table>

† Not all systems accounted for.

Thus it can be seen that the gas systems are the dominant source of energy for Borax Europe operations, accounting for just over 82% of all energy consumed in 1996 in Borax Europe. The gas systems at Coudekerque used almost 86% of the natural gas demand for the European operations, and almost 71% of the total process energy demand for the whole of Borax Europe. When its electricity demand is included, Borax Français accounts for 81% of all energy consumption by Borax Europe.
Further analysis will be needed to determine which of the three energy sources; gas, electricity, or diesel, has the highest environmental impact, but in terms of total energy demand, it becomes clear that any energy reduction programme would yield the greatest benefit by focusing on the natural gas systems of the operations before looking too closely at the electrical systems. Any percentage reduction in usage here would offer the greatest contribution to overall reduction. Within the electrical energy systems, the milling systems are the activities which require the greatest proportion of electrical energy, followed by the unloading systems. Reductions in power usage in these two areas would provide the greatest proportional contribution to overall electricity demand in Borax Europe.

That does not mean to say that the areas discussed present the most easily achievable reductions. It is possible that efficiency gains in lighting and heating systems at Guildford would be possible for the lowest proportional capital investment. However, the study highlights areas of interest for observation in the analysis phase.

9.5.2 Logistics

9.5.2.1 Existing Data and Data Gaps for Logistics

Table 15 provides a more complete breakdown of needs, sources, gaps, and solutions for the data needed for an analysis of the environmental burden associated with logistics for Borax Europe.

Table 15: Data Needs and Availability for Logistics Inventories

<table>
<thead>
<tr>
<th>Data Needed</th>
<th>Is the Data Already Available?</th>
<th>Source of Existing Data</th>
<th>Solution for Non-Existing Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inventory of operating sites</td>
<td>Yes</td>
<td>ERM Review, 1995†</td>
<td>-</td>
</tr>
<tr>
<td>Modes of transportation utilised at each location</td>
<td>Some</td>
<td>Borax Europe Logistics Function</td>
<td>Site visits to confirm with logistics/shipping co-ordinators</td>
</tr>
<tr>
<td>Quantities of product shipped per annum</td>
<td>Some</td>
<td>Schipments ex Rotterdam, 1995†</td>
<td>Site visits to confirm with logistics/shipping co-ordinators</td>
</tr>
<tr>
<td>Shipment destinations</td>
<td>Some</td>
<td>Schipments ex Rotterdam, 1995</td>
<td>Site visits to confirm with logistics/shipping co-ordinators</td>
</tr>
<tr>
<td>Distances to destinations</td>
<td>No</td>
<td></td>
<td>AutoRoute Express for overland*, Lloyds Maritime Atlas for water**.</td>
</tr>
<tr>
<td>Utilisation rate for each shipment</td>
<td>No</td>
<td></td>
<td>Site visits to confirm with logistics/shipping co-ordinators¹</td>
</tr>
<tr>
<td>Types of environmental imprint associated with the transport modes used</td>
<td>Some</td>
<td>Environmental Effects Review, Section 3</td>
<td>Life Cycle Analysis Software: PEMS 4.0***</td>
</tr>
<tr>
<td>Total environmental imprint from logistics by location and by Group</td>
<td>No</td>
<td></td>
<td>Life Cycle Analysis Software: PEMS 4.0</td>
</tr>
</tbody>
</table>

Notes to Table 15

¹ Discussions with Borax Europe logistics suggest that exact information is not likely to be known. Assumptions may have to be made based on discussions with operating companies.
9.5.2.1.1 Discussion
As can be seen, there is some data already available for the logistics activities in Borax Europe, but much of the information needed for the purposes of this review is held at the Group companies. The year 1995 provides a more complete breakdown of logistics than 1996, however. The use of data from one year (1996) for production and another year (1995) for logistics presents a risk. It is possible that production levels differ widely between 1995 and 1996. When an analysis is carried out with the aim of generating a burden value for the combined activities, errors may be introduced through the use of inconsistent data. Any final value may differ from reality - provided there is sufficient difference between the values for subsequent years.

This matter has been discussed with senior officers responsible for production and logistics across the Group. The conclusion of the Group has been that while logistics changed greatly during between 1995 and 1996, production did not. Therefore, an appropriate baseline year will be 1995. The logistics data used will be valid, since they are drawn from 1995, and the production data will be valid, since production in 1996 reflects production in 1995 closely.

9.5.2.1.1 The Need for a Review
A review remains necessary for logistics, since much of the data needed is not available at all locations. A particular gap in data concerns distances to destinations, while central knowledge of the modes of transport used remains incomplete. Figures are available for Rotterdam for the quantities of product, and their destinations, but data is not held centrally for the other locations. Therefore, a review will be needed to collate data from each operating site on logistics.

9.5.2.2 Logistics Inventories
To recap, the major information needs for the logistics inventories were as follows:
A summary of shipment volumes and destinations, modes of transport used, and the distances covered, together with vehicle utilisation rates if known. This inventory will be analysed to give an environmental effect subsequently. Site visits were established to gather data on volumes, destinations and transport modes. Where distances travelled were known, these data were also gathered during site visits. Where this data was not known, AutoRoute Express™ and Lloyd’s Maritime Atlas (Shipping Editor of Lloyd’s 1995) were used to calculate the distances covered.
In the following sections, a brief overview is provided for each location, and then the findings are presented for the European operations collectively in tabular form, followed by a discussion.

9.5.2.2.1 Logistics Review for Borax España.
Borax España was visited during the week 28th April to 2nd May 1997. The review team consisted of Peter Argust (Environmental, Borax Europe) and Jose Luis Vilar (Finance, Borax España). Borax España were able to provide:
1. Shipping Quantities, by destination
2. Shipping Destinations
3. Shipping Modes
4. Shipping Distances
This has provided sufficient information to carry out an analysis for the purposes of the environmental review.

9.5.2.2.2 Logistics Review for Borax Français
Borax Français was visited during the week 14th April to 18th April 1997. The review team consisted of Peter Argust (Environmental, Borax Europe), Jacques Dooms (Logistics, Borax Français), and Jean-Luc Deprestier (Information Technology, Borax Français). Borax Français were able to provide:
1. Shipping Quantities, by destination
2. Shipping Destinations
3. Shipping Modes
It has been necessary to calculate shipping distances separately. However, due to the large number of destinations supplied by Borax Français (hundreds), it has not been possible to generate a distance for each location. However, as the table will show, over 90% of all European shipments (by quantities) have been accounted for by direct calculation. For land based destinations, AutoRoute Express was used to determine shipping distances. If AutoRoute™ did not recognise the destination, then the distance to the nearest recognised location to the destination was determined using AutoRoute™ and the remaining distance was calculated by measurement from the Times Atlas of the World (Bartholomew et al 1990). With this information, it is possible to carry out an analysis of the data for the purposes of an environmental review.

9.5.2.2.3 Logistics Review for Borax Rotterdam
Borax Rotterdam was visited during the week 21st April to 25th April 1997. The review team consisted of Peter Argust (Environmental, Borax Europe), Arie Hoogerwerf (Logistics, Borax Rotterdam), and Cees de Graaw (Logistics, Borax Europe). Borax Rotterdam and Borax Europe were able to provide:
1. Shipping Quantities, by destination
2. Shipping Destinations
3. Shipping Modes
It has been necessary to calculate shipping distances separately. However, due to the large number of destinations supplied by Borax Rotterdam (hundreds), it has not been possible to generate a distance for each location. However, as the table will show, over 90% of all European shipments (by quantities) have been accounted for by direct calculation. For land based destinations, AutoRoute Express™ was used to determine shipping distances. If AutoRoute did not recognise the destination, then the distance to the nearest recognised location to the destination was determined using AutoRoute and the remaining distance was calculated by measurement from the Times Atlas of the World (Bartholemew et al 1990). With this information, it is possible to carry out an analysis of the data for the purposes of an environmental review. The detailed data for Borax Europe’s logistics functions in 1996 are provided in Appendix 21 (see Vol.4 APD21).

9.5.2.2.4 Discussion

The following list briefly summarises the findings for the logistics study:

- The analysis covers 91.91% (2d.p) of all shipments in 1995.
- After adjustment to 100%:
  1. Total annual shipments were: 461,684,424 tonnes
  2. Container ship accounted for the largest share of tonne-kilometres (180,316,428 tkm)
  3. Road was the second most heavily used form of transport, accounting for 148,201,954 tkm.
  4. Water Bulk Carrier accounted for the third highest share of the logistics modes: 64,716,398 tkm.
  5. Rail accounted for the fourth largest share of the logistics modes: 45,338,085 tkm.

So, although road was the most frequently used option in transportation, because of the great distances involved the container vessels accounted for the highest share of total haulage. Also, a significant proportion of the total haulage represented shipments within Borax Europe, so although total shipments represents just over 460,000 tonnes, total shipments to customers will be lower. This will be a relevant factor during the analysis phase.
9.6 Analysis of the Energy and Logistics Inventories for Environmental Impacts

The objective for this section is to generate values for the environmental impact arising from the use of energy in the processing operations of Borax Europe and in the logistics functions for moving products and materials between operating sites and to customers.

9.6.1 Analyses Required

Two analyses will be required to meet the objective:

1. Environmental impact per functional unit from energy and logistics at the level of Borax Europe.
2. Total environmental impact from energy and logistics at the level of Borax Europe.

The analysis at the level of the functional unit will provide a measure of relative environmental efficiency to be used as an index for year on year comparisons. In future years the 1995 values could be used to form a baseline against which to compare future performance, irrespective of total production or shipment levels.

The analysis at the level of a total for Borax Europe will provide an indicator for the size of 'footprint' for future comparison. Future performance targets could be expressed as reductions in total contributions to specific environmental themes (e.g. greenhouse gas formation, acidification, etc.) or as reductions in per unit contributions to the environmental themes. Values at the level of the functional unit as well as totals will provide baselines for both categories to allow future measurement against objectives.

9.6.2 Analysis of Unit Environmental Impact

9.6.2.1 The Functional Unit

The functional unit chosen for this analysis by Borax Europe has been expressed as: “1 tonne product shipped to customers”.

This expression involves the following:

1. No distinction between different product types

   In other words, for the purposes of this analysis it will be assumed that all Borax products have the same relative density and will require the same process energy.

   • In logistics terms this means that 1 tonne of boric acid will occupy the same volume as 1 tonne of Neobor, for example. This will remove any confusion over the capacity of a truck, or a water bulk carrier, for example, regarding how much of a given material they can carry.
   • In energy terms, this means that the energy requirements for the production of different products are the same. In some activities this may be unrealistic,
particularly in the chemical processing activities. In the bulk handling activities, however, the assumption is realistic.

2. No double counting in logistics

A proportion of the logistics activity arises through the movement of material from one operating site to another, for subsequent shipment to local customers. This means that there is a risk of double counting. For example, product shipped from the Rotterdam facility to Coudekerque might appear as a shipment out of Rotterdam, and subsequently reappear as a shipment out of Coudekerque to a customer in France. When the tonnages in logistics are evaluated, then, different values will be needed, as will be discussed in Section 9.6.2.2

3. No mention of return journeys in logistics.

As was discussed briefly during the evaluation of data needs for the analysis – utilisation rates for haulage were not known. Discussion with logistics personnel has revealed that Borax does not operate its own transport fleet in its European operations. Delivery of product to customers is carried out by one of two methods:

(i) The customers collect the products themselves, or by hauliers they have contracted.

(ii) A haulage firm is contracted by Borax Europe to deliver the product on behalf of the company.

- In the case of customer collection, 100% utilisation is assumed for transportation. The ‘delivery’ leg of any journey, and its attendant environmental effects fall into the sphere of influence of Borax Europe, although the actual mode of transportation can only be suggested by the organisation to the customer. Discussion with logistics personnel suggests that shipments by this method tend to involve fully laden vehicles on the delivery leg.

- On the collection leg, however, Borax has little control over the utilisation of the vehicle. Customers who collect themselves may use the collection leg to deliver their own product to customers near the Borax facilities. This is particularly the case for Borax Rotterdam. Accordingly, 100% utilisation has been used in the first instance. All customer collection at present is carried out by truck. Should this mode emerge as a dominant contributor to the environmental impact values, then this assumption will be re-evaluated.

- In the case of hauliers contracted by Borax Europe, the organisation has a much greater degree of control over the transportation modes and techniques used. Contract haulage within Europe is highly competitive and the shipping points used by Borax Europe are very near major ports – Rotterdam, Calais, and Valencia – so 100% utilisation on the collection leg is felt to be a realistic assumption.

9.6.2.2 Total Net Shipment

In this analysis:

Total Net Shipment = Total Shipments – Total Shipments to Group Companies
In the logistics inventory there were 19,307.197 tonnes of shipments between Group companies for subsequent re-shipment. Thus:

Total Net Shipment (tonnes) = 461,684.429 − 19,307.197
Total Net Shipments = 442,377.277 tonnes

9.6.2.3 Logistics Tonne-kilometres per Functional Unit

This provides a value for all shipments to customers. In the analysis at the level of the functional unit (1 tonne product shipped to customers) the total logistics requirements, in terms of tonne kilometres by mode of transport, will be divided by the total net shipments. Thus the environmental impact of shipping within the Borax operations can be included in the analysis of environmental effects at the level of the functional unit.

The following table illustrates the conversions:

Table 16: Tonne kilometres, by mode, for Borax Europe Shipping, 1995

<table>
<thead>
<tr>
<th>Mode of transportation</th>
<th>Tonne kilometres for Total Shipments</th>
<th>Tonne kilometres for Net Shipments</th>
<th>Tonne kilometres per Functional Unit (t.km / 442,377,277)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road</td>
<td>148,201,953.97</td>
<td>148,201,953.97</td>
<td>335.013</td>
</tr>
<tr>
<td>Bulk Inland Water-way</td>
<td>64,716,398.03</td>
<td>64,716,398.03</td>
<td>146.292</td>
</tr>
<tr>
<td>Ocean-going Ship</td>
<td>180,316,428.11</td>
<td>180,316,428.11</td>
<td>407.608</td>
</tr>
<tr>
<td>Rail</td>
<td>45,338,085.23</td>
<td>45,338,085.23</td>
<td>102.487</td>
</tr>
</tbody>
</table>

9.6.2.4 Energy Consumption per Functional Unit

A similar issue arises in the use of energy. Some product will be handled more than once as a result of internal shipping and this must be accounted for in the requirements per tonne for energy. Energy will be required irrespectively of the destination of the product handled. Table 17 shows the calculation for energy requirements per tonne of product shipped.

Table 17: Energy Requirements, per tonne product shipped, Borax Europe 1996.

<table>
<thead>
<tr>
<th>Energy Type</th>
<th>Energy Required for Total Shipments (kWh)</th>
<th>Energy Required for Net Shipments (kWh)</th>
<th>Energy Required per Functional Unit (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas</td>
<td>60,963,319</td>
<td>60,963,319</td>
<td>137.808</td>
</tr>
<tr>
<td>Electricity</td>
<td>12,552,708</td>
<td>12,552,708</td>
<td>28.376</td>
</tr>
<tr>
<td>Diesel Oil</td>
<td>620,573</td>
<td>620,573</td>
<td>1.403</td>
</tr>
</tbody>
</table>

9.6.2.5 PEMS 4.0™ Analysis of Functional Unit Data

PEMS 4.0™ is a software application that allows users to do the following:

1. Build a process schematic and assign input and values (energy, material, and shipping) for the steps in their process

2. Develop an environmental burden inventory for the process steps chosen. This is done by means of databases that contain burden data for different activities. By multiplying together the database values per unit by the number of units in the defined process, it is possible to generate a burden inventory.
3. Analyse the effect of the burdens against a wide variety of environmental themes, such as global warming, acidification etc.

9.6.2.5.1 Process Schematic
For the purposes of this assessment, the following process steps were chosen:
- A materials processing phase, requiring electrical, gas, and diesel energy.
- A shipping phase: involving truck, water and rail distribution.

The following were specified:

9.6.2.5.1.1 Gas Energy
The most appropriate process was felt to be 'Heat – Natural Gas', from the PEMS 3.0 database, which was created based on European data for gas combustion pre 1995.

9.6.2.5.1.2 Electricity
The most appropriate process was felt to be 'Electricity – Average European', from the PEMS 3.0 database, again created based on European data for electricity production and supply pre 1995. Initially the possibility of using country specific data for the Borax Europe operations was considered, based on the proportional use by the operations of the total energy demand, and allocating processes from the individual countries. For example, Borax Rotterdam purchases electricity from EZH (Elektrische Zuid-Holland), which generates over 80% of its total output through the combustion of coal and gas whereas Borax Français purchases its electricity from EDF (Electricité De France), which relies heavily on nuclear power stations for each output. The environmental effects for these different generation techniques could have a significant effect on the overall environmental burden for Borax Europe.

However, discussions with the Energy Technology Support Unit, ETSU, revealed that at the marginal level, it would not be appropriate to assign energy to a specific source within Europe, as there is a European supply grid, the UCPTE (ETSU 1997) This means that there is no guarantee that electricity purchased in France has not been produced in Spain, by way of example. Therefore, values generated for the UCPTE should be used for electricity analysis, rather than values for specific countries.

9.6.2.5.1.3 Diesel
The most appropriate process was 'Diesel in Construction Equipment', from the ETH-ENET database, which was created based on European data in April 1995. The diesel utilised in the European operations is used to power forklift systems, which would be most closely associated with construction equipment.

9.6.2.5.1.4 Shipping
The ETH-ENET database was used throughout the shipping analysis, as the data sets in this database most closely matched the distribution modes used by Borax Europe. These data were all updated in April 1995. The following modes were chosen:
9.6.2.5.1.4.1 Trucks
The ‘40 tonne truck’ type was specified, operating at 27 tonne capacity and 100% utilisation with no return journey, for truck based distribution operations.

9.6.2.5.1.4.2 Water bulk Carriers
The ‘Freighter -Inland Waters’ type was specified.

9.6.2.5.1.4.3 Ocean-going Ships
The ‘Freighter – Transoceanic’ type was specified.

9.6.2.5.1.4.4 Rail
The ‘Rail’ type was specified, based on 100% utilisation with no return journey.

The following schematic illustrates how these processes were assembled.

**Figure 10: Process Schematic for Energy and Materials, per Functional Unit, Borax Europe, 1995/6**

![Diagram](image)

9.6.2.5.2 Impact Analysis
Once the process schematic has been completed, with the material and energy flows assigned, then the software compiles it. This is where the application draws upon the databases to collate information on the resource demands and releases associated with each stage in the process. The application is also capable of generating a variety of impact analyses whereby the burdens are categorised according to their contribution towards chosen themes. Then the application calculates a contribution made towards, each theme, expressed as index equivalents based on their potency factors. In the case of the greenhouse effect, for example,
all aspects of the activities which release greenhouse gases are collated and expressed as carbon dioxide equivalents.

The analysis chosen for the purposes of this work is the 'Problem Oriented' analysis, which shows the contribution made towards significant environmental themes by the activities.

Table 18 presents the results of this analysis for the processing phase:

**Table 18: Processing Environmental Burdens, Per Functional Unit, Borax Europe 1996 (presented here to 4 significant figures)**

<table>
<thead>
<tr>
<th>Activity</th>
<th>Units</th>
<th>Heat (Natural Gas)</th>
<th>Electricity (Average European)</th>
<th>Diesel (Construction Equipment)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land Use</td>
<td>(m²)</td>
<td>-</td>
<td>-</td>
<td>0.022</td>
</tr>
<tr>
<td>Smog</td>
<td>(kg NOₓ)</td>
<td>0.077</td>
<td>0.041</td>
<td>0.008</td>
</tr>
<tr>
<td>Landfill</td>
<td>(dm³)</td>
<td>0.073</td>
<td>0.618</td>
<td>-</td>
</tr>
<tr>
<td>Radioactivity</td>
<td>(kBq)</td>
<td>-</td>
<td>-</td>
<td>30.26</td>
</tr>
<tr>
<td>Resource Depletion</td>
<td>(year)</td>
<td>0.219</td>
<td>0.035</td>
<td>0.004</td>
</tr>
<tr>
<td>Greenhouse</td>
<td>(kg CO₂)</td>
<td>34.13</td>
<td>13.13</td>
<td>0.460</td>
</tr>
<tr>
<td>Acidification</td>
<td>(kg SO₂)</td>
<td>0.061</td>
<td>0.179</td>
<td>0.006</td>
</tr>
<tr>
<td>Ecotoxicity</td>
<td>(m³)</td>
<td>0.009</td>
<td>0.060</td>
<td>0.000</td>
</tr>
<tr>
<td>Eutrophication</td>
<td>(kg PO₄)</td>
<td>0.010</td>
<td>0.005</td>
<td>0.001</td>
</tr>
<tr>
<td>Greenhouse (indirect)</td>
<td>(CO₂)</td>
<td>0.957</td>
<td>0.340</td>
<td>0.010</td>
</tr>
<tr>
<td>Human Toxicity</td>
<td>(kg/kg)</td>
<td>0.077</td>
<td>0.264</td>
<td>0.012</td>
</tr>
<tr>
<td>Odour</td>
<td>(kg NH₃)</td>
<td>-</td>
<td>0.000</td>
<td>0.001</td>
</tr>
<tr>
<td>Ozone Depletion</td>
<td>(kg CFC 11)</td>
<td>-</td>
<td>-</td>
<td>5.114 *10⁻⁷</td>
</tr>
<tr>
<td>Smog</td>
<td>(kg ethene)</td>
<td>0.008</td>
<td>0.012</td>
<td>0.001</td>
</tr>
</tbody>
</table>
Table 19 presents the results of this analysis for the distribution phase:

### Table 19: Distribution Environmental Burdens, Per Functional Unit, Borax Europe 1995 (presented here to 4 significant figures)

<table>
<thead>
<tr>
<th>Activity Theme</th>
<th>Units (m²)</th>
<th>Distribution 40k Truck</th>
<th>Distribution Trans-Oceanic</th>
<th>Distribution Inland Waters</th>
<th>Distribution Rail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land Use</td>
<td></td>
<td>11.38</td>
<td>0.164</td>
<td>2.541</td>
<td>1.279</td>
</tr>
<tr>
<td>Smog</td>
<td>(kg NOₓ)</td>
<td>0.316</td>
<td>0.041</td>
<td>0.076</td>
<td>0.021</td>
</tr>
<tr>
<td>Landfill</td>
<td>(dm³)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Radioactivity</td>
<td>(kBq)</td>
<td>5956</td>
<td>220.5</td>
<td>806.5</td>
<td>3394</td>
</tr>
<tr>
<td>Resource Depletion</td>
<td>(year)</td>
<td>0.198</td>
<td>0.028</td>
<td>0.069</td>
<td>0.022</td>
</tr>
<tr>
<td>Greenhouse</td>
<td>(kg CO₂)</td>
<td>24.83</td>
<td>3.548</td>
<td>9.045</td>
<td>4.209</td>
</tr>
<tr>
<td>Acidification</td>
<td>(kg SO₂)</td>
<td>0.277</td>
<td>0.099</td>
<td>0.078</td>
<td>0.029</td>
</tr>
<tr>
<td>Eutrophication</td>
<td>(m³)</td>
<td>0.008</td>
<td>0.002</td>
<td>0.002</td>
<td>0.000</td>
</tr>
<tr>
<td>Greenhouse</td>
<td>(kg PO₄)</td>
<td>0.042</td>
<td>0.005</td>
<td>0.010</td>
<td>0.003</td>
</tr>
<tr>
<td>Human Toxicity</td>
<td>(kg/kg)</td>
<td>0.578</td>
<td>0.204</td>
<td>0.165</td>
<td>0.049</td>
</tr>
<tr>
<td>Ozone Depletion</td>
<td>(kg CFC 11)</td>
<td>2.955*10⁻⁶</td>
<td>2.954*10⁻⁶</td>
<td>9.734*10⁻⁶</td>
<td>2.482*10⁻⁶</td>
</tr>
<tr>
<td>Smog</td>
<td>(kg ethene)</td>
<td>0.059</td>
<td>0.004</td>
<td>0.016</td>
<td>0.003</td>
</tr>
</tbody>
</table>

Table 20 presents the results of this analysis for the combined processing and distribution phases:

### Table 20: Combined Process and Distribution Environmental Burdens, Per Functional Unit, Borax Europe 1995/6 (presented here to 4 significant figures)

<table>
<thead>
<tr>
<th>Activity Theme</th>
<th>Units (m²)</th>
<th>Processing Sub-Total, per tonne</th>
<th>Logistics Sub-Total, per tonne</th>
<th>Total (All Processing + All Distribution) per tonne</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land Use</td>
<td></td>
<td>0.022</td>
<td>15.37</td>
<td>15.39</td>
</tr>
<tr>
<td>Smog</td>
<td>(kg NOₓ)</td>
<td>0.125</td>
<td>0.455</td>
<td>0.580</td>
</tr>
<tr>
<td>Landfill</td>
<td>(dm³)</td>
<td>0.692</td>
<td>0.000</td>
<td>0.692</td>
</tr>
<tr>
<td>Radioactivity</td>
<td>(kBq)</td>
<td>30.26</td>
<td>10380</td>
<td>10410</td>
</tr>
<tr>
<td>Resource Depletion</td>
<td>(year)</td>
<td>0.258</td>
<td>0.317</td>
<td>0.575</td>
</tr>
<tr>
<td>Greenhouse</td>
<td>(kg CO₂)</td>
<td>47.73</td>
<td>41.64</td>
<td>89.36</td>
</tr>
<tr>
<td>Acidification</td>
<td>(kg SO₂)</td>
<td>0.247</td>
<td>0.482</td>
<td>0.729</td>
</tr>
<tr>
<td>Eutrophication</td>
<td>(m³)</td>
<td>0.070</td>
<td>0.017</td>
<td>0.081</td>
</tr>
<tr>
<td>Greenhouse</td>
<td>(kg PO₄)</td>
<td>0.016</td>
<td>0.060</td>
<td>0.077</td>
</tr>
<tr>
<td>Human Toxicity</td>
<td>(kg/kg)</td>
<td>0.353</td>
<td>0.996</td>
<td>1.349</td>
</tr>
<tr>
<td>Ozone Depletion</td>
<td>(kg CFC 11)</td>
<td>1.400</td>
<td>6.921</td>
<td>8.318</td>
</tr>
<tr>
<td>Human Toxicity</td>
<td>(kg/kg)</td>
<td>0.001</td>
<td>0.091</td>
<td>0.092</td>
</tr>
<tr>
<td>Ozone Depletion</td>
<td>(kg CFC 11)</td>
<td>5.114*10⁻⁶</td>
<td>1.814*10⁻⁶</td>
<td>1.864*10⁻⁶</td>
</tr>
<tr>
<td>Smog</td>
<td>(kg ethene)</td>
<td>0.021</td>
<td>0.082</td>
<td>0.103</td>
</tr>
</tbody>
</table>
As the tables illustrate, the logistics function has a greater environmental impact than the processing function in most categories. However, the processing function has a higher contribution to direct greenhouse gases. However, when indirect contributions to the greenhouse effect are included, the total contribution from logistics is actually slightly higher. Thus, logistics has a higher overall environmental impact than processing, per tonne of product shipped, for Borax Europe, in 1995. If these values are to be used for objective and target setting, then a percentage reduction in impact from logistics would yield a higher overall improvement than an equivalent percentage reduction in impact from processing, in all of the environmental impact categories described in this analysis.

9.6.3 Analysis of Total Environmental Impact

The total environmental impact from Borax Europe will show exactly the same trends as the analysis for impact per tonne. It is calculated by multiplying all per tonne values by the number of tonnes shipped: 442,377.277 tonnes in 1995. When this figure is used the following values emerge:

**Table 21: Combined Processing and Distribution Environmental Burdens, Total, Borax Europe, 1995/6 (presented here to 4 significant figures)**

<table>
<thead>
<tr>
<th>Theme</th>
<th>Units</th>
<th>Total Borax Europe, 1995</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land Use</td>
<td>(m²)</td>
<td>6807000</td>
</tr>
<tr>
<td>Smog</td>
<td>(kg NOₓ)</td>
<td>256600</td>
</tr>
<tr>
<td>Landfill</td>
<td>(dm³)</td>
<td>306000</td>
</tr>
<tr>
<td>Radioactivity</td>
<td>(kBq)</td>
<td>4604000000</td>
</tr>
<tr>
<td>Resource Depletion</td>
<td>(year)</td>
<td>254500</td>
</tr>
<tr>
<td>Greenhouse Depletion</td>
<td>(kg CO₂)</td>
<td>39530000</td>
</tr>
<tr>
<td>Acidification</td>
<td>(kg SO₂)</td>
<td>322400</td>
</tr>
<tr>
<td>Ecotoxicity</td>
<td>(m³)</td>
<td>36010</td>
</tr>
<tr>
<td>Eutrophication</td>
<td>(kg PO₄)</td>
<td>33970</td>
</tr>
<tr>
<td>Greenhouse (indirect)</td>
<td>(kg CO₂)</td>
<td>3860000</td>
</tr>
<tr>
<td>Human Toxicity</td>
<td>(kg/kg)</td>
<td>596700</td>
</tr>
<tr>
<td>Odour</td>
<td>(kg NH₃)</td>
<td>40700</td>
</tr>
<tr>
<td>Ozone Depletion</td>
<td>(kg CFC 11)</td>
<td>8.244</td>
</tr>
<tr>
<td>Smog</td>
<td>(kg ethene)</td>
<td>45680</td>
</tr>
</tbody>
</table>

As the table shows, Borax Europe operations and distribution burdens included:

- Almost 40 million kilograms of CO₂ equivalent in Greenhouse gases
- Over 300 thousand kilograms of SO₂ equivalent towards acidification
- Over 250 thousand kilograms of NO₂ equivalent towards smog formation.

Targets to reduce these values could form a suitable basis for any environmental targets for Borax Europe in future years, as will be discussed in Section 9.7.1.6; Environmental Improvement Objectives Expressed in Impact Terms.
9.6.4 Discussion

The study carried out represents a useful starting point in any environmental improvement campaign, since without baseline data it is impossible to monitor progress – positive and adverse – over time. The inventories themselves can provide useful information, even before any environmental impact analysis is carried out, since they illustrate where the major demands for energy and logistics arise.

For example, in the case of Borax Rotterdam, there are two large storage domes that act as reservoirs for material used in operations. The conveyor systems that transfer the material away from these two domes into the process carry out exactly the same function, yet the electricity demands for the two systems are different. The systems used to unload tank 1 - Band slip conveyors C2 and C3 - have a power demand of 117.5 kW when running. However, the systems used to unload tank 2 - Screw conveyors C15A and C15B, together with Band Slip conveyor C16 (and its filter, FC16) - have a power demand of 52 kW when running. In 1995 the system for tank 1 required 189,174.5 kWh, while the system for tank 2 only required 83,720 kWh. It is possible that changing the systems used for tank 1 to match those of tank 2 would provide an energy saving of over 100,000 kWh per year – a reduction of over 4% of the total electricity demand for the site.

Yet it is only when the analysis of impacts is carried out that the improvement options become clear. If one examines the logistics functions, in many cases the customer dictates the mode of transport utilised. In others infrastructure limitations impose the use of trucks for transportation in the absence of an adequate rail or waterway alternative.

However, in many cases there are options. At the present time the truck is the dominant mode of transport used for inland transportation by Borax Europe. As has been illustrated in Section 9.4, policy developments within the European Union would suggest that the use of economic instruments will attempt to adjust the balance of transport modes used away from trucks. Direct legislation, such as the use of emission standards and engine noise limits, and the introduction of increased road taxes, will act to increase the capital cost of using road transportation. Indirect legislation, through increasing fuel levies and road pricing systems, will drive up the variable costs of using road transportation, encouraging users to look for alternatives.

The analysis carried out here provides the environmental justification for examining alternatives to road transportation. For example, if one takes the environmental burdens per 100 tonne kilometres associated with the three modes of inland transportation utilised by Borax Europe, the values presented in Table 22 emerge:
Table 22: Environmental Burden, Per 100 tkm and ranked, Inland Distribution Modes (presented here to 4 significant figures).

<table>
<thead>
<tr>
<th>Theme</th>
<th>Units</th>
<th>40 tonne truck (100 tkm)</th>
<th>Inland Waters Freighter (IWF) (100 tkm)</th>
<th>Rail (100 tkm)</th>
<th>Rank (Highest to Lowest)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land Use</td>
<td>(m²)</td>
<td>3.397</td>
<td>1.737</td>
<td>1.248</td>
<td>1,2,3</td>
</tr>
<tr>
<td>Smog</td>
<td>(kg NOₓ)</td>
<td>0.094</td>
<td>0.052</td>
<td>0.021</td>
<td>1,2,3</td>
</tr>
<tr>
<td>Landfill</td>
<td>(dm³)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Radioactivity</td>
<td>(kBq)</td>
<td>1778</td>
<td>551.3</td>
<td>3312</td>
<td>3,1,2</td>
</tr>
<tr>
<td>Resource Depletion</td>
<td>(lyear)</td>
<td>0.059</td>
<td>0.047</td>
<td>0.022</td>
<td>1,2,3</td>
</tr>
<tr>
<td>Greenhouse Depletion</td>
<td>(kg CO₂)</td>
<td>7.413</td>
<td>6.182</td>
<td>4.107</td>
<td>1,2,3</td>
</tr>
<tr>
<td>Acidification</td>
<td>(kg SO₂)</td>
<td>0.083</td>
<td>0.053</td>
<td>0.028</td>
<td>1,2,3</td>
</tr>
<tr>
<td>Ecotoxicity</td>
<td>(m³)</td>
<td>0.002</td>
<td>0.001</td>
<td>0.000</td>
<td>1,2,3</td>
</tr>
<tr>
<td>Eutrophication</td>
<td>(kg PO₄)</td>
<td>0.012</td>
<td>0.007</td>
<td>0.003</td>
<td>1,2,3</td>
</tr>
<tr>
<td>Greenhouse Indirect</td>
<td>(kg CO₂)</td>
<td>1.426</td>
<td>0.890</td>
<td>0.353</td>
<td>1,2,3</td>
</tr>
<tr>
<td>Human Toxicity</td>
<td>(kg/kg)</td>
<td>0.173</td>
<td>0.113</td>
<td>0.048</td>
<td>1,2,3</td>
</tr>
<tr>
<td>Odour</td>
<td>(kg NH₃)</td>
<td>0.0138</td>
<td>0.013</td>
<td>0.022</td>
<td>3,1,2</td>
</tr>
<tr>
<td>Ozone Depletion</td>
<td>(kg CFC 11)</td>
<td>8.819 *10⁻³</td>
<td>6.654*10⁻⁹</td>
<td>2.422 *10⁻⁹</td>
<td>2,3,1</td>
</tr>
<tr>
<td>Smog</td>
<td>(kg ethene)</td>
<td>0.018</td>
<td>0.011</td>
<td>0.003</td>
<td>1,2,3</td>
</tr>
</tbody>
</table>

The truck is seen as having the highest impact, per 100 tkm, in all but three of the categories, usually followed by the inland waters freighter and the rail option consecutively. Rail has the highest impact on 'radioactivity' and 'odour', with inland waters freighters causing the highest amount of ozone depletion of the three modes, per 100 tkm.

It is at this point that external references are needed. Although road transportation has the highest impact in the majority of categories, it does not have the highest impact in all. Perhaps the higher impact of inland water freighters and rail against ozone depletion outweigh their lower impacts in the other categories. When corporate objectives are set a weighting system will be needed to specify the relative importance of each of the categories. If, once any such weightings are accounted for, the combined scores of the truck are higher than those of the inland waterways and rail systems, then a clear corporate logistics policy would emerge:

"All other factors being equal, rail transportation is the preferred transport mode for inland logistics. Should rail infrastructure be unavailable, inland waters freighters should be used. Only if both rail and waterway infrastructure are unavailable should road transportation be used."

This policy objective would need to be ratified against other corporate objectives, including cost factors.
An example of how this could work in practice is provided by the largest customer for Borax España, Forêt, based in Zaragoza, received 40,974 tonnes of product in 1996. This is about 45% all Borax España shipments (87,007 tonnes) in 1996. Zaragoza is 283km from Borax España, and all shipments are made by truck. However, it would be possible to make the deliveries by train. Shifting some 11,595,642 tkm from truck to rail would provide a substantial reduction in environmental impact.

Table 23: Reduction in Environmental Burdens Associated with Supplying Forêt by Rail Instead of Truck, Borax España (presented here to 4 significant figures)

<table>
<thead>
<tr>
<th>Theme</th>
<th>Units</th>
<th>Current Burden</th>
<th>Alternative Burden</th>
<th>Possible Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(11595642 tkm, 40 ton truck)</td>
<td>(11595642 tkm, rail)</td>
<td>(Current Burden minus Alternative Burden)</td>
</tr>
<tr>
<td>Land Use (m²)</td>
<td>393900</td>
<td>144800</td>
<td>249100</td>
<td></td>
</tr>
<tr>
<td>Smog (kg NOx)</td>
<td>10930</td>
<td>2401</td>
<td>8529</td>
<td></td>
</tr>
<tr>
<td>Landfill (dm³)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Radioactivity (kBq)</td>
<td>206100000</td>
<td>384000000</td>
<td>-177880000</td>
<td></td>
</tr>
<tr>
<td>Resource Depletion (year)</td>
<td>6851</td>
<td>2505</td>
<td>4346</td>
<td></td>
</tr>
<tr>
<td>Greenhouse (kg CO₂)</td>
<td>859500</td>
<td>476200</td>
<td>383300</td>
<td></td>
</tr>
<tr>
<td>Acidification (kg SO₂)</td>
<td>9590</td>
<td>3268</td>
<td>6322</td>
<td></td>
</tr>
<tr>
<td>Ecotoxicity (m³)</td>
<td>262.0</td>
<td>50.46</td>
<td>211.5</td>
<td></td>
</tr>
<tr>
<td>Eutrophication (kg PO₄)</td>
<td>1448</td>
<td>341.4</td>
<td>1106</td>
<td></td>
</tr>
<tr>
<td>Greenhouse (indirect) (kg CO₂)</td>
<td>165300</td>
<td>408800</td>
<td>124400</td>
<td></td>
</tr>
<tr>
<td>Human Toxicity (kg/kg)</td>
<td>20010</td>
<td>5583</td>
<td>14420</td>
<td></td>
</tr>
<tr>
<td>Odour (kg NH₃)</td>
<td>1598</td>
<td>2558</td>
<td>-960.5</td>
<td></td>
</tr>
<tr>
<td>Ozone Depletion (kg CFC 11)</td>
<td>0.102</td>
<td>0.281</td>
<td>-0.179</td>
<td></td>
</tr>
<tr>
<td>Smog (kg ethene)</td>
<td>2045</td>
<td>316.0</td>
<td>1729</td>
<td></td>
</tr>
</tbody>
</table>

Although radiation and ozone depletion values would rise, there would be substantial reductions in the contributions to the other major environmental themes. For example, greenhouse gases would be reduced by over 380,000 kilograms CO₂ equivalent (almost 1% of all greenhouse [CO₂ equivalent] emissions associated with all Borax Europe energy and logistics in 1995).
In the case of energy systems, however, the options are different. In terms of environmental impact per unit energy the analysis presented in Table 24 compares the three energy systems used by Borax Europe:

Table 24: Environmental Burdens, per 100 kWh and ranked, Energy Sources, Borax Europe (presented here to 4 significant figures)

<table>
<thead>
<tr>
<th>Theme</th>
<th>Units</th>
<th>Heat – Gas Per 100 kWh</th>
<th>Electricity Per 100 kWh</th>
<th>Diesel Per 100 kWh</th>
<th>Rank (Highest to Lowest)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land Use</td>
<td>(m²)</td>
<td>0</td>
<td>0</td>
<td>1.547</td>
<td>3, 1 &amp; 2</td>
</tr>
<tr>
<td>Smog</td>
<td>(kg NOₓ)</td>
<td>0.056</td>
<td>0.145</td>
<td>0.551</td>
<td>3, 2, 1</td>
</tr>
<tr>
<td>Landfill</td>
<td>(dm³)</td>
<td>0.053</td>
<td>2.179</td>
<td>0</td>
<td>2, 1, 3</td>
</tr>
<tr>
<td>Radioactivity</td>
<td>(kBq)</td>
<td>0</td>
<td>0</td>
<td>2157</td>
<td>3, 1 &amp; 2</td>
</tr>
<tr>
<td>Resource Depletion</td>
<td>(/year)</td>
<td>0.159</td>
<td>0.125</td>
<td>0.256</td>
<td>3, 1, 2</td>
</tr>
<tr>
<td>Greenhouse Depletion</td>
<td></td>
<td>24.77</td>
<td>46.29</td>
<td>32.76</td>
<td>2, 3, 1</td>
</tr>
<tr>
<td>Acidification</td>
<td>(kg SO₂)</td>
<td>0.044</td>
<td>0.632</td>
<td>0.439</td>
<td>2, 3, 1</td>
</tr>
<tr>
<td>Ecotoxicity</td>
<td>(m³)</td>
<td>0.007</td>
<td>0.212</td>
<td>0.011</td>
<td>2, 3, 1</td>
</tr>
<tr>
<td>Eutrophication</td>
<td>(kg PO₄)</td>
<td>0.007</td>
<td>0.019</td>
<td>0.072</td>
<td>3, 2, 1</td>
</tr>
<tr>
<td>Greenhouse (indirect)</td>
<td>(kg CO₂)</td>
<td>0.694</td>
<td>1.200</td>
<td>7.099</td>
<td>3, 2, 1</td>
</tr>
<tr>
<td>Human Toxicity</td>
<td>(kg/kg)</td>
<td>0.056</td>
<td>0.931</td>
<td>0.840</td>
<td>2, 3, 1</td>
</tr>
<tr>
<td>Odour</td>
<td>(kg NH₃)</td>
<td>0</td>
<td>0.000</td>
<td>0.039</td>
<td>3, 2, 1</td>
</tr>
<tr>
<td>Ozone Depletion</td>
<td>(kg CFC 11)</td>
<td>0</td>
<td>0</td>
<td>3.645*10⁻⁵</td>
<td>3, 1 &amp; 2</td>
</tr>
<tr>
<td>Smog</td>
<td>(kg ethene)</td>
<td>0.006</td>
<td>0.042</td>
<td>0.080</td>
<td>3, 2, 1</td>
</tr>
</tbody>
</table>

In the first instance, the three energy sources are used for different applications, so one cannot decide whether or not to use gas, electricity, or diesel to drive the conveyors, for example. In the second instance, there is no source that clearly has a lower environmental impact than the others. Here a judgement would be needed about corporate priorities on each of the themes to determine the weighting accorded. However, it would appear that gas usually has a lower impact in each of the categories than diesel or electricity, with diesel having the highest impact in eight of the categories and electricity the highest in five categories.

In terms of setting corporate objectives, then, it emerges that gas would appear to have the lowest environmental impact of the three systems used, and so any reduction in energy consumption would give the greatest environmental return if effort was focussed on diesel and electrical consumption. on a per kilowatt hour basis. Further, there are possible alternative energy sources to diesel to drive forklift trucks. It is possible that utilising electricity or gas to drive the forklifts may be a preferred option to diesel.
9.7 Summary and Recommendations for Future Actions

As stated in the project objectives, the purpose of this study has been to determine a baseline for energy consumption and distribution in Borax Europe and the environmental burden associated with these variables. An issues overview outlined why such an assessment would be helpful and why policy trends will continue to encourage improvements to be made in environmental performance in these two areas.

Once this was complete inventories were produced for energy and logistics based partly on existing data, but based in most part on a review carried out with the collaboration of operations, technical projects, and logistics personnel from throughout the European Operations. Their support is greatly appreciated. The energy inventories indicate where power is being used, in what quantities, and from which sources.

The energy inventories showed that Borax Europe consumed 73,866,600 kWh of energy in 1996, the majority of this consumption (81%) by Borax Français, and the dominant energy source being gas (82%) for boilers.

The logistics inventories showed that Borax Europe logistics shifted 461,684,424 tonnes of material in 1995, by the following modes:

- Trans-oceanic Freighter: 180,316,428 tonne kilometres
- Truck: 148,201,954 tonne kilometres
- Inland Waterways Freighter: 64,716,398 tonne kilometres
- Rail Freight: 45,338,085 tonne kilometres

19,307,197 tonnes of these shipments were internal, with 442,377,227 tonnes being shipments to customers.

Environmental Impact Analysis was carried out using the PEMS 4.0 system, at the level of impact per unit and total impact. The functional unit chosen for Borax Europe was “1 tonne product shipped to customers”. The environmental impacts associated with processing and distribution, per tonne shipped to customers were calculated, together with calculations for total impact for Borax Europe in one year. The environmental categories assessed for impact were:

- Land use
- Smog
- Radioactivity
- Resource depletion
- Greenhouse contribution
- Acidification
- Ecotoxicity
- Eutrophication
- Human toxicity
- Odour
- Ozone depletion

Table 25 summarises the total burdens on a per tonne basis and in total for Borax Europe in 1995/6.
Table 25: Summary of Environmental Burdens, Per Tonne and Total, Borax Europe, 1995/6 (presented here to 4 significant figures).

<table>
<thead>
<tr>
<th>Theme</th>
<th>Unit</th>
<th>Per Tonne Total (All Processing + All Distribution)</th>
<th>Total Borax Europe, 1995</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land Use</td>
<td>(m²)</td>
<td>15.39</td>
<td>6807000</td>
</tr>
<tr>
<td>Smog</td>
<td>(kg NO₅)</td>
<td>0.580</td>
<td>256600</td>
</tr>
<tr>
<td>Landfill</td>
<td>(dm³)</td>
<td>0.692</td>
<td>306000</td>
</tr>
<tr>
<td>Radioactivity</td>
<td>(kBq)</td>
<td>10410</td>
<td>4604000000</td>
</tr>
<tr>
<td>Resource Depletion</td>
<td>(year)</td>
<td>0.575</td>
<td>254500</td>
</tr>
<tr>
<td>Greenhouse</td>
<td>(kg CO₂)</td>
<td>89.36</td>
<td>39530000</td>
</tr>
<tr>
<td>Acidification</td>
<td>(kg SO₂)</td>
<td>0.729</td>
<td>322400</td>
</tr>
<tr>
<td>Ecotoxicity</td>
<td>(m³)</td>
<td>0.081</td>
<td>36010</td>
</tr>
<tr>
<td>Eutrophication</td>
<td>(kg PO₄)</td>
<td>0.077</td>
<td>33970</td>
</tr>
<tr>
<td>Greenhouse (indirect)</td>
<td>(kg CO₂)</td>
<td>8.318</td>
<td>368000</td>
</tr>
<tr>
<td>Human Toxicity</td>
<td>(kg/kg)</td>
<td>1.349</td>
<td>596700</td>
</tr>
<tr>
<td>Odour</td>
<td>(kg NH₃)</td>
<td>0.092</td>
<td>40730</td>
</tr>
<tr>
<td>Ozone Depletion</td>
<td>(kg CFC 11)</td>
<td>1.864 *10⁻⁶</td>
<td>8.244</td>
</tr>
<tr>
<td>Smog</td>
<td>(kg ethene)</td>
<td>0.103</td>
<td>45680</td>
</tr>
</tbody>
</table>

In logistics, it was concluded that on a per tonne kilometre basis, rail has the lowest environmental impact of the three inland transportation systems. Truck has the highest, even when operating at 100% utilisation. In energy the picture is less clear, although it appears that gas has the lowest impact, per kilowatt hour of the three sources (gas, electricity, and diesel oil) utilised by Borax Europe.

9.7.1 Future Actions
A number of issues should be resolved to improve confidence in the findings of this study.

9.7.1.1 Completeness of Data
Some data was unavailable during the review. For example, the electrical requirements of Borax Français for unloading are still incomplete. At Borax España, the unloading of vessels is carried out by the Valencia Harbour Authority. Energy data for this activity has not been recorded. Based on the significance of the electrical demands of the cranes at Rotterdam as a proportion of total consumption, this data is important. At Guildford, the review was limited to total values for electricity and gas. There are a number of difficulties in improving the quality of this data, but given that the Guildford facility uses as much energy as Borax Rotterdam, it is recommended that a thorough review is made possible.

9.7.1.2 Review of Exact Logistics Routes Taken
Throughout the logistics review, an assumption was made that the most direct route to destination would be taken (for example, that trucks would use motorway and primary routes wherever practical), unless it was known to be otherwise for a specific customer. Verifying
the exact route for each shipment would be a time consuming task but, once done, could be
used for future calculations automatically if it was so wished.

9.7.1.3 Review of Boiler Characteristics
Given the significance of gas consumption in the energy mix for Borax Europe, particularly in
the boilers at the production sites, it is recommended that a detailed review of performance of
the boilers be carried out to establish relative efficiencies and to establish emissions baselines
for these particular installations. It may be that there are opportunities to share best practice
around Borax Europe in this regard.

A number of recommendations also emerge regarding environmental performance
improvement in energy and logistics in Borax Europe.

9.7.1.4 Alternatives to Diesel for Forklift Operations
It is possible that using alternatives to diesel in the forklift trucks would provide more
environmentally efficient power sources. In particular, natural gas has emerged from the
analysis of Borax Europe as being the most efficient of the three main power sources.

9.7.1.5 Rail Freight as the Most Favoured Option for Inland Logistics
Rail freight accounts for only 17.5% of all inland Borax Europe deliveries (in tonne
kilometres), yet, with the exception of ozone depletion, rail has the lowest impact on all the
environmental impact categories when compared with truck and inland waters freighters.
Even assuming 100% utilisation trucks have the highest impact of the three modes but
account for over 57% of all inland logistics. It is recommended that a logistics policy
expressing a preference for rail freight, followed by inland waters freight, for all inland
logistics wherever practicable be introduced. By way of example, shifting delivery of product
to Forét by Borax España from truck to rail would provide a net reduction in greenhouse gas
contribution of 1% of the total for all Borax Europe operations and logistics.

9.7.1.6 Environmental Improvement Objectives Expressed in Impact Terms
It has been found that the environmental impact, per kilowatt-hour, of the various energy
sources varies, and that the significance of burden in each of the environmental categories
assessed also varies. Thus, it is suggested that any performance targets for energy be
expressed as reductions in contributions to a particular environmental category rather than as
reductions in kilowatt-hours consumed. In certain circumstances, a net reduction in energy
consumed (e.g.: gas usage down 50kWh, electricity consumption up 30 kWh, - net decrease
20kWh) may actually involve an increase in environmental impact in some categories, for
example.
9.7.1.7 Reduction Targets expressed on a Functional Unit Basis

It is suggested that reduction targets be communicated on a per tonne product shipped to customers basis, rather than as a total. This measure is more meaningful, as it is less likely to be distorted by variations in production levels from one year to the next.

While it is important to consider the assumptions made during the analysis of the inventories, and the limitations of the data used, it is felt that the information contained in this study provides a suitable basis for the introduction of environmental performance targets for energy and logistics in the operations of Borax Europe.
10. 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 in an organisation that is among the pioneers in Rio Tinto 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. 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 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.² 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).

² 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).
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. This project emphasises just how important consideration of downstream activities may be through the case study of distribution in a European minerals organisation. 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.

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)
MINERALS IN THE ENVIRONMENT:
A GLOBAL MASS BALANCE FOR BORON

PROJECT DOCUMENT 4
(Vol. 3 PD4)

April 1996
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1. **A Global Mass Balance for Boron**

1.1 Introduction

The objective for this project is to establish mass balances for boron in the environment. This will include values for stores and reservoirs of boron, and values for flows within and across environmental media. In order to carry out this mass balance the element boron will be introduced, with a summary of boron chemical behaviour in the global environment. The pathways by which boron can move within the environment will be discussed, and the geochemical processes from which boron arises and is dispersed in the environment will be introduced.

Anthropogenic mechanisms for boron dispersion will be introduced, together with an introduction into the commercial applications for elemental boron and its compounds. The processes for conversion of boron and boron compounds into forms which can be used in these commercial applications will be examined, and flows arising from these processes quantified. Natural processes, such as movement in atmospheric media, soil, organic media, and aqueous media will be examined to determine mass volumes for transfers in the environment.

This is the first project in a four year engineering doctorate research portfolio pursuing the development of environmental management systems for RTZ Borax. This work will contribute towards the development of that thesis by establishing the background to the environmental context of the management of borates. This work will provide an understanding of the relative scale of the reservoirs and flows of boron in the environment and will provide an understanding to the processes by which boron is transported in the environment. A substantial part of this work has included an examination of the local soil mass balance in the Thames River catchment area of south-east England. That work is included in the portfolio as a separate document, ‘A Local Mass Balance for the River Thames’.

2. Boron Chemistry

Boron is the fifth element in the periodic table, with a relative atomic mass of 10.8. It has properties intermediate between metals and electronegative non-metals. (see Arnold 1991, Romheld & Marschner 1991, Sprague 1972) It is in periodic Group III and, according to Kemp (1956), it is the most electronegative element in the group, and resembles non-metals such as silicon rather than metals in Group III. Cotton and Wilkinson (1968) point out that boron's first ionisation potential is 8.296 eV, a high value, and the second and third potentials are higher still. They argue that,

"The total energy required to produce B^{3+} ions is far more than would be compensated by lattice energies of ionic compounds or by hydration of such ions in solution. Consequently, simple electron loss to form a cation plays no part in boron chemistry. Instead, covalent bond formation is of major importance, and boron compounds usually resemble those of other non-metals, notably silicon, in their properties and reactions." (Cotton & Wilkinson 1968, page 255)

Bulliet (1993) notes out that boron differs from other covalent bond forming elements, such as carbon, in that it is intrinsically electron deficient. He states that,

"With only 3 valence electrons per atom a three dimensional network of conventional pair bonds cannot be formed. Instead boron presents to us, in its elemental forms and in the higher borides, the richest variety of crystal structures of any of the elements." (Bulliet 1993, page 31)

Sprague (1972) explains that boron has an electron structure of 1s^22s^2p, which means that it usually forms three bonds to other elements. The fourth unoccupied orbital can be used for forming another bond by accepting an electron pair from another element. He uses the example of boron trifluoride with ammonia as shown below (see Sprague 1972, page 13):

(Boron Trifluoride)  (Boron Trifluoride + Ammonia Compound)

Cotton and Wilkinson stress the importance of boron compounds with oxygen, arguing that with the possible exception of fluorine, boron appears to have its greatest affinity for oxygen. (see Cotton & Wilkinson 1968, page 262) They observe that boron is always found in oxygenated form in nature, predominantly as borates, and that most boron compounds are converted to oxide, boric acid, or borates upon hydrolysis or burning. The chemical construction of borates is outlined by Sprague (1972) who explains that in a borate, one or more atoms of boron will be linked to a number of oxygen atoms. This forms a negatively charged borate ion which then associates with positively charged ions. Such positively charged ions are usually from sodium, calcium or hydrogen. (see Sprague 1972, page 14) This association gives the crystalline borates or boric acid, B(OH)_3.
2.1 **Borates**

Farmer (1982) illustrates the major basic units found in borate structures. These include the monoborate, diborate, triborate, tetraborate, and pentaborate structures, illustrated below.

**Figure 1: Borate Structures**

- **Monoborate**
- **Diborate**
- **Triborate**
- **Tetraborate**
- **Pentaborate**

Balynina (1993) states that,

"On reacting with oxygen containing compounds, boron exhibits the properties of an active reducing agent. Water vapour reacts with boron (at red heat temperature) producing boric oxide ($B_2O_3$) and displacing oxygen from the water; carbon dioxide is reduced by boron (at 1200°C) to form $B_2O_3$ and carbon." (Balynina 1993, pages 5 to 6)
2.2 **Boric Acid**

The specific reaction between boric oxide and water which gives boric acid is described by Kirk et al (1978) as follows:

\[
B_2O_3 \text{ (glass)} + 3H_2O \rightarrow 2B(OH)_3
\]

(see Kirk et al 1978, page 69)

At elevated temperatures this process can be reversed. Boric acid is moderately soluble in water: ~4% w/w at 15°C. It has a large negative heat of solution, with a solubility of ~27% w/w reached at 100°C. (see Arnold 1991, Kemp 1956) Boric acid is weak and monobasic in its acid behaviour, acting as an OH⁻ acceptor rather than a proton donor. Cotton and Wilkinson (1968) describe the reaction with water as:

\[
B(OH)_3 + H_2O = B(OH)_4^- + H^+
\]

\[
pK = 9.0
\]

Arnold (1991) suggests that the second and third dissociation constants are such that dissociation beyond B(OH)_4⁻ is inconsiderable below pH 13 and agrees with Kirk et al (1978) and Cotton and Wilkinson (1968) that boric acid can polymerise at high concentrations. Farmer (1982) describes the major complex ion formed, B_3O_3(OH)_4⁻:

\[
3B(OH)_3 = B_3O_3(OH)_4^- + H^+ + 2H_2O \quad pK = 6.8
\]

The major boric acid dissociations are as follows:

\[
3B(OH)_3 = B_3O_3(OH)_4^- + H^+ + 2H_2O \quad pK = 6.8
\]

\[
3B(OH)_3 = B_3O_3(OH)_5^{2-} + 2H^+ + H_2O \quad pK = 16.5
\]

\[
4B(OH)_3 = B_4O_6(OH)_4^- + 2H^+ + 2H_2O \quad pK = 14.8
\]

\[
5B(OH)_3 = B_5O_6(OH)_4^- + H^+ + 5H_2O \quad pK = 6.8
\]

Kirk et al (1978) observe that for alkali metal (1:1) borates such as Na_2O.B_2O_3.4H_2O,

"Mixtures of B(OH)_3 and B(OH)_4⁻ would appear to form classical buffer systems where the solution pH is governed primarily by the acid/salt ratio, i.e., [H⁺] = Ka [B(OH)_3 / B(OH)_4⁻]. This relationship is nearly correct for solutions of sodium or potassium (1:2) borates (such as borax; Na_2B_4O_7.10H_2O), where the ratio B(OH)_3 / (OH)_4⁻ = 1, and the pH remains near 9.0 over a wide range of concentrations. However, for solutions that have pH values much greater or much less than 9.0, the pH changes greatly on dilution." (Kirk et al 1978, page 77)

Below pH 9.0 the principal polymeric species contain more B(OH)_3 than B(OH)_4⁻ due to dilution effects increasing the B(OH)_3 / (OH)_4⁻ ratio. The opposite is true above pH 9.0. Polymerisation in saturated boric acid will decrease the concentration of B(OH)_4⁻ in equilibrium with the solid phases, according to Kirk et al (1978), and thus allow more Borax (Na_2B_4O_7.10H_2O), for example, to dissolve.

A widely cited work into the equilibria of borates in aqueous solution is that of Ingri (1963) His values, shown above from Farmer (1982), are used by Mellor (1980), Kirk et al (1978), and Farmer (1982), among others, to demonstrate the distribution of boron species in aqueous solution at 25°C.

Figure 2: Distribution of Boron in Various Ions

At a given pH, the fraction of the total boron in a given ion is represented by the portion of vertical line falling within the corresponding range.
3. Material Pathways

To assist in this mass balance, a material pathway model will be used. Bullock (1993) uses a pollution pathway model to demonstrate how pollution could enter the food chain.

Figure 3: Pollution Pathways (Based on Bullock 1993, page 7; Dennis 1989, page 7)

For the purposes of this work, the model can be adapted to be useful to describe boron flows in the environment instead of pollution. (see ). Landfill needs to be included as a potential long term accumulation site of domestic products containing boron. Some landfills are not contained, so it is possible that boron will be dispersed into other media from this point. Further, a path of material flow from aquatic animals to sediments can be added. When aquatic shellfish die, their shells become part of marine sediment formation. There is also a pathway directly from air to soil, representing dry deposition of material. The revised model pathway looks as shown below:
Figure 4: Materials flows in the environment for boron.
3.1 Interaction Between Environmental Media

The European Environmental Research Organisation (EERO) uses a model to illustrate the systems in the environment and how they interact. The model, illustrated below, shows how materials enter water systems through sewage and effluents entering rivers and seas, through sedimentation processes, through interactions with atmosphere and interactions with soil systems. The model is designed for organic materials but many of the processes will also take place for inorganic materials such as boron.

Figure 5: Environmental Processes for Organic Materials. (Based on European Environmental Research Organisation 1996)
4. Natural Boron Sources

4.1 Global Geochemical History

Before looking at boron specifically, the macro-processes which led to the distribution of minerals and metals in the earth's geochemical history must be introduced. Hartley et al (1980) give a summary of the formation processes. They observe that the consensus among geochemists indicates that the earth began as a gas, which then cooled in three stages:

Stage 1: Gas to Liquid
Stage 2: Liquid to Solid
Stage 3: Solid to Solution

The first stage led to the formation of phases: an iron core, a sulphide layer, a silicate layer, a crust, and an atmosphere. According to Hartley et al.,

"Elements more electropositive than iron occur in the 'hard' silicate phase, whilst the less electropositive 'softer' metals occur in the 'soft' silicate phase. The very soft metals probably occur in the core, which is thought to be metallic." (Hartley et al 1980, page 300)

During the second stage, the cooling from liquid to solid, the rocks were formed. Hartley et al. identify three crystallisation steps in this stage:

Step 1 (~1200°C):
Heavy refractory oxides sank to the bottom. \([\text{Fe}_3\text{O}_4, \text{Cr}_2\text{O}_3, \text{FeTiO}_3, \text{Al}_2\text{MgO}_4, \text{Ca}_5(\text{PO}_4)_3\text{F}, (\text{FeMg})\text{SiO}_4]\)

Step 2 (1200 to 500°C):
Solvent was molten \(\text{SiO}_2\), containing as solutes; \(\text{FeO}, \text{MgO}, \text{CaO}, \text{Al}_2\text{O}_3, \text{B}_2\text{O}_3, \text{Na}_2\text{O}, \text{K}_2\text{O}, \text{CO}_2, \text{SO}_2, \text{H}_2\text{S}, \text{HF}, \text{H}_2\text{O}\). During cooling the metallic elements separated to a limited extent, rarely enough to be extracted economically.

Step 3 (<500°C):
Main solvent was water, containing as solutes; metal ions either too large or too small to fit into any of the lattices formed thus far. This step is associated with anions such as borate, phosphate, sulphide, niobate, molybdate (all rejected by silicate lattices) (see Hartley et al 1980, page 300)

The slow cooling process which took place enabled the metal salts to crystallise out stepwise, according to Hartley et al., and this gives a concentration in layers of the individual ions of metals around the central crust. The third stage is the change from a solid to solution, with the modification of the second stage by weathering processes. Hartley et al. note that the action of water, carbon dioxide, humic acids, volcanic hydrogen chloride and sulphur dioxide selectively extract the principle elements of life; the alkali and earth metals, iron, and manganese, leaving a residue of \(\text{TiO}_2, \text{SiO}_2, \text{Fe}_2\text{O}_3\) and clay. They summarise by saying,

"The incipient earth can be considered as a vast, albeit poorly stirred, soup of metals and ligands which slowly form their preferred complexes." (Hartley et al 1980, page 302)
4.2 Boron Mineral Formation

Boron does not usually occur in its elemental state in the environment. However, it does occur bound in with other elements in many minerals. According to Kistler and Helvaci (1994), over one hundred and fifty minerals, known as borates, contain the element boron. These are summarised in ‘Table 1: Boron-bearing minerals in commercial deposits (from Harben & Bates 1990, page 31)’.

The formation of boron containing minerals appears to be strongly associated with volcanic activity. Kistler and Helvaci (1994) refer to the work of Ozol (1977), and Alonso et al. (1988) and observe that,

“The major borate deposits are found in tectonically active extensional terrain associated with plate boundaries.” (Kistler & Helvaci 1994, page 171)

The process by which boron containing minerals are formed from igneous sources is explained by Kistler and Helvaci. To summarise their explanation, granites have an average boron concentration of 10 parts per million, but boron cannot easily enter the crystal structure usually found in rock forming minerals. As a consequence, when magma crystallises the boron does not become bound in to the structure and is washed out by the water released during the crystallisation process. Boron is released from the crystallising magma, along with any boron removed from any of the surrounding rocks by the high temperatures (300°C to 400°C) and high fluid pressures, and bonds with water driven out as steam to form a borate solution.

For borate to accumulate in any given location, however, a boron source, while clearly a prerequisite, is not enough by itself. Harben and Bates (1990) identify four requirements for the accumulation of boron:
1. A source, like volcanic activity.
2. A body of water in which boron compounds can dissolve.
3. Conditions of evaporation to concentrate the solution to the point of precipitation.
4. Deposition of a protective layer of sediment to preserve the highly soluble borate minerals. (see Harben & Bates 1990, pages 31 to 37)

Once the boron source has released boron which combines with other elements, such as sodium, calcium, and magnesium, among others, to form a borate, water is required to transport the borate. Borates come in many forms with varying degrees of solubility. The more soluble a borate is, the more likely it is to be transported in solution. Once the borate has entered a solution to form a salt, it can either remain in that solution, or it can precipitate out. An example of where this might be possible is in a lake, where the water evaporates out, leaving behind the borate salt. Finally, a protective layer of sediment is needed, otherwise the borates would be dispersed by natural forces such as air movement and water movement.

Such a process would account for inland deposits of borates, such as Ulexite, which is found in lakes and marshes particularly in California, USA, and in Turkey. It would also give rise to marine deposits of boron, where there is a sea floor borate source, such as tectonic boundary activity. But there needs to be a restricted water basin for borate concentrations to increase, so
that evaporation gives rise to progressive decanting, concentrating the boron. (see Kistler & Helvaci 1994, pages 171 to 186) If the borate minerals are not transported away from the crystallising igneous activity then they can be found in assemblages in the metamorphic rocks which are formed under conditions of heat and pressure during volcanic activity. These are found in Eastern Russia and China, as ‘skarn’ deposits.

Table 1: Boron-bearing minerals in commercial deposits (from Harben & Bates 1990, page 31)

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Chemical Composition</th>
<th>B₂O₃ wt. %</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SODIUM BORATES</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Borax (Tincal)</td>
<td>Na₂B₄O₇ · 10H₂O</td>
<td>36.5</td>
<td>The major ore mineral; produced in California, USA and Kirka, Turkey.</td>
</tr>
<tr>
<td>Tincalconite</td>
<td>Na₂B₄O₇ · 5H₂O</td>
<td>47.8</td>
<td>Intermediate or accessory mineral only</td>
</tr>
<tr>
<td>Kernite</td>
<td>Na₂B₄O₇ · 4H₂O</td>
<td>51.0</td>
<td>Major mineral; often converted to borax in the deposit</td>
</tr>
<tr>
<td><strong>SODIUM-CALCIUM BORATES</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ulexite</td>
<td>NaCaB₅O₉ · 8H₂O</td>
<td>43.0</td>
<td>Major ore mineral; particularly common in South America</td>
</tr>
<tr>
<td>Probertite</td>
<td>NaCaB₅O₉ · 5H₂O</td>
<td>49.6</td>
<td>Secondary / accessory mineral</td>
</tr>
<tr>
<td><strong>CALCIUM BORATES</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inyoite</td>
<td>Ca₂B₆O₁₁ · 13H₂O</td>
<td>37.6</td>
<td>Major ore mineral</td>
</tr>
<tr>
<td>Priceite</td>
<td>Ca₄B₁₀O₁₉ · 7H₂O</td>
<td>49.8</td>
<td>Ore mineral in Bigadic, Turkey; minor elsewhere</td>
</tr>
<tr>
<td>Meyerhofferite</td>
<td>Ca₂B₆O₁₁ · 7H₂O</td>
<td>46.7</td>
<td>Intermediate mineral, rarely survives in quantity</td>
</tr>
<tr>
<td>Colemanite</td>
<td>Ca₂B₆O₁₁ · 5H₂O</td>
<td>50.8</td>
<td>Major ore mineral, particularly in Turkey. Often secondary after inyoite</td>
</tr>
<tr>
<td><strong>OTHER BORATES</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sassolite</td>
<td>B(OH)₃</td>
<td>56.4</td>
<td>Natural boric acid. Once extracted in Italy, of historic interest only.</td>
</tr>
<tr>
<td>Hydroboracite</td>
<td>CaMgB₅O₁₁ · 6H₂O</td>
<td>50.5</td>
<td></td>
</tr>
<tr>
<td>Szaibelyite</td>
<td>MgBO₂ (OH)</td>
<td>41.4</td>
<td>Main ore mineral in the C.I.S.</td>
</tr>
<tr>
<td>Boracite</td>
<td>Mg₃B₇O₁₅ · Cl</td>
<td>62.2</td>
<td>Associated with potash deposits, particularly in Europe</td>
</tr>
<tr>
<td>Howlite</td>
<td>H₂Ca₂SiB₅O₁₄</td>
<td>44.5</td>
<td>Accessory mineral</td>
</tr>
<tr>
<td>Kurnakovite</td>
<td>Mg₂B₅O₁₄ · 15H₂O</td>
<td>37.3</td>
<td>Accessory mineral</td>
</tr>
</tbody>
</table>

As the table shows, borates usually have water molecules attached to them. Borax has ten water molecules, so it is called disodium tetraborate decahydrate. Tincalconite is a disodium tetraborate pentahydrate because it has only five water molecules. The number of water molecules attached has a direct bearing on the percentage weight of B₂O₃ in the borate. The higher the water content, the lower the percentage B₂O₃. The process which determines this water content is known as diagenesis. Diagenesis according to the American Geological Institute (1962) is,
"A process involving physical and chemical changes in sediment after deposition that converts it to consolidated rock; includes compaction, cementation, recrystallisation, and perhaps replacement." (American Geological Institute 1962)

In the case of borates, this means that water content is reduced with depth, but can be increased with exposure and weathering processes. So, borax will go through diagenesis to become tincalconite, which in turn can become kernite. Equally, kernite can become tincalconite, which can become borax. (see Harben & Bates 1990, page 31)

Diagenesis fits into a wider cycling system of elements at the earth’s surface. Jenkins and Jones (1980) introduce a schematic for these cycling systems, and show how boron fits into the cycle, along with other minerals. A summary of this schematic is presented in Figure 6.
This demonstrates how natural processes work to give borate deposits in certain conditions in specific geological locations. The US Bureau of Mines (see Lyday 1993 and Crowson 1992) provide information to indicate the quantities and distributions of borates throughout the earth, detailed in Section 4.3, 'Geographic Distribution of Borate Deposits'
4.3 Geographic Distribution of Borate Deposits

4.3.1 Location of Deposits

Crowson (1992) identifies eight countries with significant deposits of borates. Such deposits are usually expressed in terms of the boric oxide (B$_2$O$_3$) content of the available minerals. As has been shown, different borates contain widely differing proportions of their weight in B$_2$O$_3$, depending on the extent to which they are hydrated. A country having large reserves of boron containing minerals does not necessarily have boron reserves in direct proportion. For this reason a B$_2$O$_3$ content for each of the different minerals is identified and this figure is used for the purposes of calculating production and reserves available. Boron oxide contains 31% boron. According to Crowson, in 1991 the B$_2$O$_3$ content of the total reserve base for the planet was some twenty three times greater than anticipated cumulative primary demand between 1991 and 2010. This translates to a static reserve life of 295 years. To compare the figures for boron with those for other minerals and metals:

Table 2: The ‘Adequacy’ of Reserves of Minerals and Metals (From Crowson 1992, page xiii)

<table>
<thead>
<tr>
<th>Mineral/ Metal</th>
<th>Static Reserve Life (years)</th>
<th>Ratio of Identified Reserve Base to Cumulative Primary Demand 1991 - 2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boron</td>
<td>295</td>
<td>23</td>
</tr>
<tr>
<td>Bauxite</td>
<td>220</td>
<td>14</td>
</tr>
<tr>
<td>Chromium</td>
<td>105</td>
<td>23</td>
</tr>
<tr>
<td>Gold</td>
<td>22</td>
<td>0.7</td>
</tr>
<tr>
<td>Lead</td>
<td>20</td>
<td>1.1</td>
</tr>
<tr>
<td>Magnesium</td>
<td>Very Large</td>
<td>Over 40 (excluding brines)</td>
</tr>
<tr>
<td>Sulphur</td>
<td>24</td>
<td>2.9</td>
</tr>
<tr>
<td>Talc</td>
<td>46</td>
<td>6</td>
</tr>
<tr>
<td>Zinc</td>
<td>21</td>
<td>2.1</td>
</tr>
</tbody>
</table>

Harben and Dickson (1984) state that,

“Reliable figures on world reserves of boron minerals are difficult to obtain, but it is clear that the USA and Turkey have as much as 90% of the total. One estimate assigns the USA 200 to 250 million tons of borate ore averaging 25% B$_2$O$_3$; Turkey 150 to 525 million tons averaging 30% B$_2$O$_3$; the USSR 7 to 20 million tons of 20% B$_2$O$_3$; and South America 8 to 15 million tons of 20% B$_2$O$_3$.” (Harben & Dickson 1984, page 19)

In terms of B$_2$O$_3$, then, the USA has between 50 and 62.5 million tons B$_2$O$_3$, Turkey has between 45 and 157.5 million tons B$_2$O$_3$, the former USSR has between 1.4 and 4 million tons B$_2$O$_3$, and South America has between 1.6 and 3 million tons B$_2$O$_3$. These figures would give a world reserve base of between 98 and 227 million tons B$_2$O$_3$. In 1994, world sales of B$_2$O$_3$ came to ~990,000 tons. At this rate of consumption, B$_2$O$_3$ reserves could be expected to last
between 99 and 230 years. The changes in consumption will be discussed in Section 5.2.1, Trends in the End-Use Sectors:

### 4.3.2 Global Borate Mine Production

Boron reserves, then, are substantial in terms of meeting anticipated world demand. The US Department of the Interior’s Bureau of Mines gathers information from all the borate mining companies and carries out its own mineralogy work to assemble data for US and world-wide production and consumption of borates. Their figures give an indication of where major deposits have been discovered which can be commercially extracted.

**Table 3: Boron Minerals: World Production by Country (From Lyday 1993, page 11)**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Argentina</td>
<td>270</td>
<td>261</td>
<td>260 *</td>
<td>250 *</td>
<td>250</td>
</tr>
<tr>
<td>Bolivia (Ulexite)</td>
<td>1</td>
<td>10</td>
<td>3</td>
<td>14</td>
<td>11</td>
</tr>
<tr>
<td>Chile</td>
<td>32</td>
<td>131</td>
<td>132</td>
<td>97</td>
<td>100</td>
</tr>
<tr>
<td>China *</td>
<td>95</td>
<td>74</td>
<td>75</td>
<td>76</td>
<td>77</td>
</tr>
<tr>
<td>Iran (borax)</td>
<td>2</td>
<td>&lt;0.5</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Peru</td>
<td>15 *</td>
<td>25</td>
<td>20</td>
<td>26</td>
<td>30</td>
</tr>
<tr>
<td>Turkey</td>
<td>1231</td>
<td>1174</td>
<td>1253</td>
<td>1100 *</td>
<td>1000</td>
</tr>
<tr>
<td>C.I.S.</td>
<td>200</td>
<td>200</td>
<td>180</td>
<td>160</td>
<td>130</td>
</tr>
<tr>
<td>United States</td>
<td>1149</td>
<td>1114</td>
<td>1094</td>
<td>1240</td>
<td>1009</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>2994</strong></td>
<td><strong>2998</strong></td>
<td><strong>3018</strong></td>
<td><strong>2965</strong></td>
<td><strong>2608</strong></td>
</tr>
</tbody>
</table>

* Estimates.

As the table shows, borate deposits of commercial significance are only found in nine countries. Crowson does not include Iran as a significant world source of borates, which is perhaps not surprising given that Iran’s contribution over the five years indicated ranges from <0.017% to a maximum of 0.067% of the total production in a given year. It is unlikely that there are substantial land based deposits of borates which are not mined due to geographic difficulty of access. The South American deposits are found high in the Andes, and the Chinese deposits are found in the Himalayas, both extremely challenging terrain, as one would expect with tectonic boundaries, yet mining takes place in these locations.

It is important to observe that the US Bureau of Mines figures show how much ore is mined from the ground, not global production of B\textsubscript{2}O\textsubscript{3}. As has been seen, borates contain widely differing B\textsubscript{2}O\textsubscript{3} equivalent compositions. US deposits for example, work out at an average of 50.45% B\textsubscript{2}O\textsubscript{3}, while deposits in Turkey contain approximately 42.08% B\textsubscript{2}O\textsubscript{3}. These figures were cross checked within Borax (Bolton, 1996) by examining approximate sales figures, in tonnes, for the company’s leading three products. Their exact B\textsubscript{2}O\textsubscript{3} content was known, and these percentages gave an approximate B\textsubscript{2}O\textsubscript{3} content, in tonnes, for their products.

These figures gave an average B\textsubscript{2}O\textsubscript{3} content of 50.34%, which corresponds quite closely with the calculation from Crowson’s figures of 50.45% B\textsubscript{2}O\textsubscript{3}. This makes the world mineral production figures clearer. For example, even though Turkey extracts the largest quantity of minerals from reserves in 1989, at 1,174,000 tonnes, compared with the US, at 1,114,000
tonnes, the US actually produced more B2O3 equivalent from their extraction. Crowson gives an average Boron mass ratio of 31(B) : 100(B2O3). (Crowson 1992, page 50) So boron represents 31% of the mass in B2O3.
5. Anthropogenic movement of boron

The geological processes which cause the formation and precipitation of borates have thus been established. But borates very rarely stay near these sources. Two factors have an impact on what happens to borates once they are formed; the influence of nature and the influence of man. This work will look firstly at man’s influence on the distribution, and then at the natural processes.

5.1 Commercial Boron Applications

Borates are important to man for a wide variety of reasons. Many anthropogenic activities require boron and borates as a raw or intermediate material. Arthur F. Taggart, Visiting Professor Emeritus of Mining at Columbia University in 1927, summed up the applications of boron concisely when he said simply,

“Few substances have so diversified applications.” (Taggart 1945, page 3/11)

Boron is used in the glass industry, for borosilicate glass. Manufacturers use boric oxide in their formulations at a range of 10-13%. The use of boron gives glasses of high thermal shock resistance, acid resistance, physical strength, and high aqueous and chemical durability. These glasses are used in oven to table cookware, lab ware, pharmaceuticals containers, vacuum flasks. Nuclear containment depends on low leaching from borosilicate glass. Boron is used in insulation fibre glass, the principal insulating material in the construction industry. It is composed of very thin fibres spun from molten glass, designed to trap and hold air. Usually 4% to 5% B$_2$O$_3$ is incorporated into the formulation to help melting, inhibit devitrification, and improve aqueous durability of insulation fibre glass. Textile fibre-glass contains 6-8% B$_2$O$_3$. Textile fibre-glass used to be used for electrical applications so low sodium was important. Now its major application is for plastics reinforcement. According to Lyday (1993),

“The non-conductive and low dielectric properties of high strength glass-reinforced materials make them transparent to radar and thus valuable for ‘stealth’ applications. Carbon-fibre-reinforced resins can be stronger than metals and, with higher modulus, more stable.” (Lyday 1993, page 4)

Lyday goes on to talk about the use of fibreglass reinforced plastics in flue-gas desulphurisation processes.

“As a result of nearly four decades of research ... fabrication of essentially the entire flue gas desulphurisation system of fibreglass reinforced composites for new large central station units is being considered. This will represent the largest single use of fibreglass reinforced composites in the world.” (Lyday 1993, ibid.)

Boron also finds a variety of uses in the agro-chemicals industry. Butterwick et al (1989) elaborate:

“Boron is an essential trace element for plant growth, and in situations where rapid correction of deficiency is required, borax is applied in fertilisers. Where controlled use over long periods is appropriate, slowly soluble borosilicate frits are used. When applied in higher concentrations, boron is a non-selective herbicide, used for weed control, particularly for non-agricultural purposes.” (Butterwick et al 1989, Page 341)
Boron is also used in vitreous enamels and ceramic glazes. A glaze is a thin coating fused onto ceramic, while an enamel is a thin coating fused onto metal. Here, the glazes and enamels are used for floor tiles, tableware, earthenware, bone china, porcelain, white goods, pots and pans, architectural panelling. There are two reasons for the use of glazes and enamels; protective and decorative. There is no typical composition for these applications since it depends very much on the performance needs of the application. Boron can be added to glass so that it reduces thermal expansion coefficient if glass is fused to a body. It is very important to have a good thermal fit between components. Boron can increase the refractive index and helps resist chemical and aqueous attack.

Boron is used in boride and borohydride form for certain applications. Metallic borides are very hard substances with high melting points and good thermal and electrical conductivity. They are frequently used in abrasive and cutting equipment: boron carbide, $\text{B}_4\text{C}$, has crystal structure and hardness close to industrial diamond. Sodium borohydride is used in bleaching wood pulp, bleaching clay, textile dye reduction, and removal of heavy metal ions from industrial effluent. Sodium borohydride is a powerful reducing agent and converts ions to free metals which can be removed from the waste. Examples include lead recovery from petrol, gold recovery from electroplating, silver from photographic film, mercury from chlor-alkali plants, and copper from printed circuit boards. Sodium borohydride is made by reacting trimethyl borate with sodium hydride. Trimethyl borate is an ester of boric acid.

Boron has applications in the nuclear industry and in related applications such as radiotherapy. The boron-10 isotope is an essential component of nuclear control rods - boron has a high neutron absorbing capacity, enabling high boron steels to be used to regulate the rate of fission reaction in nuclear reactors. These neutron capture properties can be applied in malignant brain and skin cancer treatment. Boron also has applications in the detergents industry. Sodium perborate is a stable oxygen bleach for hot water washing systems. According to Brohult and Forsberg, (1970)

"Sodium perborate is used because of its ability to oxidise certain types of stain which are difficult to wash, for example: tea, coffee, fruit, perspiration." (Brohult & Forsberg 1970, page 3)

Other boron applications include flame retardation, fungicides, electroplating, electrolytic capacitors, dyestuffs, antifreeze additives, cement and concrete for setting rate control, and as an additive in starch adhesives. Finally, as Professor Taggart explains, “Boric acid is used in eye-washes, for hair waving,” and, enigmatically, “in other ways.” (Taggart 1945, page 3/11)

With such a wide range of end uses, one would expect geographic consumption of borates to be fairly widespread. Between 1988 and 1992, just two countries; the USA and Turkey, account for between 76.57% and 79.49% of total world production in any given year. Yet, according to figures from the US Bureau of Mines, the US exported boric acid and sodium borates to 42 countries directly in 1991 and 1992. (see Lyday 1993) Many of the ports receiving directly from the United States, such as Rotterdam, Holland and Valencia, Spain act as break of bulk points for further distribution within Europe. Therefore, the number of countries who use borates as primary or secondary materials in production could be even higher than the forty two declared by the US Bureau of Mines.
5.2 Consumption Levels of Borates in Commercial Applications

As the following table demonstrates, glass products, ceramics, bleaches, and agricultural applications dominate consumption of borates.

Table 4: Regional End Use Patterns for Borates (percentages of regional total) (Based on Crowson 1992, page 51)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Glass products</td>
<td>58</td>
<td>Glass products</td>
<td>26</td>
<td>Glass products</td>
<td>37</td>
</tr>
<tr>
<td>Agricultural and biological</td>
<td>5</td>
<td>Agricultural</td>
<td>2</td>
<td>Agricultural</td>
<td>8</td>
</tr>
<tr>
<td>Porcelain and enamel</td>
<td>3</td>
<td>Ceramics</td>
<td>18</td>
<td>Ceramics</td>
<td>16</td>
</tr>
<tr>
<td>Soaps and detergents</td>
<td>8</td>
<td>Bleaches</td>
<td>39</td>
<td>Other</td>
<td>39</td>
</tr>
<tr>
<td>Chemical fire retardants</td>
<td>4</td>
<td>Other</td>
<td>15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>22</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5.2.1 Trends in the End-Use Sectors:

Harben and Dickson (1984) compiled an overview for the economic and market outlook for borates, discussing the production trends in the borate producing countries, and the market trends in the various application areas for borates. The key markets were identified as being glass, particularly glass fibre; and soaps and detergents; as well as enamels, frits and glazes; agricultural applications. It was observed that demand for borates is strongly linked to macro-economic factors. For example, growth in the insulation fibreglass market between 57,880 tons in 1982 and 91,400 tons in 1983 in the USA was argued to be a result of improving macro-economic conditions, leading to growth in the construction of new housing.

Textile fibre glass has been identified as a growth market, as demand for glass fibre composites for automobile construction, sports equipment applications, and aircraft construction, among others, grows rapidly. Use of borates in detergents, on the other hand, has been identified as a declining market, as detergent manufacturers seek to reduce costs by reducing the quantity of active ingredients they use. Harben and Dickson go on to discuss other market trends, observing that demand for agricultural applications is extremely variable, being driven by agricultural produce market changes and temporal climatic conditions, and noting for other markets that,

"There are various miscellaneous uses including the manufacture of some materials for high technology applications in advanced ceramics for example. Although there is a high added value factor in the production of advanced materials, and growth promises to be high, the volume is small and these markets are not expected to have a major effect on the overall market for boron minerals." (Harben & Dickson 1984, page 23)
Market share data estimates from Borax Europe, the European division of RTZ Borax who represent over 50% of world B$_2$O$_3$ sales, give a breakdown of borate end-use in terms of metric tons of B$_2$O$_3$ for the years 1994-1996 based on its own market research and planning data. Global consumption is divided along similar lines to the US Bureau of Mines, with the three major regions: North America, Europe, and International (the rest of the world), being classified. Detailed figures for the former Soviet Union and China are extremely scarce. It is only possible to determine how much product is going into and out of these countries. Determining accurately what is taking place within these countries, by end-use, is not possible. Estimates for production within these countries were given earlier, based on figures from the US Bureau of Mines. Due to reasons of commercial sensitivity, however, these figures cannot be disclosed. For the purposes of this research, global totals for each end-use area, rounded to the nearest 10,000 tonnes B$_2$O$_3$ will be used. The global end-use figures for 1994 break down as shown in Table 5.

**Table 5: Global End Use Volume, to Nearest 10,000 Metric Tons B$_2$O$_3$, 1994. (From Lawrence 1995)**

<table>
<thead>
<tr>
<th>Product</th>
<th>Total Market Sales 1994 (Metric Tons B$_2$O$_3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insulation Fibreglass</td>
<td>180,000</td>
</tr>
<tr>
<td>Textile Fibreglass</td>
<td>130,000</td>
</tr>
<tr>
<td>Borosilicate Glass</td>
<td>80,000</td>
</tr>
<tr>
<td>Frit/ Ceramics</td>
<td>120,000</td>
</tr>
<tr>
<td>Detergents</td>
<td>20,000</td>
</tr>
<tr>
<td>Perborate</td>
<td>170,000</td>
</tr>
<tr>
<td>Distributors</td>
<td>100,000</td>
</tr>
<tr>
<td>Plant Food</td>
<td>50,000</td>
</tr>
<tr>
<td>Cellulose Insulation</td>
<td>20,000</td>
</tr>
<tr>
<td>Other</td>
<td>120,000</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>990,000</strong></td>
</tr>
</tbody>
</table>

The underlying growth rate for borates markets is anticipated to be approximately 2% p.a. in terms of B$_2$O$_3$ sold (Taylor, 1996) What the export information and the end-use figures demonstrate is that there are few concentrated sources of boron which, through anthropogenic activity, disperse boron into the wider environment. The figures show where boron is used in production or sold for further break of bulk by distributors but do not show how much wider still the consumption of products with borate ingredients is. Some of the processes and products themselves involve a great degree of dispersion of boron or borates into various media. For example, agricultural applications of boron will entail the movement of boron into land plants and land animals, and, through leaching and rainwater surface run off, into water systems as well. Detergents will end up in the water system also, by being washed out of domestic and industrial laundry processes into the waste water treatment system. As Brohult and Forsberg elaborate:

"Upon oxidation, perborate is reduced to borate. At temperatures below 65°C, some of the perborate remains unreduced and passes out with the wash water into the outlet, where it should, however, be reduced by readily oxidisable compounds present there." Brohult & Forsberg 1970, page 3)
Antifreezes and paints may also end up in the water system, and ceramic and enamel glaze and frit manufacture will have waste water which will contain boric oxides. Thus, the activities of boron consumption will introduce boron into the environment from a wide variety of sources. For the purposes of this work it is necessary to make a detailed investigation of the processes associated with the dominant end-use applications of borates to gain an understanding of the size of anthropogenic contribution to global borate dispersion.
5.3 Process Losses from Anthropogenic Conversion

5.3.1 Primary Processing

A considerable amount of process research has taken place at Borax' major mining and processing operation, at Boron, USA. Borates are mined and refined into borax, Na₂B₄O₇·10H₂O, or converted into boric acid, B(OH)₃, or related products before being stored in silos or domes ready for shipping. Boron recovers approximately 450,000 metric tonnes B₂O₃ equivalent per annum. (1991 figures) The majority of this recovered ore goes straight to borax pentahydrate (350,000 metric tonnes), with the rest going to borax decahydrate, anhydrous borax, boric oxide, and boric acid. The group has processing operations in Coudekerque in northern France, producing boric acid at levels of approximately 18,000 metric tonnes B₂O₃ per annum, and in Argentina, producing borates from mines in the Andes. (see Bates 1996)

5.3.1.1 Mining and Refining Borates: Primary Processing System

There are four basic steps for the mining of borates at Boron.
1. The overburden, the clay material which covers the ore, and the borate ore itself are loosened by the use of explosives blasting;
2. The overburden is removed using electronic shovels and trucks. Each truck can carry 200 tons of material;
3. The borate ore is then mined using electronic shovels and is transported by truck to a primary crusher at the pit. Large skip-loaders blend the ore as it is transported towards the primary crusher;
4. A conveyor belt system transports the now crushed ore from the open pit to stockpiles on the surface.

The main borax production schematic is shown in Figure 7.
Process research in 1991 carried out at Boron quantified materials streams in the production process. This included a breakdown of the fractions of materials carried in suspension and solution in the water streams. To summarise the borax production process:

1. A bucket wheel reclaimer moves borate ore from the stockpile to the conveyor belts.
2. The conveyor belts carry the ore past separators which removes any magnetic contaminants such as iron. The ore is then crushed and screened, and is held in the fine ore bins ready for processing.

3. The fine ore moves to the turbo dissolver and thence through Tyrock screens. Here it dissolves through agitation in contact with hot borate solutions. Rock, sand and other solids are removed during this process. The removed materials are lost to the environment as gangue.

4. The now saturated borax solution is pumped to the thickeners, which are settling tanks where any remaining insoluble matter is removed from the solution. Again, this matter is lost to the environment as gangue.

5. Clear borax solution is taken from the top of the thickeners and enters vacuum crystallisers which cool the solution to form crystals of borax pentahydrate (known as ‘5 mol’) and borax decahydrate (‘10 mol’).

6. The crystallised products are dried and cooled, and then stored in silos to await shipping.

5.3.1.2 Process Flow Volumes

For the purposes of this work the exact values identified by the process research at Boron will not be used. Given that the operations at Boron represent slightly under half of world boron production, the data from this site will only give a general indication of activity at a global level. The use of data accurate to fractions of a tonne from Boron would give a false representation of the accuracy of data at a global level. However, process data from other operations is not available for this work. Based on data from Boron (Bolton 1996), it will be assumed that primary processing recovers between 80% and 90% of B₂O₃ equivalent. During the pre-processing stage, when the ore is crushed and ground ready for processing, a great deal of dust is generated, but this takes place in a ‘dust house’ where any airborne particulates can be collected and fed into the production process. Losses, therefore, are in the form of the gangues and losses to solar ponds.

There are two sources of gangue in the primary processing. The first is gangue from the screening at the end of the dissolving phase. This includes B₂O₃ equivalent in the gangue and anhydrous borax. The second gangue loss takes place during the thickening phase. This flow is a dense mud, containing anhydrous borax, borax decahydrate, insolubles, and water. The solar ponds at Boron cover an area of over 300 acres. The purpose of the solar ponds is to collect residue from the cold crystallisation phase of primary processing. The action of sunlight evaporates water from the residue, concentrating the remaining solution. The flow to solar ponds will include anhydrous borax and borax decahydrate.

Given a process recovery of approximately 450,000 tonnes B₂O₃ per annum at Boron, representing 80% to 90% of process input, the process losses to gangue and solar ponds will be in the range of 45,000 tonnes to 90,000 tonnes per annum. The B₂O₃ recovered at Boron represents approximately 90% of Borax B₂O₃ sales in 1994, and almost 47% of global B₂O₃ sales in 1994. Process data is not available for non-Borax companies so accurate data cannot be used. However, one can use the figures from Boron to estimate what the flow volumes will be on a global level. There will be errors associated with such an exercise. Non-Borax companies, for example, sell some ore direct to customers, without primary processing.
Different ores will have different levels of process loss associated with them, but if, for the purposes of this project, we assume that global primary processing recovers between 80% and 90% of $\text{B}_2\text{O}_3$ going into processing, and the relative percentages lost to gangue and solar ponds are the same as those at Boron, then it will be possible to gain an estimate of global volumes for 1994, by working backwards from sales data. In order to do that however, the secondary processing stage must be analysed.

5.3.2 Secondary Processing

If boron is not to be distributed in a form based on the crystallisation process in the primary production phase, it can be converted to boric acid, $\text{H}_3\text{BO}_3$. According to sources at US Borax, shipped production of boric acid at Boron, California, contains approximately 90,000 tonnes $\text{B}_2\text{O}_3$ (Bates 1996). The production process is as follows:

1. Kemite ore is dissolved in a mixture of sulphuric acid and hot borax liquor;
2. The resulting solution passes next into ‘classifiers’, where large insolubles are removed by mechanical rakes;
3. The liquor then passes through a series of thickeners where fine insolubles are settled out;
4. The resulting solution is filtered and pumped to storage tanks that feed the crystallisers, where the desired boric acid crystals are formed;
5. Slurry containing the boric acid crystals is pumped into the granulating area where the crystals are washed, centrifuged, and dried;
6. Each day’s production is stored in day bins for sampling and analysis. Subsequently, the product is transferred to large storage silos to await shipment.
The boric acid process looks as shown in Figure 8.

**Figure 8: Boric Acid Process Schematic**

The two major process losses are tailings and gangue, which go to tip, so process losses can be designated as going to land, with leaching a possibility for the soluble fraction of gangues and tailings. The process efficiency of the boric acid plant at Boron, California, in terms of B$_2$O$_3$ yield, is approximately 75%. Using a final product volume of 90,000 tonnes B$_2$O$_3$, the following process volumes arise for Boron:

B$_2$O$_3$ Output to Product = ~90,000 tonnes
B$_2$O$_3$ Input to Process = ~90,000 * (1/0.75) tonnes = ~120,000 tonnes
B$_2$O$_3$ To Tailings & Gangue = ~30,000 tonnes

**5.3.3 Global Processing Volumes**

Referring back to Section 5.3.1.2, which looked at process flow volumes for Boron's primary process, it can be seen that primary processing yielded ~450,000 tonnes of B$_2$O$_3$ each year, of which, ~120,000 tonnes goes into secondary processing to boric acid, which in turn yields

~90,000 tonnes $\text{B}_2\text{O}_3$. In other words, approximately 27% of primary production then goes to boric acid processing, with approximately 20% of the primary process yield emerging as boric acid product. If one makes an assumption that this data is representative of production systems for boron elsewhere it is possible to work backwards from sales data to produce a mass balance for the processing systems.

World-wide sales of $\text{B}_2\text{O}_3$ are ~990,000 tonnes. Of the net output from the primary processing stage, 27% goes to boric acid production (20% reaches the market, 7% is lost to tailings and gangue), and 73% goes to market without passing through the boric acid plant. Thus, 93% of primary process yield reaches the market. Using process yield data from sections 5.3.1.2 and 5.3.2, the following calculation is possible:

\[
\begin{align*}
\text{Total B}_2\text{O}_3 \text{ Sales} & = \sim 990,000 \text{ tonnes} \\
\text{Sales as } \% \text{ of Primary Yield} & = 93\% \\
\text{Primary Yield} & = \sim 1,065,000 \text{ tonnes} \\
\text{Primary Yield as } \% \text{ of Primary Input} & = 80\% \text{ to } 90\% \\
\text{Primary Input} & = \sim 1,180,000 \text{ to } \sim 1,330,000 \text{ tonnes} \\
\text{The following process flows can thus be calculated:} \\
\text{Primary Process Input} & = \sim 1,180,000 \text{ to } \sim 1,330,000 \text{ tonnes} \\
\text{B}_2\text{O}_3 \\
\text{Primary Process Losses to} \\
\text{Gangue and Solar Ponds} & = 10\% \text{ to } 20\% \text{ of Primary Input} \\
\Rightarrow & \sim 118,000 \text{ to } \sim 265,000 \text{ tonnes} \\
\text{Primary Process Yield} & = \sim 1,065,000 \text{ tonnes} \\
\text{Primary Process Direct to Sales} & = \sim 73\% \text{ of Primary Process Yield} \\
\Rightarrow & \sim 775,000 \text{ tonnes} \\
\text{Input into Boric Acid Processing} & = \sim 73\% \text{ of Primary Process Yield} \\
\Rightarrow & \sim 290,000 \text{ tonnes} \\
\text{Boric Acid Losses to Tip} & = \sim 25\% \text{ of Boric Acid Input} \\
\Rightarrow & \sim 73,000 \text{ tonnes} \\
\text{Boric Acid Yield to Sales} & = \sim 217,000 \text{ tonnes} \\
\Rightarrow & \sim 217,000 \text{ tonnes} \\
\text{Net B}_2\text{O}_3 \text{ Produced for Sales} & = \sim 775,000 \text{ + } 217,000 \text{ tonnes} \\
\Rightarrow & \sim 992,000 \text{ tonnes}
\end{align*}
\]

The starting point for the calculation was a total sales figure of ~990,000 tonnes $\text{B}_2\text{O}_3$. Given the rounding of data in the calculations, an error of 2,000 tonnes, or 0.2%, is satisfactory. Thus, to produce ~990,000 metric tonnes of $\text{B}_2\text{O}_3$ for sales, between 1,180,000 and 1,330,000 tonnes of $\text{B}_2\text{O}_3$ must be mined. There are caveats which need to be emphasised. The first is that not all $\text{B}_2\text{O}_3$ is mined. Boron can occur in nature as undissociated boric acid. Italy, for example, has sources of boric acid in certain mountainous areas. The second is to restate that boron occurs in different ores at different levels. Insoluble $\text{B}_2\text{O}_3$ cannot be removed from the ore using the primary process used at Boron since the process can only be used for $\text{B}_2\text{O}_3$ in dissolved form. Different ores will have different insoluble $\text{B}_2\text{O}_3$ contents. Nonetheless, the majority of global $\text{B}_2\text{O}_3$ production uses process techniques similar to those used at Boron,
and the figures used will give an indication of the magnitude of global losses during production.

5.3.4 Insulation Fibreglass

Insulation fibreglass, or insulation glass wool, applications accounted for approximately 180,000 metric tons of B$_2$O$_3$ sales in 1994. This application area was the largest market for B$_2$O$_3$, taking 17.84% of total world-wide B$_2$O$_3$ sales that year. In North America insulation fibreglass was even more significant, accounting for 30.35% of B$_2$O$_3$ sales in 1994. Ceuterick (1993) carried out a life cycle analysis into insulation fibreglass in 1993. His figures are used in this report. The primary life cycle for insulation fibre glass is shown below:

**Figure 9: Primary Life Cycle of Insulation Fibre Glass. (From Ceuterick 1993, page 30)**

The figures in Table 6 were produced for the materials used in the manufacture of glass (per ton of glass produced) for insulation glass wool purposes.

**Table 6: Raw materials used in producing 1 metric ton of insulation fibre glass. (from Ceuterick 1993, ibid.)**

<table>
<thead>
<tr>
<th>Material</th>
<th>Manufacturer 1</th>
<th>Manufacturer 2</th>
<th>Manufacturer 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartz Sand</td>
<td>580 - 650 kg</td>
<td>560 kg</td>
<td>320 kg</td>
</tr>
<tr>
<td>Soda (Na$_2$CO$_3$)</td>
<td>140 - 170 kg</td>
<td>215 kg</td>
<td>125 kg</td>
</tr>
<tr>
<td>Dolomite (CaCO$_3$ + MgCO$_3$)</td>
<td>70 – 120 kg</td>
<td>140 kg</td>
<td>75 kg</td>
</tr>
<tr>
<td>Resort (B$_2$O$_3$)</td>
<td>20 - 80 kg</td>
<td>82 kg</td>
<td>82 kg</td>
</tr>
<tr>
<td>Limestone</td>
<td>not specified</td>
<td>50 kg</td>
<td>18.5 kg</td>
</tr>
<tr>
<td>Sodium sulphate</td>
<td>-3 kg</td>
<td>3.5 kg</td>
<td>3.5 kg</td>
</tr>
<tr>
<td>Cullet</td>
<td>not specified</td>
<td>0 kg</td>
<td>310 kg</td>
</tr>
</tbody>
</table>

Primary raw materials and cullet are mixed and melted in a furnace. Operating temperatures here are about 1400°C. Once melted, the mixture is spun, during which silicon oil and
bonding agents are added. The resulting mass is cured at ~220°C. The material has any facing, such as aluminium, or paper, added and is then cut to shape, packed, stored, or shipped. (Ceuterick 1993, page 30) There are process inefficiencies which give rise to emissions of B₂O₃. Ceuterick calculates a figure for borax emissions of 56 mg particulate B₂O₃ per kilogram glass wool and 448 mg gas B₂O₃ per kilogram glass wool produced, during the glass melt stages of production. (Ceuterick 1993, page 35)

Water is also needed in the production of glass wool. Water is necessary for diluting bonding agents, flue gas washing, and cooling operations. According to Ceuterick, “A quasi closed water process is possible. A first circuit uses the waste water stream caused by cleaning the electrostatic precipitators. By filtering this flow, the particulates are removed and an almost clean flow of process water is generated which can be used for supplementing the next circuit. The purpose of the second circuit is to wash the flue gases generated by the production of glass wool. After skimming the solids, an almost clean flow of process water is derived. This flow is used for the dilution of bonding agents.” (Ceuterick 1993 page 35)

As far as can be determined, with the exception of airborne material, any borates which are not used during glass melting, are recovered as caked material and can be returned to the material feed without release into the external water stream. Airborne emissions, do exist, nonetheless. Using B₂O₃ global sales figures for insulation fibreglass of 180,000 metric tons in 1984 and maximum possible figures for total airborne emissions, i.e. the highest quantity of B₂O₃ consumed in production: 82kg per product ton, airborne emissions can be calculated:

\[
\text{Airborne emissions from insulation fibre glass production:}
\]
\[
= 56 \text{ mg/kg dust} + 448 \text{ mg/kg gas}
\]
\[
= 56 \text{ g/ton dust} + 448 \text{ g/ton gas.}
\]

Remaining B₂O₃ which goes into product or cake:
\[
= 82 \text{ kg} - 0.056 \text{ kg} - 0.448 \text{kg}
\]
\[
= 81.496 \text{ kg.}
\]

Thus, 0.068% of B₂O₃ used is lost as B₂O₃ dust, 0.546% is lost as B₂O₃ gas, and 99.386% either goes into product or is cycled in process fluids before returning to the production process. If 180,000 metric tons of B₂O₃ are used in insulation fibre glass production, then:
\[
\sim 122 \text{ tons is released to the atmosphere as B}_2\text{O}_3 \text{ dust.}
\]
\[
\sim 983 \text{ tons is released to the atmosphere as B}_2\text{O}_3 \text{ gas.}
\]
\[
\sim 178,895 \text{ tons goes into product or fluid cycling.}
\]

5.3.5 Borosilicate Glass and Textile Fibre Glass

In 1994, approximately 210,000 tonnes of B₂O₃ was sold for use in textile fibre glass and borosilicate glass applications. At an atomic level, the average co-ordination number in a silicate glass is dependent on the amount of Na₂O present. B₂O₃ has a natural three fold co-ordination, but in the presence of modifying oxides such as Na₂O some B₂O₃ will change to four fold co-ordination (see Shand 1958). Donohoe (1988) explains the resulting anomaly,
“Upon addition of a modifier oxide, one of two things can occur; a non-bridging oxygen can be formed or a boron atom can become bonded to four bridging oxygen atoms. There is a negative charge associated with the tetrahedrally co-ordinated boron atom which is compensated by a nearby alkali ion. There is a marked increase in the strength and connectivity of the structure which is attributed to the $\text{BO}_4^{5-}$ groups bonding in four directions, creating a three dimensional rather than two dimensional structure.” (Donohoe 1988, pages 1 to 2)

The use of $\text{B}_2\text{O}_3$ in glass reduces melting temperatures in furnaces by approximately 20°C for every 1% $\text{B}_2\text{O}_3$ w/w addition to the melt (see Simon 1993, pages 579 to 581). $\text{B}_2\text{O}_3$ will reduce the tendency of glass to suffer devitrification - the formation of crystallites within the glass - which will, therefore, reduce points of weakness within the glass (see Simon 1993, ibid.). Borosilicate glasses are used in laboratory applications, and are made from hollow glass. Insulation and textile glasses using boron are made using a fibering technique. The various glass production routes are shown over-page (see Figure 10: Glass Product Processing Routes (Based on Commission of European Communities 1988, page 26)).
Particulate emissions from glass furnaces results from three main sources; 1. volatilisation of glass forming compounds from glass melt surface and from batch. 2. carry-over of fine batch particles. 3. metal oxides and sulphates from combustion of fuel oil. Previous studies have shown that carry-over in modern furnaces typically contributes only 5% to 15% of total particulate emissions and that volatilisation is the most important mechanism for gas fired furnaces (see Kobayashi et al 1993, page 47).
There is insufficient data to calculate a value for atmospheric losses of boron from the various glass production routes by using data from Tooley (1984) on emissions from uncontrolled glass melting furnaces and data from Beerkens (1995) on the composition of emissions from glass furnaces. Tooley divides the glass industry into five categories: flat glass, container glass, pressed and blown soda lime glass, pressed and blown non soda lime glass, and wool fibre glass. According to Tooley, the non soda lime pressed and blown glass consists of 47.8% borosilicate glass, 30.4% opal glass, and 21.7% lead glass (Tooley 1984, page 1070). Tooley discusses the amount of particulate matter released per unit product for uncontrolled glass melting furnaces, electric melting furnaces and furnaces with air filter systems, but does not discuss how much of this particulate matter may be boron.

Beerkens (1995) has eight categories: container glass made using oil fired furnaces, container glass made using natural gas fired furnaces, flat glass, borosilicate glass made using oil fired furnaces, borosilicate glass made using electrical melting furnaces, oil fired lead glass, gas fired flat glass, and gas fired sodium borosilicate glass. He discusses gaseous emissions in some detail, giving a breakdown of the proportion of different compounds, including B$_2$O$_3$, per unit volume of gaseous emission. However, he does not discuss how much gaseous emission is actually released per unit product. In other words, the texts give only half of the information needed to carry out a calculation to determine quantities of boron released.

However, the work of Ceuterick on insulation fibre glass can be used to give an estimate of emissions for other glass products. To restate the findings herein based on Ceuterick (1993):

'Thus, 0.068% of B$_2$O$_3$ used is lost as B$_2$O$_3$ dust, 0.546% is lost as B$_2$O$_3$ gas, and 99.386% either goes into product or is cycled in process fluids before returning to the production process' (see Section 5.3.4, 'Insulation Fibreglass'). Using these relative values for borosilicate glass and textile fibre glass, the following calculation can be made:

If 210,000 metric tons of B$_2$O$_3$ are used in borosilicate glass and textile fibre glass production, then:

-143 tons is released to the atmosphere as B$_2$O$_3$ dust.
-1147 tons is released to the atmosphere as B$_2$O$_3$ gas.
-208,710 tons goes into product or fluid cycling.

5.3.6 Perborate and Detergents

Globally, the second most important end-use area for B$_2$O$_3$ is perborate, with approximately 170,000 tons going to this area in 1994, with a further 20,000 tonnes going directly to detergents. The main application areas for sodium perborate are detergents, household cleaners, and antiseptics. Information about the exact breakdown of market shares in these application areas is commercially sensitive and is not available for this work. From an environmental standpoint, it could be argued that this information is non-essential. In final use, all three applications are disposed of into the drainage system and end up in river systems. Perborate is used in two forms in detergents: PBS4 and PBS1. PBS4 is sodium perborate tetrahydrate, while PBS1 is the partially dehydrated form of sodium perborate tetrahydrate: sodium perborate monohydrate.
The sodium perborate production process is summarised by Raymond and Butterwick (1992):

“The chemical production of sodium perborate is now the dominant method of manufacture and involves the treatment of borax (and in most cases the pentahydrate form, $\text{Na}_2\text{B}_4\text{O}_7 \cdot 5\text{H}_2\text{O}$) with sodium hydroxide and then hydrogen peroxide:

$$\text{Na}_2\text{B}_4\text{O}_7 + 2\text{NaOH} + 4\text{H}_2\text{O}_2 + 11\text{H}_2\text{O} \rightarrow 4\text{NaBO}_3 \cdot 4\text{H}_2\text{O}$$

After treatment the tetrahydrate crystallises out and can be easily separated from the parent liquid by standard filtration or centrifugal methods.” (Raymond & Butterwick 1992, page 290)

In fact, for greater clarity, the reaction should be expressed as:

$$\text{Na}_2\text{B}_4\text{O}_7 \cdot 5\text{H}_2\text{O} + 2\text{NaOH} + 4\text{H}_2\text{O}_2 + 6\text{H}_2\text{O} \rightarrow 4(\text{NaBO}_3 \cdot 4\text{H}_2\text{O})$$

The disodium tetraborate pentahydrate form is used in perborate manufacture as the decahydrate form is more costly to transport since extra $\text{H}_2\text{O}$ has to be transported. Continued controlled drying will drive off sufficient free water to yield firstly the tetrahydrate, then, if continued, the monohydrate.

A general schematic of the production process used for PBS4 production is shown below:

**Figure 11: PBS4 Production Schematic (from Bolton 1995)**
Assessing the emissions and releases to the environment of boron containing material during production is not straightforward. Raymond and Butterwick maintain that there are negligible amounts of solid waste perborate related discharges associated with perborate production, and that perborate discharges to liquid phase are ‘minimal’ (see Raymond & Butterwick 1992, page 292) due to recycling of crystallisation liquors. Bolton (1995) stresses that process losses will range from 1% to 4% depending on the source of $\text{B}_2\text{O}_3$ used. This is indirectly due to the variation in crystallising systems used - some will remove water from the system, others will not. The need to balance water in the process will affect the amount of boron ‘purged’ in process liquors and solids. Processes based on sources of $\text{B}_2\text{O}_3$, such as borax pentahydrate and borax, experience process losses of approximately 1%. ~0.16% of process volume is lost as solid waste, and ~0.87% is lost in liquid effluent. Processes based on borate ores such as tincalconite will experience process losses of approximately 3.1% as solid waste and 0.9% as liquid effluent. Using these relative values for perborate production, then the following calculation can be made:

If ~190,000 tonnes of $\text{B}_2\text{O}_3$ are used in perborate and detergent manufacture, then:

- ~304 tonnes to ~5890 tonnes are released to landfill as $\text{B}_2\text{O}_3$ solid waste.
- ~1653 tonnes to ~1710 tonnes are released to aqueous systems as $\text{B}_2\text{O}_3$ liquid effluent.
- ~182,400 tonnes to ~188,043 tonnes is sold as product.

### 5.3.7 Frit / Ceramics

Sales of $\text{B}_2\text{O}_3$ into the ceramics frits market accounted for 118,462 tons of product worldwide in 1994, the fourth largest specified application area for boron. The Italian Ministry for the Environment carried out a life cycle assessment of the ceramic wall and floor tile industry as part of a study aiming towards a European eco-label for ceramic floor and wall tiles in 1993 (see Marzocchini & Iacontino 1993). There are three major production techniques for ceramics; single firing, double firing, and unglazed. Mingarelli et al (1993) place Italy, Spain, and Brazil as the three largest producers of ceramic tiles world-wide in 1991, as Table 7 demonstrates.

**Table 7: World-wide Ceramic Tile Production (1991) (from Mingarelli et al 1993)**

<table>
<thead>
<tr>
<th>Country</th>
<th>Production of ceramic tile (million m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Italy</td>
<td>432.4</td>
</tr>
<tr>
<td>Spain</td>
<td>218</td>
</tr>
<tr>
<td>Brazil</td>
<td>174</td>
</tr>
<tr>
<td>Germany</td>
<td>80</td>
</tr>
<tr>
<td>Japan (estimate)</td>
<td>80</td>
</tr>
<tr>
<td>France</td>
<td>45</td>
</tr>
<tr>
<td>USA</td>
<td>40.4</td>
</tr>
<tr>
<td>Other European countries (estimate)</td>
<td>190</td>
</tr>
<tr>
<td>Other Non-European production (est.)</td>
<td>340.2</td>
</tr>
<tr>
<td>TOTAL</td>
<td>1600</td>
</tr>
</tbody>
</table>
This break-down gives Italy 27% of global production, with Spain and Brazil the next largest producers with 13.6% and 10.9% respectively. Market research figures suggest that the major producers are consolidating their position in a market experiencing slow growth. Figures for 1993 to 1994 give Italy an annual production of 450 million m², Spain 250 million m², with Germany holding steady at 80 million m², and France falling slightly to 40 million m² (Vickery & Carr 1995). Production trends in Italy and Spain, who account for approximately 40% of world production, are the most significant contributors to global changes in production techniques.

In these two countries there has been a shift over the past fifteen years. In 1979 approximately 93% of Spanish glazed tile production was by traditional double firing technology, but by 1991 this had fallen to less than 20%, with single fired techniques used in only approximately 7.5% of production in 1979, but accounting for over 80% of glazed tile production by 1991 (Vickery & Carr 1995). In Italy, by 1991, single firing systems accounted for approximately 74% of glazed tile production by 1991, with double firing systems used in 26%. About 15% of total tile production in Italy in 1991 was unglazed (Mingarelli et al 1993). These figures are significant for a boron mass balance because these different techniques have different boron emissions to water, as will be illustrated in the following sections. According to Marzocchi and Iacontino (1993), a single firing system is a process,

"In which the glazes and decorations are applied on the dried but unfired tile body, which is then subjected to a single heat treatment "single firing" during which consolidation of the tile body and stabilisation of the glazes takes place at the same time." (Marzocchi & Iacontino 1993, page 35)

By contrast,

"Double firing technology ... obtains its name from the fact that two distinct firing treatments are employed, one to consolidate the tile body and the other to stabilise the glazes and decorations applied onto the fired tile body.” (Marzocchi & Iacontino 1993, ibid.)
Figure 12: The Three Major Production Cycles for Ceramic Tiles. (from Palmonari et al 1993)

5.3.7.1 Unglazed Tile Production

Unglazed tiles such as Klinker and Terracotta are prepared by crushing the raw materials in shredders and homogenising them in wet mixers. They are shaped by extrusion and then dried in slow dryers or fast hot air tunnel dryers. Klinker is fired in tunnel kilns at 1170°C to 1180°C, and Terracotta is fired in tunnel kilns at 1100°C to 1150°C (Marzocchi & Iacontino 1993). Borates are not used in these processes as they are only used in the frits for the glazes for vitrification and fluxing purposes.

5.3.7.2 Double Fired Glazed Tile Production

Double fired glazed tiles are shaped with either, or both, mechanical and hydraulic presses, dried in tunnel dryers or vertical fast hot air dryers. This is followed by the first firing stage, carried out in tunnel kilns and roller kilns. Firing temperatures vary between products, with Majolica and Cottoforte types fired at between 950°C and 1020°C, and Earthenware types...
fired at between 1030°C and 1080°C. The glaze is then prepared by wet grinding the glaze mix components (including B₂O₃), and applied using a variety of techniques (The technique chosen depends on the appearance required). There follows a second firing stage, called 'gloss' firing which is carried out at temperatures between 850°C and 950°C (Marzocchi & Iacontino 1993).

5.3.7.3 Single Fired Glazed Tile Production

For single fired glazed tiles the clay mixture is prepared using various techniques, including wet grinding and spray drying, dry grinding and granulation, dry grinding and wetting. The mixtures are shaped using hydraulic presses and dried in fast hot air dryers. The glazing stage takes place next, using the same process as for double fired glazed tiles, and then firing takes place in roller kilns. Higher temperatures than those used for double firing are applied, with red-ware fired at 1100°C to 1150°C, and white-ware fired at 1150°C to 1200°C (Marzocchi & Iacontino 1993).

5.3.7.4 Boron Flows from Ceramics Manufacture.

5.3.7.4.1 Boron flows to air from ceramics manufacture

Boron flows from the manufacture of ceramics are to air and to water. According to Marzocchi and Iacontino (1993) the main airborne emissions include fluorine compounds, which are released during firing as the mineral structure of the clay collapses, and particulate material: powders, dust, zinc, lead, cadmium, iron, manganese, boron, sulphur oxides, combustion by-products (SOx, NOx, CO₂, CO, etc.). They discuss figures from measurements taken over a ten year period in the Ceramic District of Sassuolo by Centro Ceramico of Bologna, the PMP of Modena, and USL 17 of Sassuolo. They found no significant correlation between concentrations of airborne pollutants and product type. Therefore, they discuss tile production as a whole. They break down atmospheric pollutants into the two categories mentioned: fluorine compounds and particulate matter. They break down each category into the contribution at each stage of the production process. The tile production process binds the glaze to the tile in such a way that the boron in the glaze will not be lost through leaching once the tile reaches the end of its life and is discarded.

They do not give figures for boron specifically. As such it is not possible to calculate an accurate estimate for airborne boron flows arising from ceramic manufacturing. What is possible, however, is to calculate an absolute upper limit for boron flows into the air. Boron use is confined to glazes in ceramic manufacture. Therefore, it can be assumed that boron flows into the environment from ceramic manufacturing will only arise during the glazing stage of production of glazed tiles. Although boron is present in the fossil fuel used for the firing processes, this value will be determined elsewhere. It is not calculated here to avoid possible double-counting.
According to Marzocchi and Iacontino, airborne releases will be produced at a rate of between 80 and 100 'N'm$^3$ per m$^2$ of ceramic product during the glazing stage.\textsuperscript{1} Within this, untreated emissions will account for between 40 and 50 mg/'N'm$^3$, and treated emissions for 5 mg/'N'm$^3$ (Marzocchi & Iacontino 1993, page 118). In the worst possible case, with boron accounting for 100% of all airborne emissions from the glazing stage, there will be 5500 mg of boron released into atmosphere for every m$^2$ of ceramic produced. In 1991, 1600 million m$^2$ of ceramic tile were produced world-wide, of which 15% was unglazed. Hence, in 1991, 1360 million m$^2$ of glazed tiles were produced. Making the following assumptions, we can calculate a worst case scenario for boron emissions:

1. Overall tile production remained at 1600 million m$^2$ until 1994.
2. The proportion of unglazed production in this total remained at 15% until 1994.
3. Data from measurements taken in Italy are representative of the entire ceramics industry.
4. 100% of boron emissions to air arise during the glazing stage.
5. 100% of airborne particulate emissions from the glazing stage are boron.

With these assumptions, if 1360 million m$^2$ of glazed ceramic tile are produced, then:

\[
\text{Boron released to air} = 1,360,000,000 \times 5500 \text{ mg} \\
= 7,480,000,000,000 \text{ mg} \\
= 7,480 \text{ tonnes}
\]

5.3.7.4.2 Boron flows to water from ceramics manufacture

Emissions to water from ceramics manufacture come in three forms: material suspended or dissolved in water evaporating during production, material suspended or dissolved in water leaving the waste-water treatment system as treated waste-water, and material dissolved or suspended in water in the sludge leaving the waste-water treatment system. Different firing systems use different quantities of water in the glazing process, and the proportion of the water going to different media will vary.

Double firing systems use 1.5 m$^3$ of water/1000 m$^2$ of ceramic in the glaze preparation stage and 15 m$^3$/1000m$^2$ in the glazing stage. Of this total, 15.7 m$^3$/1000m$^2$ goes on to the wastewater treatment system, where 15.5 m$^3$ leaves as treated waste-water and 0.2 m$^3$ leaves in the sludge. 0.2 m$^3$/1000m$^2$ evaporates, and 0.6m$^3$/1000m$^2$ remains in the material, to evaporate during firing. Single firing systems, which account for at least 80% of glazed tile production, or 1280 million m$^2$, per year, consume 1.5 m$^3$ of water/1000 m$^2$ of ceramic in the glaze preparation stage and 15.2 m$^3$/1000m$^2$ in the glazing stage. Of this total, 15.7 m$^3$/1000m$^2$ goes on to the wastewater treatment system, where 15.5 m$^3$ leaves as treated waste-water and 0.2 m$^3$ leaves in the sludge. 0.2 m$^3$/1000m$^2$ evaporates, and 0.8 m$^3$/1000m$^2$ remains in the material, to evaporate during firing (Marzocchi & Iacontino 1993).

Thus, both systems release the same quantity, per 1000m$^2$ of tile, of waste-water. No figures are available for the boron content of evaporated water from the systems. Boron has been

\textsuperscript{1} The term 'N'm$^3$ is used here to express a 'Normal' cubic metre. Normal, in this case, refers to process condition parameters including heat and pressure. In other words, when the authors compiled their data, they converted the volumes of airborne emissions from a range of plants with varying heat and pressure...
found to be present in the treated waste-water at a mean concentration of approximately 55mg/l (Marzocchi & Iacontino 1993). There are 1000 l/m³, thus: boron is present in treated waste-waters at 0.055kg/m³. If 15.5 m³ of waste-water is released for 1000m² of glazed tile, and approximately 1360 million m² glazed tiles are made in a year (85% of tile production), then 21,080,000 m³ of treated wastewater will be released, containing 1,159,400 kg of boron, 1159.4 tonnes (3733.268 tonnes B₂O₃ equivalent).

5.3.7.4.3 Boron flows to landfill from ceramics manufacture

Sludge is released at approximately 0.26kg per m² of tile produced, with mean B₂O₃ contents in the three major types of double fired tile of 6.40%, 8.03% and 8.63% (Marzocchi & Iacontino 1993). The average of the three figures, 7.69% will be used here. If double firing systems produce 70,720 tonnes of sludge a year, then 5438.37 tonnes of B₂O₃ will be in the sludge, assuming majolica, cottoforte, and earthenware each represent one third of all double fired glazed tiles produced. For single firing systems, mean B₂O₃ contents in the sludge are 5.37% and 3.91%, an average of 4.64%. If single firing systems produce 332,800 tonnes of sludge per year, then 15,441.92 tonnes of B₂O₃ will be in the sludge, assuming that redware and whiteware each represent one half of all single fired glazed tiles produced.

5.3.8 Fertilisers

Approximately 50,000 tonnes of B₂O₃ was sold to the fertiliser industry in 1994. Boron is added as a micro-nutrient to nitrogen / phosphorus / potassium (NPK) fertilisers. The production of fertilisers can be a fairly complex operation, and the major processing routes, as described by Bockman et al (1990) are outlined in Figure 13.

Borate can be added to the NPK fertiliser production process either during mechanical mixing, or during the dusting phase, where the dried product is dusted to avoid the pellets agglomerating. Process losses of borate are negligible. Lynch (1996) believes process losses are confined to product handling, and estimates such losses to be less than 0.5% B₂O₃. Fertiliser manufacturing plants are almost exclusively located on or near water-courses or ports, so any process losses of borate are likely to enter the aqueous waste stream.

If ~50,000 tonnes of B₂O₃ is used in the fertiliser industry, then <250 tonnes are lost to aqueous waste streams, with the remaining ~49,750 tonnes going to product. Fertilisers are subsequently added to the soil system.
Figure 13: Simplified Fertiliser Production Process Schematic (based on Bockman et al 1990, page 20)

5.3.9 Cellulose Insulation

Cellulose insulation accounted for approximately 20,000 metric tons of B$_2$O$_3$ end-use in 1994. The majority of this type of product is based on waste newspaper. The newspaper industry is a major cellulose consumer: cellulose is a carbohydrate polymer produced by photosynthesis at a rate of 100,000 million tonnes per year (see Porteous 1993, page 56). According to Porteous,

"It is the chief structural element ... of the cell walls of trees and other higher plants where it is bound up with a glue (lignin) to form plant stems. ... A major use is in paper manufacture when it has been freed from its matrix of lignin and other organic matter by treatment with sodium sulphate or alkali to yield a pulp feed-stock of cellulose fibres." (Porteous 1993, page 56)

The process for converting waste paper to cellulose insulation is outlined by Ceuterick (1993) as follows:

"The paper is re-fibrized in a dry milling process. Boric acid and borax are added as dry powders. The components are mechanically combined in a dry mixing process. The paper fibres receive a three dimensional structure. The fibre mixture is cleared from dust in several stages, slightly compressed and packed in paper bags." (Ceuterick 1993, page 123)

Borax and boric acid represent about 20% by mass of the finished cellulose insulation. They are added to improve fire resistance (Smith 1987)
As an insulating material, cellulose insulation cannot be used on external walls and masonry cavities. Cellulose insulation is used, however, in flat and pitched roofs, ceilings and floors. The life cycle for cellulose insulation is outlined by Ceuterick in Figure 14.

**Figure 14: Primary Life Cycle for Cellulose Insulation (based on Ceuterick 1993, page 117)**

On the subject of process losses, the life cycle analysis carried out by Ceuterick found, “Dust (cellulose fibres and boron compounds) can be emitted to the environment. In normal circumstances, this dust is removed by filters. Per kg of Isofloc\textsuperscript{TM}, 4.5 g of filter dust is collected.” (Ceuterick 1993, page 123) The work did not classify the composition of the filter dust, how much was waste paper, how much was borax, etc. In this work, a maximum possible process loss scenario will be examined. In other words, if, as in the case of Isofloc, 4.5 g of dust is produced per kg of cellulose insulation, then all of this dust will be made up of boron compounds, and all of this dust will be released into the atmosphere rather than being filtered out. Many processes use filtering techniques to greatly reduce the amount of particulate emission, but remain unquantified to date.

According to product specifications supplied by Borax Europe, borax (disodium tetraborate decahydrate, Na\textsubscript{2}B\textsubscript{4}O\textsubscript{7} \cdot 10H\textsubscript{2}O) has a theoretical B\textsubscript{2}O\textsubscript{3} content of 36.51%, while boric acid (orthoboric acid, H\textsubscript{3}B\textsubscript{0}3) has a theoretical B\textsubscript{2}O\textsubscript{3} content of 56.30% (Borax, 1995). In the maximum possible process loss scenario we would have 100% boric acid lost in the dust, since boric acid has a higher boron content than borax by weight. This gives the following calculation for process losses for insulation fibre glass production:

\[
4.5 \text{ g } H_3BO_3 \text{ lost as dust per kg product produced } \\
= 4.5 \times 0.5630 \text{ g } B_2O_3 \text{ lost per kg product produced } \\
= 2.5335 \text{ g } B_2O_3 \text{ lost per kg product produced.}
\]
According to Ceuterick, the production of 1 kg of cellulose insulation requires 0.811 kg waste paper, 0.1205 kg borax [or 0.04399 kg B$_2$O$_3$], and 0.0804 kg boric acid [or 0.04527 kg B$_2$O$_3$]. This works out as a theoretical equivalent of 0.08926 kg B$_2$O$_3$ going into the production of 1 kg of cellulose insulation, of which 0.0025335 kg (2.8383%) is lost as dust and 0.0867265 kg (97.1617%) goes into product. Taking global figures for B$_2$O$_3$ with cellulose insulation as the designated end-use of 20,000 metric tons, the following figures result:

- 19,432 tons B$_2$O$_3$ as cellulose insulation
- 568 tons B$_2$O$_3$ released to the environment as dust.

These are maximum process loss figures for the production of cellulose insulation, with the following assumptions:
1. The figures prepared by Ceuterick (1993) are correct.
2. All dust produced is not filtered, but is lost to the atmospheric environment.
3. The dust is composed entirely of boron compounds.
4. Boric acid represents 100% of the boron compounds, and borax represents 0%, because boric acid has a greater B$_2$O$_3$ content.

It should be emphasised that it is extremely unlikely that the assumptions are correct. In the production of cellulose insulation it is perhaps more realistic to assume that the majority of the dust produced will be fibre dust, in which case boron losses will be proportional to the boron content of the fibre. As stated earlier, borax (36.51% B$_2$O$_3$) and boric acid (56.30% B$_2$O$_3$) account for only 20% by mass of the product, so the B$_2$O$_3$ content of the dust will range from 7.30% B$_2$O$_3$ to 11.26% B$_2$O$_3$. If 4.5g of dust per 1 kg of product are produced then between 0.3285g and 0.5067g B$_2$O$_3$ will be lost as dust per 1kg product produced. Following the earlier calculation, If 0.08926 kg B$_2$O$_3$ enters the process, and between 0.0003285kg (0.368%) and 0.0005067kg B$_2$O$_3$ (0.0568%) is lost, then between 99.642% and 99.442% of B$_2$O$_3$ reaches the final product. If 20,000 tonnes of B$_2$O$_3$ go to cellulose insulation production, then the following figures result:

- 72 to 112 tons B$_2$O$_3$ released to air as dust.
- 19,888 to 19,928 tons B$_2$O$_3$ as cellulose insulation.

There is no empirical evidence to support this calculation but one could argue that it is more realistic than assuming that all of the dust lost will be borate when borate represents only 20% of the raw material for the product.
5.4 Summary of Anthropogenic Flows

The boron flows arising specifically from processes associated with the mining, conversion, and application of borates can be summarised using the following table (Table 8) and figure (Figure 15). Mass values are expressed in kilograms boron. The conversion values used in this report are presented in Appendix 3 (see Vol. 4 APD3). Here the term ‘raw material’ is used to express material which has been through primary processing and is destined for secondary processing, to boric acid. Here the term ‘sub material’ is used to express material yield from primary and secondary processing which is destined for conversion to product in a different industry.

It is assumed that there is, in the long term, no net accumulation of product in the ‘Use’ reservoir. In other words, boron is discarded after use. The process losses associated with ‘Other Products’ is not known. For the purposes of this work it assumed that there are no losses associated with conversion of boron into unknown products, since any value attached to such processes would be no more than conjecture.

Table 8: Anthropogenic Boron Flow Matrix

<table>
<thead>
<tr>
<th>Flow→</th>
<th>IN</th>
<th>Extracted Deposits OUT (kg)</th>
<th>Raw Material OUT (kg)</th>
<th>Sub-Material OUT (kg)</th>
<th>To Landfill OUT (kg)</th>
<th>To Air OUT (kg)</th>
<th>To Water OUT (kg)</th>
<th>Product OUT (kg)</th>
<th>To Soil OUT (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary Process</td>
<td>Extracted Deposits 3.665 × 10⁸ to 4.131 × 10⁸</td>
<td>9.007 × 10⁸</td>
<td>2.407 × 10⁸</td>
<td>3.665 × 10⁸ to 8.321 × 10⁷</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Boric Acid</td>
<td>Raw Material 9.007 × 10⁷</td>
<td>-</td>
<td>6.740 × 10⁷</td>
<td>2.267 × 10⁷</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Ceramics Production</td>
<td>Sub-Material 3.727 × 10⁷</td>
<td>-</td>
<td>-</td>
<td>6.485 × 10³</td>
<td>7.48 × 10³</td>
<td>1.59 × 10⁸</td>
<td>2.334 to 3.082 × 10⁷</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Detergents Production</td>
<td>Sub-Material 5.901 × 10⁷</td>
<td>-</td>
<td>-</td>
<td>1 - 18.29 × 10²</td>
<td>-</td>
<td>5.134 to 5.311 × 10⁵</td>
<td>5.665 to 5.841 × 10⁷</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Glass Based Production</td>
<td>Sub-Material 1.211 × 10⁶</td>
<td>-</td>
<td>-</td>
<td>2.396 × 10⁸</td>
<td>-</td>
<td>1.204 × 10⁸</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fertiliser Production</td>
<td>Sub-Material 1.553 × 10⁷</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>7.765 × 10⁴</td>
<td>1.545 × 10⁸</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cellulose Insulation Production</td>
<td>Sub-Material 6.212 × 10⁸</td>
<td>-</td>
<td>-</td>
<td>1.76 × 10⁸</td>
<td>-</td>
<td>6.035 × 10⁸</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other Production</td>
<td>Sub-Material 6.883 × 10⁹</td>
<td>-</td>
<td>-</td>
<td>?</td>
<td>?</td>
<td>?</td>
<td>6.833 × 10⁹</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Use</td>
<td>Product 2.902 × 10⁹</td>
<td>-</td>
<td>-</td>
<td>(2.818 to 2.932 × 10⁹)</td>
<td>-</td>
<td>5.665 to 5.841 × 10⁷</td>
<td>-</td>
<td>1.545 × 10⁸</td>
<td>-</td>
</tr>
</tbody>
</table>

Figure 15: Schematic Summary of Anthropogenic Boron Mass Flows.

**KEY:**
- Product Flow.
- Materials Flow.
- Flow to the Environment.
- Assumed Flow.
- Reservoir.

All flows are expressed in kilograms B per annum.
6. Natural Movement of Boron

While it is extremely useful to look at how anthropogenic activities lead to boron being moved from localised concentrations of land based borates to a much wider dispersion, it has to be remembered that eventually these movements will involve the boron returning to the natural environment where it will be affected by natural processes. It is also of paramount importance to understand that mines are not the only source of boron and borates in the natural environment, and that shipping them around the world to various markets is not the only way to disperse them.

6.1 Atmospheric Boron Loading

As discussed earlier, borate formation is associated with igneous activity at tectonic plate boundaries. While some of the boundaries are at land mass boundaries, and are manifested by mountain ranges when they collide, they are also manifested on land by volcanoes at points where plates are moving apart. Both of these actions are also taking place on the ocean floors. This means that there are borates/ boron carried up into the atmosphere by volcanic activity, and we have sources of boron on the ocean floor. To concentrate on ways in which boron is moved into the atmosphere by natural processes first, work has been carried out into particulate and gas phase boron by Anderson et al (1994), among others. Anderson et al. calculated figures for atmospheric boron concentrations, converted here from grams per year to kilograms per year.

Table 9: Summary of Sources of atmospheric boron \((10^{10} \text{g/yr.})\) (from Anderson et al 1994)

<table>
<thead>
<tr>
<th>Source</th>
<th>Gas-Phase Boron (10^3 \text{kg/yr.})</th>
<th>Particulate Boron (10^3 \text{kg/yr.})</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Natural Sources</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Marine</td>
<td>80-400</td>
<td>50</td>
</tr>
<tr>
<td>Volcanism</td>
<td>30*</td>
<td>0.01</td>
</tr>
<tr>
<td>Forest Fires</td>
<td>0.59</td>
<td>0.06</td>
</tr>
<tr>
<td>Vegetation</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Crustal</td>
<td>Unknown</td>
<td>0.3</td>
</tr>
<tr>
<td><strong>Total Natural</strong></td>
<td>110-430</td>
<td>51</td>
</tr>
<tr>
<td><strong>Anthropogenic Sources</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Agricultural burning</td>
<td>13.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Coal combustion</td>
<td>15</td>
<td>1.2</td>
</tr>
<tr>
<td>Fuel wood</td>
<td>5</td>
<td>0.6</td>
</tr>
<tr>
<td>Glass industry</td>
<td>0.45</td>
<td>0.05</td>
</tr>
<tr>
<td>Oil and gasoline combustion</td>
<td>0.041</td>
<td>0.005</td>
</tr>
<tr>
<td>Metallurgy</td>
<td>0.011</td>
<td>0.002</td>
</tr>
<tr>
<td>Refuse incineration</td>
<td>4.1</td>
<td>0.4</td>
</tr>
<tr>
<td>Mining and processing</td>
<td>-</td>
<td>0.9</td>
</tr>
<tr>
<td>Fertilisers and pesticides</td>
<td>0.15</td>
<td>0.15</td>
</tr>
<tr>
<td>Soaps and detergents</td>
<td>0.001</td>
<td>0.001</td>
</tr>
<tr>
<td><strong>Total Anthropogenic</strong></td>
<td>38</td>
<td>5</td>
</tr>
<tr>
<td><strong>Global Grand Totals</strong></td>
<td>150-470</td>
<td>56</td>
</tr>
</tbody>
</table>

* Based on B:SO\(_2\) ratio at Mt. St. Helens. Ratio varied by ± two order of magnitude at other sites in the study.
Some discussion of these figures is necessary here. The single most important source of atmospheric boron, according to Anderson et al. is marine based, accounting for between $130 \times 10^{10}$ g per year from a total of $206 \times 10^{10}$ g per year, to $450 \times 10^{10}$ g per year from a total of up to $526 \times 10^{10}$ g per year. This works out at between 63.11% and 85.55% of the entire atmospheric input, from both natural and anthropogenic sources put together. Volcanic activity, as explained before, takes place under water as well as on land, and the sea acts as a solvent as well as a transport agency, carrying boron away from these sites in solution and in suspension as the boron is released from under water igneous sources. The sea will also receive boron from the land, as weathering processes near land based borate sources mobilise the mineral into the hydrological system, with rivers and rainfall depositing boron bearing water into the sea. As a result of this, natural sea water has a boron concentration of 4.6 mg per kilogram (see Pytkowicz & Kester 1971) compared with an average land surface water boron concentration of boron at 0.1 mg per kilogram (see Sprague 1972).

6.1.1 Marine Sources of Atmospheric Boron

The process by which boron passes directly from marine water to the atmosphere is described by Fogg and Duce (1985). They took the concentration of sea-water boron in one gram of sea salt to be $1.3 \times 10^{-4}$ g, or 130 ppm.\(^2\), and the global annual production of atmospheric sea salt to lie between $10^{15}$ g per year and $10^{16}$ g per year (see Fogg & Duce 1985, Blanchard 1963, Ericksson 1959, Petrenchuk 1980). They use these figures to give a particulate boron contribution from the ocean at between 1 and $10 \times 10^{11}$ g per year. Anderson et al. (1994) take a marine particulate boron contribution of $5 \times 10^{11}$ g per year, which falls midway between the 1 and $10 \times 10^{11}$ g per year calculated by Fogg and Duce. The amount of boron in the gas phase from marine sources, according to Anderson et al. lies between 80 and $400 \times 10^{10}$ g per year.

6.1.2 Volcanic Sources of Atmospheric Boron

The next most important contribution of boron, according to Anderson et al., comes from land based volcanic activity. According to their work, volcanism accounts for $30 \times 10^{10}$ g per year of gas phase boron. Fogg and Duce gave a much higher value of $210 \times 10^{10}$ g per year of gas phase boron (Fogg & Duce 1985) from volcanic sources. Fogg and Duce base their estimate on work by Oana, in 1962, who found the ratio of boron to sulphur dioxide in volcanic gas production to be 0.14 (Oana 1962). They then took figures for total annual $S\text{O}_2$ production from Berresheim and Jaeschke at $15 \times 10^{12}$ g per year (who derived their figures over the period 1961 to 1979) (Berresheim & Jaeschke 1983). This gave Fogg and Duce a gas phase boron contribution from volcanoes of $\sim 210 \times 10^{10}$ g per year. Anderson et al. looked at these figures and discovered that the four sampling sites used by Berresheim and Jaeschke gave $B/\text{SO}_2$ ratios varying by up to four orders of magnitude. They chose to use only the value for the Mount St. Helens, in north west USA for their own figure of $\sim 30 \times 10^{10}$ g per year.

The problem, as Fogg and Duce acknowledge, is that,

"The concentration of boron, and indeed all elements, in volcanic emanations varies widely among volcanoes and as a function of eruptive history. Fumarolic composition may also be influenced by groundwater and, in the case of boron, by sea-water. Thus this calculation has a rather large degree of uncertainty." (Fogg & Duce 1985, page 3790)

The suggestion is, then, that the contribution of boron from a volcano will depend very much on how frequently, and how violently, a volcano erupts. Badrudin (1994) looked at pH and concentrations of boron, chlorine, SO₄, and magnesium, in a crater lake next to Kelut Volcano in East Java, Indonesia. Badrudin found the following trend for boron concentrations in the lake next to the volcano:

**Table 10: SO₄ and Boron concentration of Kelut crater lake water (from Badrudin 1994, page 238)**

<table>
<thead>
<tr>
<th>Date</th>
<th>SO₄ Concentration (ppm)</th>
<th>Boron Concentration (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>08/06/1987</td>
<td>362</td>
<td>1.1</td>
</tr>
<tr>
<td>11/07/1988</td>
<td>331</td>
<td>1.1</td>
</tr>
<tr>
<td>06/10/1989</td>
<td>359</td>
<td>1.1</td>
</tr>
<tr>
<td>04/11/1989</td>
<td>396</td>
<td>2.1</td>
</tr>
<tr>
<td>03/12/1989</td>
<td>389</td>
<td>1.9</td>
</tr>
<tr>
<td>02/01/1990</td>
<td>372</td>
<td>2.2</td>
</tr>
<tr>
<td>15/01/1990</td>
<td>404</td>
<td>3.1</td>
</tr>
</tbody>
</table>

The volcano finally erupted on the 10th February 1990. Badrudin argues that the increase by a factor of almost three in boron concentrations is due to acid degassing of magma into the lake, and direct leaching of lava both associated with increasing volcanic activity (Badrudin 1994, pages 238 and 240). The important point to recognise is that the level of boron being released into media such as air and water is directly related to the level of volcanic activity at any given time. Given the irregularity of volcanic eruptions, and the widely varying proportions of sulphur dioxide and boron which are emitted, it is almost impossible to calculate an entirely accurate figure for annual volcanic contribution of boron.

### 6.1.3 Combustion Sources of Atmospheric Boron

The next major source of boron into the atmosphere comes from combustion processes such as forest fires, agricultural burning, coal combustion, and fuel wood. These four activities together account for $34.09 \times 10^{10}$ g/yr. of particulate boron and $4.36 \times 10^{10}$ g/yr. of gas phase boron. The reason so much boron is released from these natural fuels is that boron is present in organic matter. Bowen (1966) found the average boron concentration in plant material to be ~50 ppm.

#### 6.1.3.1 Boron in Coal and Ash

Mellor (1980) presented the results of a number of investigations into the boron content of different coals throughout the earth's crust, finding that,
"The boron content of coal and the associated sediments is related to the paleosalinity. The boron content of coal is considerably higher than that of the earth's crustal average, the coefficient of enrichment being about $10^2$ to $10^3$. The boron content of most coals is in inverse ratio to the ash content and is largely confined to the organic material present." (Mellor 1980, page 105)

A comprehensive review of the coal industry is presented by SRI International (1994) Coal reserves of different regions throughout the world are presented along with production and consumption patterns by region. By collating data in Mellor (1980) on the boron content in various types of coal, and SRI International on coal quantities, along with data from the BP Statistical Review of World Energy (BP 1995), a table illustrating the distribution of boron in coals throughout the world, can be generated.

To obtain a value for total reserves of coal involved a number of assumptions. The first concerns the nature of the coal. Both BP and SRI discuss reserves in terms of 'coal', but discuss production in terms of 'hard coal' and 'brown coal'. Geologically, brown coal is much younger than hard coal; and as a result has a lower density. Densification serves to concentrate carbon within the coal, and to reduce the volume of organic matter. Thus, in a given volume of brown coal, it is possible that there will be a higher proportion of boron containing organic matter than in hard coal. However, it is possible that densification over time causes concentration of boron in the coal. Christ and Harder, writing a review of the biogeochemistry of boron in the Handbook of Geochemistry (1974), conclude, however, that,

"The boron content from one sample to another varies over a very wide range, but no significant differences in boron content were found by comparing the mean values of different coal types, coals of different age and different area." (Christ & Harder 1974, page 5-L-1)

For the purposes of this work, then, it will be assumed that there will be no change in boron concentration in coal samples as they densify over time from brown coal to hard coal.

On a second assumption; SRI only discusses demonstrated recoverable reserves and economically recoverable reserves. Figures for global economically recoverable reserves are given by BP and SRI, but for the United States a second set of figures: the demonstrated reserves by region is also used. SRI suggest that for the United States, Economic Reserves = 0.557 * Demonstrated Reserves. SRI suggest that for Western Europe, Total Reserves = 10 * Economic Reserves.

On a third assumption; the most recent figures for coal reserves and production are provided by BP (1995), who use data from 1994. SRI, however, break down the US production and reserves by region, using figures from 1992 giving the Appalachian region 23% of US reserves and 45.65% of US coal production, the Western region 49% of reserves and 34.7% of US coal production, and the Interior region 28% of reserves and 19.65% of US coal production in 1992. For the purposes of this work it is assumed that the relative proportions of reserves and production in the various regions of the USA remained unchanged between 1992 and 1994.
On a fourth assumption; although Mellor (1980) identifies a boron content in fly ash in the Eastern Interior region of the USA, he does not identify a value for the coal. For the purposes of this exercise, it will be assumed that the boron content of the coal in the Eastern Interior region of the USA lies between the value for Appalachian Region of eastern USA and that for the Western Region of western USA (i.e. a value of between 25 ppm and 33 ppm will be used). In other locations it has been necessary to use a value for boron content in a coal sample from the nearest region measured if a value from the actual location is not available. For example, there are no values for boron content in Chinese coal so a value from the Transbaikal region of central and southern USSR and northern Mongolia has been used for China.

The figures desired for a boron mass balance will be total coal reserves and annual coal production. If figures for total reserves have not been given then the assumption has been made that the relationships between total reserves, demonstrated reserves, and economic reserves shown for Western Europe and USA are valid at a global level. It is possible that this will cause sizeable error in the final values, but should give sufficient accuracy to determine orders of magnitude of volumes and flows.
Table 11: Boron content in world coals, after SRI International & Mellor & BP.

<table>
<thead>
<tr>
<th>Location of coal reserve (After SRI and BP)</th>
<th>Location of Boron Measurement (After Mellor)</th>
<th>Total reserves of coal 1994 (kg*10^12)</th>
<th>Production of this reserve type 1994 (kg*10^12)</th>
<th>Boron conc. in coal (ppm)</th>
<th>Boron conc. in ash (ppm)</th>
<th>Total Boron in Reserves 1994 (kg*10^12)</th>
<th>Total Boron in Produced Coal 1994 (kg*10^12)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appalachian USA</td>
<td>Appalachians</td>
<td>55.32834</td>
<td>426.83</td>
<td>25</td>
<td></td>
<td>13.832085</td>
<td>10.67075</td>
</tr>
<tr>
<td>Interior USA</td>
<td>Eastern Interior</td>
<td>67.356492</td>
<td>183.73</td>
<td>(25-33)</td>
<td>2200</td>
<td>16.839123</td>
<td>4.59325</td>
</tr>
<tr>
<td>Western USA</td>
<td>Western</td>
<td>117.37842</td>
<td>324.44</td>
<td>33</td>
<td></td>
<td>38.7348786</td>
<td>17.07652</td>
</tr>
<tr>
<td>Remaining North America</td>
<td>Western</td>
<td>9.8340</td>
<td>79.5</td>
<td>33</td>
<td></td>
<td>3.24522</td>
<td>2.6235</td>
</tr>
<tr>
<td>Southern and Central America</td>
<td>Western</td>
<td>10.197</td>
<td>34.2</td>
<td>33</td>
<td></td>
<td>0.330501</td>
<td>1.1286</td>
</tr>
<tr>
<td>Germany</td>
<td>Germany</td>
<td>80.069</td>
<td>257.1</td>
<td>5-420</td>
<td>70-10000</td>
<td>4.00345</td>
<td>1.2855</td>
</tr>
<tr>
<td>Rest of Western Europe</td>
<td>Germany</td>
<td>15.065</td>
<td>198.9</td>
<td>5-420</td>
<td>70-10000</td>
<td>0.75325</td>
<td>0.9945</td>
</tr>
<tr>
<td>Poland</td>
<td>Poland</td>
<td>42.1</td>
<td>200.4</td>
<td>3.8-20.1</td>
<td></td>
<td>1.5998</td>
<td>0.76152</td>
</tr>
<tr>
<td>Former USSR</td>
<td>Transbaikal</td>
<td>241</td>
<td>475.0</td>
<td>10-100</td>
<td></td>
<td>24.1-241</td>
<td>4.75-47.5</td>
</tr>
<tr>
<td>Rest of Eastern Europe</td>
<td>Poland</td>
<td>32.23</td>
<td>219.8</td>
<td>3.8-20.1</td>
<td></td>
<td>1.22474</td>
<td>0.83524</td>
</tr>
<tr>
<td>South Africa</td>
<td>Transvaal</td>
<td>55.333</td>
<td>195.3</td>
<td>12-68</td>
<td></td>
<td>6.63996</td>
<td>2.3436</td>
</tr>
<tr>
<td>Rest of Africa and Middle East</td>
<td>Transvaal</td>
<td>5.989</td>
<td>9.4</td>
<td>12-68</td>
<td></td>
<td>0.71888</td>
<td>0.1128</td>
</tr>
<tr>
<td>Australia</td>
<td>Australia (NSW)</td>
<td>90.94</td>
<td>230.2</td>
<td>2-300</td>
<td></td>
<td>1.818</td>
<td>0.4604</td>
</tr>
<tr>
<td>China</td>
<td>Transbaikal</td>
<td>114.5</td>
<td>1210.0</td>
<td>10-100</td>
<td></td>
<td>11.45 - 114.5</td>
<td>12.1 - 121</td>
</tr>
<tr>
<td>New Zealand</td>
<td>North Island</td>
<td>0.117</td>
<td>3.3</td>
<td>0-465</td>
<td>0-14900</td>
<td>0 - 0.54405</td>
<td>0 - 1.5345</td>
</tr>
<tr>
<td>Rest of Asia and Australasia</td>
<td>Australia (NSW)</td>
<td>105.933</td>
<td>403.3</td>
<td>2-300</td>
<td></td>
<td>2.11866</td>
<td>0.8066</td>
</tr>
<tr>
<td>GLOBAL TOTAL</td>
<td></td>
<td>1043.864</td>
<td>4451.4</td>
<td></td>
<td></td>
<td>127.41145-1481.29025</td>
<td>54.17278</td>
</tr>
</tbody>
</table>

Following these calculations it is possible to estimate that there is between approximately 12.7 million tonnes and 148.1 million tonnes of boron held in the earth's reserves of just over one trillion tonnes of coal. In 1994, just under four and a half billion tonnes of coal were removed, containing between 54 and 605 thousand tonnes of boron. The mean concentration of boron in the coal produced in 1994, from these calculations, lies between and 12.17 mg/kg and 135.95mg/kg. This range corresponds with earlier work by Bertine and Goldberg (1971), who reported boron to be present in coal at 75 mg/kg in an analysis of the elemental composition of coal. They stressed, however, that wide variations could exist for a given element (Bertine & Goldberg 1971, page 231).

Figures comparing production and consumption of coal are not presented in the BP Statistical Review of World Energy in terms of coal tonnes, but instead a value for oil equivalent is
given, because brown coal, being younger than hard coal, with a lower carbon concentration, produces less energy per unit weight. To overcome any difficulties presented by possible changes in the proportion of hard coal to brown coal in production and consumption, values are converted to tonnes oil equivalent, using a conversion factor of approximately 3.25 tonnes brown coal to 1 tonne hard coal. Oil equivalent values, nonetheless, will allow relative amounts of production and consumption to be compared.

According to figures in the BP Statistical Review of World Energy (BP 1995), the pattern of coal production versus consumption, from 1990 to 1994 looks as follows:

**Table 12: World Production and Consumption of Coal, 1990 to 1994 (After BP 1995, pages 28-29).**

<table>
<thead>
<tr>
<th>Year</th>
<th>Coal Produced (kg* 10^6)</th>
<th>(oil)</th>
<th>Coal Consumed (kg* 10^6)</th>
<th>(oil)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>2261.0</td>
<td></td>
<td>2239.3</td>
<td></td>
</tr>
<tr>
<td>1991</td>
<td>2183.9</td>
<td></td>
<td>2169.2</td>
<td></td>
</tr>
<tr>
<td>1992</td>
<td>2186.2</td>
<td></td>
<td>2159.6</td>
<td></td>
</tr>
<tr>
<td>1993</td>
<td>2120.9</td>
<td></td>
<td>2142.9</td>
<td></td>
</tr>
<tr>
<td>1994</td>
<td>2158.3</td>
<td></td>
<td>2153.2</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>10910.3</td>
<td></td>
<td>10864.2</td>
<td></td>
</tr>
<tr>
<td>Annual Average 1990-94</td>
<td>2182.06</td>
<td></td>
<td>2172.84</td>
<td></td>
</tr>
</tbody>
</table>

Over a five year period, then, coal was produced at an average rate of 10.78 million tonnes oil equivalent higher than it was consumed. In 1994, of the 2158.3 million tonnes oil equivalent of coal produced, 2153.2mtoe were consumed, and 5.1 million tonnes went to coal stockpiles (i.e. 0.236% of net annual production was not consumed but was stockpiled). In terms of actual coal produced and consumed then, it can be estimated that if 4451.4 million tonnes of coal was produced, 10.5 million tonnes went to stockpile with 4440.9 million tonnes actually consumed.

When coal undergoes combustion boron will either volatilise into boric acid or be released into the fly ash. According to Fogg and Duce (1985), 50% volatilisation can be assumed for boron into boric acid, B(OH)₃. This boric acid is soluble and will go first into the atmosphere, and will then return to either land or aqueous media through wet deposition. The proportion of fly ash which goes to atmosphere and the proportion which remains as 'bottom ash' is estimated variously at approximately 5% to atmosphere (see US National Committee for Geochemistry 1980), 8% to atmosphere (see Forstner 1991), and 10% to atmosphere (see Bertine & Goldberg 1971). Eventually the airborne dry ash will be deposited onto land and aqueous media as dry deposition or washout. The bottom ash from coal combustion will enter the land and then aqueous media through leaching.

Bottom ash from coal combustion in the energy sector and industrial sector will usually go to landfill. Ultimately the boron in the land-filled bottom ash may leach out into soil systems, although this will depend very much on the species of the boron in the landfill and the presence of other minerals, such as calcium and limestone. As will be explained later (see Section 6.3.5) the presence of some minerals will lock boron in the soil or landfill, whilst others will encourage leaching.
A study carried out by Cerbus et al. (1994) for the US Army Corps of Engineers investigated the leachate potential of coal ash from stoker boilers, using coal from three different sources in Illinois, USA. They discussed that while coal ash could be used in cement and pavement, with elevated levels of most metals found in soil and plant tissues near ash resurfaced highways, the majority of coal ash is destined for land disposal either in landfills or at the site of generation in storage piles or ponds. They simulated a monofill environment and carried out a variety of tests for leaching from bottom ash and fly ash for over 32 elements, including boron.

They simulated the long-term washing of ash using a water-batch extraction technique. In bottom ash, as the liquid to solid ratio of solution was increased from 2 to 8 for two of the sample types the boron concentrations fell from ~ 3.5 to ~ 0.5 ppm and from ~ 2.3 to ~ 0.1 ppm respectively. They concluded for bottom ash that,

"The elements that exhibited the most significant water extraction leaching from the bottom ash include, in descending order, Ca, S, Si, Na, K, Al, Sr, and B." (Cerbus et al 1994, page 35)

In the case of fly ash, boron concentration in solution dropped from 20 to 3.5 ppm and 16 to 2.5 ppm as the liquid to solid ratio was increased from 2 to 8, leading Cerbus et al to conclude that,

"The elements that exhibited the most significant leaching from the fly ash were, in descending order, S, Ca, Na, K, B, Si, Mg, Al, and Sr." (Cerbus et al 1994, page 41)

It can be concluded that boron has been observed to be highly mobile in leachate from coal ash and thus will find its way into soil systems if it is not contained.

In 1992, the OECD nations (North America, Western Europe, Australasia and Japan) consumed 41.53% of world coal consumption that year (see SRI International (1994). Of this, in 1992, 79.63% went to the energy sector, 17.35% went to the industrial sector; iron and steel, non-metallic minerals, chemicals, paper, pulp and print production systems, with just 3.02% going to residential and commercial markets. In other words, of the bottom ash produced by coal burning in the OECD, almost all goes to landfill.

In the non-OECD countries information is less comprehensive. The International Energy Authority publishes statistics for energy consumption in the non-OECD countries (International Energy Authority 1993). In China, for example, in 1991, slightly over 1 billion tonnes of coal was consumed according to the IEA. 33% of coal consumption was specified as being in the energy sector, with approximately 11% used in industry, and 16% used in residential coal burning. However, the remaining 40% of coal consumption in China is ‘non-specified’. In India, which consumed slightly less than 250 million tonnes of coal in 1991, less than 0.5% of consumption was for residential purposes, but nearly 25% of consumption was non-specified. This precludes an accurate calculation of the proportions of ash from coal burning going to landfill or directly to soil.

Nonetheless, the figures make it possible for us to generate figures for boron flows arising from coal, assuming an extracted coal boron concentration range of 12.7 mg/kg to 135.95 mg/kg:
### Table 13: Boron Mass Volumes Arising from Coal Combustion

<table>
<thead>
<tr>
<th>Boron Store / Flow</th>
<th>Boron Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boron in Coal Reserves</td>
<td>127.41415 - 1481.29025 kg * 10^8</td>
</tr>
<tr>
<td>Boron Extracted in 1994</td>
<td>54.17278 - 605.16258 kg * 10^6</td>
</tr>
<tr>
<td>Boron to atmosphere as volatilised B(OH)_3 (50% of extracted coal boron)</td>
<td>27.08639 - 302.58129 kg * 10^6</td>
</tr>
<tr>
<td>Boron to atmosphere as airborne fly ash (5-10% of fly ash)</td>
<td>1.35432 - 30.25813 kg * 10^6</td>
</tr>
<tr>
<td>Boron to soil (possible interaction with landfill) from bottom ash (90-95% of fly ash)</td>
<td>24.37775 - 287.45223 kg * 10^6</td>
</tr>
</tbody>
</table>

#### 6.1.4 Industrial Sources of Atmospheric Boron

As shown in Table 9, Anderson et al. suggest that the glass industry contributes at total of 0.5 * 10^7 kg of boron to the atmosphere, fertilisers and pesticides 0.3 * 10^7 kg per year, mining and processing 0.9 * 10^7 kg per year, soaps and detergents 0.002 * 10^7 kg per year. Many of these figures are highly suspect. The values for mining losses, detergents industry losses, glass industry losses and fertiliser losses are based on data obtained by Davis in 1969 (Davis 1972). Processes, particularly dust collection systems, may have changed sufficiently in the past 27 years to render this information obsolete.

For example, the primary processing of borates now involves the use of dust houses to remove boron dust to filter bags rather than release to atmosphere. Cellulose insulation processes employ similar dust collection techniques. Atmospheric emissions legislation has become more stringent since 1969, with bodies like the US Environmental Protection Agency and the UK Royal Commission not established until 1970, with an EC Environmental Policy not coming until 1972 (Hunt 1994). The introduction of such bodies and policies, and others, may have had a substantial influence upon levels of boron emission to atmosphere from industrial activity.
6.2 Boron in Rocks

Boron is present to varying degrees across a wide range of rock forming minerals, with concentrations as high as 8,000 ppm boron in nesosilicates and sorosilicates and as low as 1 ppm in Siberian ultramafic igneous rocks (Christ & Harder 1974). Some rocks will have no boron present. However, to generate a calculation for the boron mass present in rocks it would be necessary to know the mass of each of the different rock types present in the earth’s continental and oceanic crusts. As Taylor and McLennan (1996) explain,

"Many elements that are otherwise rarely found on the earth are enriched in granitic rocks. ... But geologists have not been able to estimate the overall composition of crust - a necessary starting point for any investigation of its origin and evolution - by direct observation. One conceivable method might be to compile existing descriptions of rocks that outcrop at the surface. But even this large body of information might well prove insufficient. A large scale exploration program that could reach deeply into the crust for a meaningful sample would press the limits of modem drilling technology and would, in any event, be prohibitively expensive." (Taylor & McLennan 1996, page 62)

It has been suggested that the use of geological tracers such as rare earth elements, whose relative abundance is unchanged by transformation from crust to sediments, may give information on the possible structure of the crust. Taylor and McLennan argue that the use of tracers would suggest that,

"The composition of the upper part of the continental crust approximates that of granodiorite, an ordinary igneous rock that consists largely of light coloured quartz and feldspar, along with a peppering of various dark minerals." (Taylor & McLennan 1996, ibid.)

The oceanic basin is described as likely to be mostly basalt, with a very thin layer of sediments across the top. Christ and Harder give what they describe as a tentative average boron concentration in granodiorite of 15 ppm, based on analyses giving concentrations in the range 0.3 ppm to 2,500 ppm. The boron concentration in JB-1, the Geochem. Standard Basalt is 10 ppm (Christ & Harder 1974).

Taylor and McLennan state that,

"The basaltic oceanic basins of our planet ... constitute about one tenth of 1 percent of the earth’s mass. ... Its tertiary crust - the continents - ... amount to just half of 1 percent of the mass of the planet. (Taylor & McLennan 1996, page 62)"

According to Bartholemew et al. (1990), the earth has a mass of 5.97 * 10^{24} kg. These figures give a continental crust mass of 2.985 * 10^{22} kg and an oceanic crust mass of 5.97 * 10^{21} kg.

From these figures a calculation can be made which will give a value for total boron in the oceanic crust and the continental crust. It must be stressed, however, that the figures being used are extremely uncertain: even if one does accept that the entire crust can be viewed as possessing characteristics of one rock type, the boron concentrations in those rocks are widely variable - granodiorites vary from 0.3 to 2,500 ppm, and basalts vary from 2.2 to 26 ppm.
Continental crusts with a mass of $2.985 \times 10^{22}$ kg and a boron concentration of 15 ppm will have a boron content of: $4.4 \times 10^{18}$ kg B.

Oceanic crusts with a mass of $5.97 \times 10^{21}$ kg and a boron concentration of 10 ppm will have a boron content of: $5.97 \times 10^{16}$ kg B.
6.3 **Boron in Soils.**

There are various systems to move boron across environmental media. Some agencies can act to disperse or concentrate boron from various sources. As explained before (see Section 2, 'Boron Chemistry') various forms of boron have relatively high solubility in water. This means, from an environmental stand-point, it is important to understand the processes within the water and soils systems involving boron movement. Boron can be deposited on the land by various agencies. Dry and wet deposition from the atmosphere of boron will take place. One also has to consider natural soil formation processes such as weathering of sediments and older rocks. Butterwick et al 1989) report that an estimated 360,000 tonnes of boron per year world-wide are mobilised by natural weathering of minerals.

6.3.1 **Precipitation of Atmospheric Boron**

Some writers do not consider any other atmospheric transport of boron other than fossil fuels. Berger (1949), for example, introduces a boron cycle, shown over-page, which looks at organic and inorganic soil boron processes. Interestingly, he identifies boron fertilisers, fossil fuels, and boron minerals, as well as local sea spray, as the main sources of boron in soils.

**Figure 16: The Boron Cycle, from Berger (1949)**
This schematic shows Berger’s assumption that boron either enters the soil through the decomposition of organic matter, which corresponds with Bowen’s finding that boron is present in organic matter, or through processes such as weathering, the application of boron fertilisers, fossil fuel burning, or local sea spray (Bowen 1966). All these processes do move boron into the soil: burning fossil fuel not only releases boron into the atmosphere, but the residue at the end of combustion will also contain boron which can leach into the soil. Sea water, as has been explained, has boron present. The use of boron containing fertilisers is designed to move boron into the soil system, and natural weathering processes will also liberate and translocate boron into the soil system.

However, atmospheric sources of soil boron, i.e. wet deposition and dry deposition, are overlooked. Volcanoes, transmission of boron salt from the sea surface to the atmosphere, the airborne releases from combustion of organic materials, are all ignored. There is a two-way process by which boron moves between soils and sea-water, according to the schematic; spray of boron onto the land from the sea, and leaching of boron out of soils. The movement from soil to sea is not elaborated upon beyond that there is a mechanism which makes it happen. The United Kingdom Atomic Energy Authority carried out work into atmospheric trace elements, including boron, in 1972-73 (see Cawse 1974). They found the following rainfall boron concentrations for samples taken between August and December 1973 in the UK:

Table 14: Rain soluble boron and wet deposition concentrations in the UK 1972-73 (from Cawse 1974, pages 73 and 84)

<table>
<thead>
<tr>
<th>Site Location</th>
<th>Rain soluble boron concentration (μg/litre)</th>
<th>Soluble boron deposition (μg/cm²/yr.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lerwick Observatory, Shetland Islands</td>
<td>21.8</td>
<td>4.0</td>
</tr>
<tr>
<td>Plynlimon, Gwent</td>
<td>4.5</td>
<td>1.4</td>
</tr>
<tr>
<td>Trebanos, Glamorgan</td>
<td>7.4</td>
<td>0.93</td>
</tr>
<tr>
<td>Wraymires, Lancashire</td>
<td>3.9</td>
<td>0.73</td>
</tr>
<tr>
<td>Styrrup, Nottinghamshire</td>
<td>11.3</td>
<td>0.48</td>
</tr>
<tr>
<td>Leiston, Suffolk</td>
<td>8.7</td>
<td>0.45</td>
</tr>
<tr>
<td>Chilton, Berkshire</td>
<td>8.0</td>
<td>0.43</td>
</tr>
</tbody>
</table>

These measurements are useful in that they highlight the difference in boron concentration in rainfall in marine environments, such as the Shetlands, and the concentration in rainfall over land. Clouds formed from evaporation from sea water, which go on to precipitate over the sea contain a much higher concentration of boron than clouds formed by evaporation of surface water. This is consistent with the findings of Pytkowicz and Kester (1971) and Sprague (1972) who, as stated earlier, identified respectively that sea water contained boron at a concentration of 4.6 mg/l and surface waters contained boron at a concentration of 0.1 mg/l. The on land precipitation boron concentrations will vary according to the proportion of the precipitation due to marine evaporation against precipitation from surface waters. The higher the proportion of marine evaporation in the rainfall, the higher the boron concentrations will be (if there are no other inputs of boron). Further, local geology will have an impact on boron concentrations.
concentrations within surface waters, some will have a much greater boron concentration than others.

### 6.3.2 Boron and Clays

The main products of chemical weathering, according to Knapp (1988), are clay minerals. He explains that these minerals are small colloidal particles less than 0.002 mm across, which have a thin, platy crystal structure, and a large surface area compared to volume. He states that,

"Most importantly, they carry at their surfaces a significant electrical charge." (Knapp 1988, page 248)

The following is an illustration of the construction of the clay mineral

**Figure 17: Clay mineral construction (from Knapp 1988, ibid.).**

Knapp explains the basic principles which govern mineral movement in soils:

"During weathering you get insoluble products - for example: oxides - and substances which remain in solution: these may be carried away as the water percolates through the soil or they may be used by plant roots as nutrients. Most substances here are ions that do not readily combine with each other in the soil solution. Nevertheless, because the ions are electrically charged, the positive ions (cat-ions) are attracted to the negative surfaces of the clays, where they are loosely held." (Knapp 1988, ibid.)

Davies (1980) looks at how this relates to boron specifically. He explains that boron can go into a silicate structure, such as a clay, by substituting for Al$^{3+}$ and or Si$^{4+}$ ions. He goes on to state that initial adsorption onto clay surfaces is followed by slower diffusion into the lattice proper. Davies identifies four main adsorption sites for boron in soil structures and gives examples:

1. Broken Si - O and Al - O bonds at the edges of aluminosilicate materials.
2. Amorphous hydroxide structures. (The association of boron with allophane in weathered soils.)
3. Magnesium hydroxide structures. (In arid soils magnesium hydroxide coatings tend to form on ferromagnesium minerals and micaceous larger silicates.)
6.3.3 Boron and Soil Moisture

Many variables impact on the extent to which boron is adsorbed into soil structures. Brohult and Forsberg (1970) argue that boron eluviation from soil depends on the amount of rainfall entering the soil, and the degree to which boron is fixed to soil structures. They argue that, “Fixation increases substantially ... with a decreasing degree of acidity, i.e. increasing pH. ... Consequently, eluviation from light soils with a low pH value and with a low content of organic substance in areas subject to heavy rainfall is significant and proceeds rapidly.” (Brohult & Forsberg 1970, page 5)

Work by Rai and Zachara supports this view. They produced the chart shown here as Figure 18 to support their opinion that, “Boron adsorption displays marked pH dependency.” (Rai & Zachara 1984, page 8-3)

![Figure 18: Activity of different species when activity of H\textsubscript{3}BO\textsubscript{3} fixed at 10\textsuperscript{-5}, F\textsuperscript{-} = 10\textsuperscript{-4}, and CO\textsubscript{2} (gas) = 10\textsuperscript{-3.55} atmospheres.]

Rai and Zachara observed that maximum adsorption occurred between pH 7.5 and pH 10 on clay minerals, on aluminium and iron oxides, on soil organic matter and soils. They proposed that “The pH dependency of B adsorption may be related to the hydrolysis of boric acid: $\text{B(OH)}_3 + \text{H}_2\text{O} \rightarrow \text{B(OH)}_4^- + \text{H}^+$ log. $K = 9.24.$” (Rai & Zachara 1984, page 8-3)

They go on to explain that $\text{B(OH)}_4^-$ is much more likely to be adsorbed onto oxide and clay surfaces than $\text{B(OH)}_3$, and that at pH greater than 9.5 there are higher concentrations of OH\textsuperscript{-}, which compete with boron for adsorption sites. Butterwick et al (1989) identify several factors, not just pH, which will influence how much boron is adsorbed into the soil. They argue that soil retention of boron is influenced by boron concentration in the soil solution, soil pH, texture, organic matter, cat-ion exchange capacity, type of clay, and mineral coating on...
Butterwick et al. introduce the notion of the soil as a 'sink' for boron. They argue that, "Soil texture plays an important role in determining boron availability to plants. Clay soils have a large capacity for boron absorption, and initially they can provide a ‘sink’ for the element. However, if boron continues to be applied to the soil once its absorption capacity has been exceeded, then a dramatic increase in plant availability can occur." (Butterwick et al 1989, page 357)

This returns the discussion to Berger’s boron cycle, in which he referred to ‘available boron’ rather than ‘total boron’ (Berger, 1949). As has been shown, boron does more than simply go into a soil and then become either instantly used by plants or, if not, simply fall out of the soil as leachate. There are many processes which act to hold the boron in the soil, and it is possible that soils which are rich in total boron can still be termed ‘boron deficient’ because this boron is not available for plants. As has been shown, boron species, soil pH, the nature of the clay in the soil, the availability of adsorption sites, as well as the amount of water physically transporting boron out of the system, will all influence residence times of boron in a soil.

6.3.4 Boron in Soils and Organic Activity

The rate at which boron in the soil is used by organic matter will influence boron residence times and depends on a number of variables, including the availability of other nutrient minerals in the soil. Plants need a wide variety of minerals to grow successfully and there may be a lack of plant activity using boron stored in the soil due to a lack of other vital minerals. Different plants have different boron requirements, there has been a great deal of attention in papers to boron uptake by plants.

For the purposes of this study it is inappropriate to report all the work in this area. Many papers look at boron requirements for individual flora. Romheld and Marschner (1991) discuss the functions of boron in plants. They note that observed effects arising after boron starvation in plants include a change in chemical composition and ultrastructure of cell walls, changes in phenol metabolism including enhanced production of oxygen free radicals followed by impairment of plasma membrane, a decreased level of diffusible auxins, and inhibited lignin synthesis. Also observed are morphological and physiological changes of cell wall - plasma membrane interface such as inhibition of plasma membrane enzymes and processes, and inhibition of elongation, growth and xylem differentiation followed by changes in carbohydrate distribution due to altered RNA / DNA metabolism and phytohormone metabolism (See Romheld & Marschner 1991, page 317).

It is important to observe that different plants have different needs for boron, and in fact there are boron threshold levels for most plants, below which they become deficient, and above which they suffer toxic effects. More extensive reviews of boron uptake by plants are available in Maas (1984), Keren and Bingham (1985), Gupta et al (1985), or Butterwick et al...
Keren and Bingham generated a table of comparative boron tolerance of plants, categorised as sensitive, semi-tolerant, and tolerant to boron, reproduced below:

Table 15: Comparative Boron Tolerance of Plants Listed According to the Maximum Permissible Concentration of Boron in Irrigation Water (from Keren & Bingham 1985, page 265).

<table>
<thead>
<tr>
<th>Sensitive (0.028 to 0.093 mol. B/m³)</th>
<th>Semi-tolerant (0.093 to 0.19 mol. B/m³)</th>
<th>Tolerant (0.19 to 0.37 mol. B/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grapefruit</td>
<td>Lima bean</td>
<td>Carrot</td>
</tr>
<tr>
<td>Avocado</td>
<td>Sweet potato</td>
<td>Lettuce</td>
</tr>
<tr>
<td>Blackberry</td>
<td>Bell pepper</td>
<td>Cabbage</td>
</tr>
<tr>
<td>Apricot</td>
<td>Pumpkin</td>
<td>Turnip</td>
</tr>
<tr>
<td>Peach</td>
<td>Oat</td>
<td>Onion</td>
</tr>
<tr>
<td>Cherry</td>
<td>Milo</td>
<td>Broad-bean</td>
</tr>
<tr>
<td>Persimmon</td>
<td>Corn</td>
<td>Alfalfa</td>
</tr>
<tr>
<td>Fig</td>
<td>Wheat</td>
<td>Garden beet</td>
</tr>
<tr>
<td>Grape</td>
<td>Barley</td>
<td>Mangel</td>
</tr>
<tr>
<td>Apple</td>
<td>Olive</td>
<td>Sugar beet</td>
</tr>
<tr>
<td>Pear</td>
<td>Field pea</td>
<td>Date Palm</td>
</tr>
<tr>
<td>Plum</td>
<td>Radish</td>
<td>Asparagus</td>
</tr>
<tr>
<td>Bean</td>
<td>Tomato</td>
<td></td>
</tr>
<tr>
<td>Artichoke</td>
<td>Cotton</td>
<td></td>
</tr>
<tr>
<td>Walnut</td>
<td>Potato</td>
<td></td>
</tr>
<tr>
<td>Pecan</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

With such a variation in levels of boron which plants require, it is very difficult to generate a value for boron content of organic matter which does not allow a wide margin of error. An international workshop on the behaviour, function and significance of boron in agriculture, held at St. John’s College Oxford in 1990, did calculate an approximate boron in plants concentration of between 30 and 50 mg/kg. The workshop calculated that,

"On the basis of the generally accepted assumption that passive mass flow accounts for all boron uptake by roots, it is possible to calculate the approximate average boron content in the soil solution that would permit satisfactory growth. Using a transpiration coefficient of 300 to 500 l/kg it would be possible to maintain an average plant concentration of 30 - 50 mg/kg B if the soil solution contains as little as 0.1 mg/l water soluble boron." (Shorrocks 1990, page 1)

Myers (1994) estimates the total dry weight of the total biomass (the phytomass) on earth to be approximately $1 \times 10^{15}$ kg (1 trillion tonnes), representing 25% of the wet weight of the biomass, of which approximately 99% is plant matter (Myers 1994, pages 22 to 23). Using these figures a boron content of organic matter can be calculated:

$\text{Boron in plants} = \sim (30 \text{ to } 50) \times 10^{15} \text{ mg.}$

$\sim 3 \times 10^{16} \text{ to } 5 \times 10^{16} \text{ mg.}$

$\sim 3 \times 10^{10} \text{ to } 5 \times 10^{10} \text{ kg B.}$

The majority of the boron in plants is cycled between soil and plant as vegetation dies it is returned to the soil as humus to be used by subsequent vegetation. Any boron in plants
consumed by land animals will be returned as manure. The only movement outside this
system will come from human agricultural activities. Crops will be removed and transported
to human centres where the boron will be moved into the sewage system and thus to the river
system. However, plants removed in crop yields, as a proportion of total phytomass, are
minor.

According to Bartholemew et al. (1990), the major sources of agricultural trade are as shown
here in Table 16:

**Table 16: Major Net Agricultural Production Sources (from Bartholemew et al. 1990, plate 6)**

<table>
<thead>
<tr>
<th>Food Type</th>
<th>Net Yield (Million Tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat</td>
<td>517.1</td>
</tr>
<tr>
<td>Rice</td>
<td>464.5</td>
</tr>
<tr>
<td>Maize</td>
<td>458.0</td>
</tr>
<tr>
<td>Raw Sugar</td>
<td>101.7</td>
</tr>
<tr>
<td>Potatoes</td>
<td>283.8</td>
</tr>
<tr>
<td>Soya Beans</td>
<td>100.0</td>
</tr>
<tr>
<td>Ground Nuts</td>
<td>21.0</td>
</tr>
<tr>
<td>Palm Oil</td>
<td>8.3</td>
</tr>
<tr>
<td>Citrus</td>
<td>58.0</td>
</tr>
<tr>
<td>Apples</td>
<td>37.7</td>
</tr>
<tr>
<td>Bananas</td>
<td>42.1</td>
</tr>
<tr>
<td>Coffee</td>
<td>6.2</td>
</tr>
<tr>
<td>Cocoa</td>
<td>2.0</td>
</tr>
<tr>
<td>Tea</td>
<td>2.3</td>
</tr>
<tr>
<td>Eggs</td>
<td>33.7</td>
</tr>
<tr>
<td>Milk</td>
<td>463.0</td>
</tr>
<tr>
<td><strong>Sub-Total</strong></td>
<td><strong>2599.4</strong></td>
</tr>
</tbody>
</table>

Thus, agricultural removal represents approximately $2.599 \times 10^{12}$ kilograms from a total
biomass of $4 \times 10^{15}$ kg. In other words, less than 0.1% of global biomass is not in the soil-
plant–soil cycle. In boron terms, this value can be estimated to be in the range:

$7.797 \times 10^7$ kg to $12.995 \times 10^7$ kg B per year.

This boron will return to the environment in sewage streams, as will be discussed in Appendix
2 (see *Vol. 4 APD 2*). It should be observed, however, that most of the boron in plants is
present in the leaves, rather than the crop, so the actual amount of boron removed may be less
than that suggested for the crops above. To counter that, however, one must remember that
the above list represents only the major agricultural crops, so the tonnage of agricultural
produce will be greater, off-setting a possible lower actual boron concentration than that
shown. The objective is to show the relative scale of the boron flows within soil–plant–soil
systems against flows in soil–plant–harvest systems.
6.3.5 Soil Boron Availability

The total boron content of soils has been studied by Whetstone et al (1942) in the United States surveying 200 soils of various soil groups and finding an average boron content of 30 mg/kg in a range of 4 mg/kg to 98 mg/kg, but much of this is unavailable boron. Davies (1980) identifies calcium, nitrogen, and potassium as having an impact on soil boron availability to varying degrees. Davies explains that plants deficient in boron are unable to carry out complete protein photosynthesis, showing a relationship between nitrogen and boron in plants. However, he stresses that nitrogen fertilisers have no direct impact on boron availability in the soil beyond the effect that,

"Under border-line conditions the increased growth resulting from the use of nitrogen would obviously predispose towards deficiency." (Davies 1980, page 165)

Calcium has a clear impact on boron soil availability. Davies states that,

"In alkaline soils where free calcium ions are present, boron availability is much less." (Davies 1980, ibid.)

Davies explains the importance of this to boron deficiency and toxicity by introducing studies by Fox (1968), Brenchly and Warrington (1927), and Reeve and Shive (1944). He summarises the findings:

"In culture solutions it was shown that as the calcium content was increased more boron was required both to prevent deficiency and to produce toxicity. The addition of calcium thus increased the plants' requirement for, and ability to absorb, boron." (Davies 1980, page 165)

The case for potassium is somewhat different than that for calcium, as it is complicated by a relationship between potassium and calcium as well as the one between potassium and boron. Like calcium, when potassium levels are increased in soils where boron levels are low, boron deficiency symptoms are exacerbated. However, when boron supply levels are high, increasing amounts of potassium actually increase the likelihood of toxic boron effects on plants. Davies (1980) observes that Berger (1949) argued that adding potassium to plants tends to decrease calcium levels, thus upsetting the calcium : boron ratio.

Liming the soil will also have an impact on soil availability. Rai and Zachara (1984) explain this process as follows,

"Liming soil may increase B adsorption by displacement of exchangeable Al\(^{3+}\) and formation of Al(OH)\(_3\) (s), an effective adsorbent. Similarly, Mg hydroxy clusters appear important in B retention in arid regions." (Rai & Zachara 1984, page 8-4)

Arnold (1991) argues that,

"The idea that freshly precipitated aluminium hydroxide was responsible for scavenging for boron has been widely held for many years. With the passage of time the ability of aluminium hydroxide to adsorb boron diminishes, which ties in with the findings of Dermot and Trinder (1947) that it is the effects of recent liming rather than the general pH rise which has the dramatic relatively short term influence on boron status." (Arnold 1991, page 22)

It has been argued that in some cases adsorption can be irreversible. According to Rai and Zachara the evidence is mixed on desorption of boron. They refer to work by Hatcher and


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Bower, Hingston, and Keren and Gast, when arguing that in some soils and soil components adsorption appears to be easily reversible. However, they go on to say that, “Other soils demonstrate marked hysteresis in desorption. Wetting and drying cycles not only increase the B adsorption capacity but render a substantial portion irreversibly adsorbed.” (Rai & Zachara 1984, page 8-4)

They offer the explanation that this may be happening due to solid phase formation or fixation by clay minerals. Al$^{3+}$ and Fe$^{3+}$ could be displaced by Ca$^{2+}$ when boron is present and precipitated out with boron as aluminium borates, iron borates or hydroxy borates.

### 6.3.6 Global Soil Boron

Thus, there are many variables which impact upon soil boron levels precluding the calculation of a soil boron loading of greater accuracy of a mean 30 mg/kg in the range 4 mg/kg to 98 mg/kg calculated by Whetstone et al (1942). Using this figure it may be possible to generate a value for global boron level in the soil. According to Myers (1994), the ice free land surface of the earth covers 13 billion hectares, with land-use divided as follows:

<table>
<thead>
<tr>
<th>Land Use</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tundra</td>
<td>1%</td>
</tr>
<tr>
<td>Boreal Forest</td>
<td>16%</td>
</tr>
<tr>
<td>Chaparral</td>
<td>1%</td>
</tr>
<tr>
<td>Temperate Grassland</td>
<td>2%</td>
</tr>
<tr>
<td>Temperate Forest</td>
<td>19%</td>
</tr>
<tr>
<td>Desert</td>
<td>1%</td>
</tr>
<tr>
<td>Tropical Shrub &amp; Woodland</td>
<td>7%</td>
</tr>
<tr>
<td>Tropical Savannah &amp; Grassland</td>
<td>5%</td>
</tr>
<tr>
<td>Tropical Deciduous Forest</td>
<td>9%</td>
</tr>
<tr>
<td>Tropical Evergreen Forest</td>
<td>34%</td>
</tr>
</tbody>
</table>

Thus, given a soil boron concentration, a soil area, and a depth of soil at which boron is present it would be possible to determine a global soil boron value. However, the figures for soil boron concentration must be treated with caution. For agricultural purposes the most important horizons in the soil profile are those into and through which plant roots pass. The soil boron concentration at a depth of ten metres, for example, would not be important to an agronomist if plants with a root system which utilised only nutrients in the upper two metres of the profile were being considered. The nature of values for ‘boron concentration in the soil’ must be questioned. Are these values for the entire profile, or simply the upper horizons? The literature referred to in this section does not specify the depth at which soil boron concentration took place, or the depth of the soils under consideration. This precludes the calculation of a value for total boron present in the soil system.

The issues related to the calculation of boron fluxes in soil systems is explored at the local level through a Case Study of the River Thames Region. This case study is presented as Appendix 2 (see Vol. 4 APD2) and builds on a Case Study examining surface water systems in the River Thames Region presented as Appendix 1 (see Vol. 4 APD1).
6.4 Global Water Transport Systems

Ferguson (1982) introduces the global water cycle, showing the major water movement flows as follows:

**Figure 19: The Global Water Cycle (based on Ferguson 1982, page 32)**

Ferguson also includes numerical values for these stores and flows of water in kilograms per year. Numerical values for stores and flows have also been located in Shaw (1994), Ross (1982), Press and Siever (1978), Barry (1971), and Weyl (1970). Porteous (1993) also presents a hydrological cycle, including values for the flows of water, but not the stores. Porteous expresses his values in terms of cubic kilometres of water per day. These figures have been converted to kilograms per year using the following calculations:

1 cubic km water = (10^3 m^3) water = 10^9 m^3 water
1 m^3 water will have a mass equal to 10^3 kg of water at density 1
1 cubic km water will have a mass equal to 10^3 kg * 10^9 m^3 water = 10^{12} kg water
1 cubic km per day = 365.25 cubic km per year
1 cubic km per day = 365.25 * 10^{12} kg per year.

This conversion value can be used as shown in Table 17.

The figures presented by the various authors appear to be in broad agreement with each other. With the exception of ground-water, orders of magnitude for the components of the hydrological cycle correspond across the table. Values for ground-water range from 5 * 10^{17} kg to 3.2 * 10^{20} kg, with a median value of 3.4 * 10^{18} kg. The range of values for the volume of water in the oceans, which represent the majority of water on the earth, is 1.31 * 10^{21} kg to 1.4 * 10^{21} kg, a difference of 0.09 * 10^{21} kg or 6.38% of the upper value.
Table 17: Global Water Reservoir and Flow Volumes

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Water in Oceans</td>
<td>1.37 * 10^17</td>
<td>-</td>
<td>1.31 * 10^17</td>
<td>1.4 * 10^17</td>
<td>1.35 * 10^17</td>
<td>1.31 * 10^17</td>
<td>1.4 * 10^17</td>
</tr>
<tr>
<td>Ground Water</td>
<td>6.0 * 10^16</td>
<td>-</td>
<td>8.36 * 10^14</td>
<td>3.2 * 10^16</td>
<td>8.4 * 10^16</td>
<td>5.0 * 10^17</td>
<td></td>
</tr>
<tr>
<td>Water in Ice</td>
<td>2.4 * 10^15</td>
<td>-</td>
<td>2.6 * 10^14</td>
<td>1.7 * 10^15</td>
<td>2.9 * 10^15</td>
<td>75% of Fresh Water</td>
<td>1.5 * 10^19</td>
</tr>
<tr>
<td>Water in Lakes</td>
<td>2.6 * 10^15</td>
<td>-</td>
<td>2.29 * 10^14</td>
<td>3.4 * 10^14</td>
<td>-</td>
<td>0.3% of Fresh Water</td>
<td></td>
</tr>
<tr>
<td>Evaporation from Oceans</td>
<td>~ 3.196 * 10^17 per year</td>
<td></td>
<td>3.8 * 10^17</td>
<td>-</td>
<td>84% of Total Evaporation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Precipitation on Oceans</td>
<td>2.631 * 10^17 per year</td>
<td></td>
<td>3.5 * 10^17</td>
<td>-</td>
<td>77% of Total Evaporation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ocean Evaporation moved over Land</td>
<td>3.653 * 10^16 per year</td>
<td></td>
<td>-</td>
<td>7% of Total Evaporation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Evaporation/Transpiration from Land</td>
<td>~ 5.844 * 10^16 per year</td>
<td></td>
<td>6.3 * 10^16</td>
<td>16% of Total Evaporation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Precipitation on Land</td>
<td>~ 9.497 * 10^16 per year</td>
<td></td>
<td>9.3 * 10^16</td>
<td>23% of Total Evaporation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>River Discharge</td>
<td>~ 3.2 * 10^16 per year</td>
<td></td>
<td>3.2 * 10^16</td>
<td>0.03% of Fresh Water</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ground-water to Oceans</td>
<td>~ 4.0 * 10^16 per year</td>
<td></td>
<td>-</td>
<td>7% of Total Evaporation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Run Off</td>
<td>~ 5.844 * 10^16 per year</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

The oceans, then, are the largest store of water on the earth. If boron is present here, even in small concentrations, the cumulative loading will be considerable. According to Mellor (1980),

"About 98% of the earth’s water is in the world ocean, leaving only about 2% for all other waters. The total amount of ocean and sea water has been estimated to be about 1.37 * 10^9 km^3, which, using Clarke’s mean density of 1.03, gives a total weight of 1.41 * 10^16 tons, of which about 96.5% is water and 3.5% is dissolved salts." (Mellor 1980, page 75)

Mellor goes on to state that boron is present in both ocean water and ocean salts at a level of 0.014%, i.e. a total of 7 * 10^15 kg boron in the ocean (see Mellor 1980, page 76). Mellor also shows how the actual local concentration of boron can vary, as the following table illustrates:

Table 18: Boron Concentration in Ocean Waters (from Mellor 1980, page 77)

<table>
<thead>
<tr>
<th>Area</th>
<th>mg B / kg H_2O</th>
</tr>
</thead>
<tbody>
<tr>
<td>North East Pacific, Beyond Continental Shelf</td>
<td>4.56</td>
</tr>
<tr>
<td>North East Pacific, Including Continental Shelf Waters</td>
<td>4.17</td>
</tr>
<tr>
<td>North Atlantic Coast of USA</td>
<td>4.75</td>
</tr>
<tr>
<td>Baltic Sea</td>
<td>0.52 - 1.6</td>
</tr>
<tr>
<td>Mediterranean Sea</td>
<td>9.57</td>
</tr>
<tr>
<td>Western Pacific</td>
<td>4.73</td>
</tr>
<tr>
<td>Indian Ocean</td>
<td>2.2</td>
</tr>
<tr>
<td>Average of all Oceans</td>
<td>4.6</td>
</tr>
</tbody>
</table>
Areas where the primary water input is glacial melting, such as the Baltic Sea, show relatively low levels of boron, whereas areas which are confined, like the Mediterranean, enabling evaporation to concentrate levels of boron, have relatively high levels of boron present.
6.5 **Boron in Surface Waters**

The processes influencing the level of boron in the soil at any given time have a direct impact upon the levels of boron in surface and ground waters. The higher the volumes of boron leaving the soil through translocation into water systems, the higher the volume of boron in those water systems. For this reason, a global figure for boron levels in surface and ground waters is difficult to determine, although Matthews (1973) quoted a value as low as 13 ug/l for surface waters from Livingstone (1963). Mellor (1980) summarises the findings of extensive trace element analysis of rivers in the former Soviet Union:

**Table 19: Boron content of rivers in the Former Soviet Union (from Mellor 1980, page 81)**

<table>
<thead>
<tr>
<th>Rivers flowing into:</th>
<th>Boron Concentration (ppm)</th>
<th>Tons Boron transported per year.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baltic Sea</td>
<td>0.009 - 0.030</td>
<td>2060</td>
</tr>
<tr>
<td>Black Sea and Sea of Asov Basins</td>
<td>0.013 - 0.081</td>
<td>5200</td>
</tr>
<tr>
<td>Aral - Caspian Basin</td>
<td>0.033 - 0.096</td>
<td>19800</td>
</tr>
<tr>
<td>Barents and Beloye Sea Basins</td>
<td>0.009 - 0.022</td>
<td>5120</td>
</tr>
<tr>
<td>Kara Sea Basin</td>
<td>0.011 - 0.022</td>
<td>18400</td>
</tr>
<tr>
<td>Laptev, East Siberian and Chukchi Sea Basins</td>
<td>0.010 - 0.015</td>
<td>12300</td>
</tr>
<tr>
<td>Bering, Okhotsk and Japan Sea Basins</td>
<td>0.005 - 0.009</td>
<td>7500</td>
</tr>
<tr>
<td>Total for Territory of the USSR</td>
<td></td>
<td>50600</td>
</tr>
</tbody>
</table>

Mellor gives the mean boron concentration of all rivers draining North America and the former Soviet Union to be 0.012 mg/l. He states that,

"With a total world influx of $3.3 \times 10^{16}$ litres of fresh water per year, the total annual boron entering the sea from all continental drainage is approximately $4 \times 10^{14}$ mg / year." (Mellor 1980, page 82)

Earlier in his treatise, Mellor affirms that the boron concentration of seawater is neither increasing nor decreasing (see Mellor 1980, page 76). Across a geological time-scale, however, it is possible that there is a flow into the oceans from the basaltic ocean crusts. As discussed in Section 6.2 (see page 58), figures for boron concentrations in crusts are speculative in the extreme, and a discussion of possible additions to the seas from this source on an annual basis would amount to little more than conjecture.

6.5.1 **Boron in Surface Waters in Low Population Density Areas**

Work by various parties has shown that underlying geological and geographical conditions and land use may be significant in determining surface water boron levels. Lambing et al (1988) investigated water quality in a wildlife refuge in north-eastern Montana, United States. The study area chosen had a population density of less than five people per square mile, with no major industries discharging into the main river, the Milk River, and small municipal sources of waste water. The underlying bedrock was relatively uniform Cretaceous bedrock covered by glacial alluvium. 16 samples were taken from 13 sites and the results for boron...
ranged from <0.01 mg/l (the detection limit) to 6 mg/l for a flowing well in the area. The median value for this sample was a boron concentration in water of 0.12 mg/l.

Further north-west, in the Yoho National Park, on the border between British Columbia and Alberta, work by Block (1980) on the Kicking Horse River and its tributaries, a study area of 1313 km² in the heart of the Canadian Rockies, measured boron levels at five points along a 30 mile stretch of the Kicking Horse River, as well as making measurements along the eight tributaries of the river. This area was almost devoid of anthropogenic activity, with the town of Field (population 200) the only urban activity area. The bedrock was Early Cambrian; mostly sedimentary rocks with rare igneous outcrops. The results are shown in Table 20, with site 5 being the furthest upstream, and site 1 the furthest downstream. The town of Field lies between sites 5 and 4.

Table 20: Boron Concentration (mg/l) in the Kicking Horse River 1976-1978 (from Block 1980)

<table>
<thead>
<tr>
<th>Sample Date</th>
<th>Site 1</th>
<th>Site 2</th>
<th>Site 3</th>
<th>Site 4</th>
<th>Site 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>21.6.76</td>
<td>0.03</td>
<td>0.03</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>24.8.76</td>
<td>0.05</td>
<td>0.04</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>27.10.76</td>
<td>0.11</td>
<td>0.10</td>
<td>0.10</td>
<td>0.08</td>
<td></td>
</tr>
<tr>
<td>7.2.77</td>
<td>0.03</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>13.6.77</td>
<td>0.02</td>
<td>&lt;0.02</td>
<td>&lt;0.02</td>
<td>&lt;0.02</td>
<td></td>
</tr>
<tr>
<td>16.8.77</td>
<td>&lt;0.02</td>
<td>&lt;0.02</td>
<td>&lt;0.02</td>
<td>&lt;0.02</td>
<td></td>
</tr>
<tr>
<td>18.10.77</td>
<td>0.02</td>
<td>&lt;0.02</td>
<td>&lt;0.02</td>
<td>&lt;0.02</td>
<td></td>
</tr>
<tr>
<td>11.1.78</td>
<td>&lt;0.02</td>
<td>&lt;0.02</td>
<td>&lt;0.02</td>
<td>&lt;0.02</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>&lt;0.0375</td>
<td>&lt;0.0357</td>
<td>&lt;0.02</td>
<td>&lt;0.03</td>
<td>&lt;0.0275</td>
</tr>
</tbody>
</table>

Boron levels in this location, with little anthropogenic input, little organic input due to the extremes of slope making it almost impossible for sufficiently deep soils to form (the highest point in this region is Mount Goodsir at 3562 metres above sea level and the lowest is the Kicking Horse River at 1006 metres), and little geological input (boron is rarely found in igneous rock locations as it is lost from magma during crystallisation), will be lower (mean <0.0301 mg/l) than in areas with greater natural and non natural sources of boron.

6.5.2 Land Use and Boron in Surface Waters

Wilber et al (1985) carried out a study into water quality in an area of western and southwestern Indiana, USA, covering 6,500 square miles, along the eastern side of the Illinois drainage basin. They surveyed the bed rocks in the area and discovered them to be either alternating cyclical layers of shale, sandstone and limestone, or alternating cyclical layers of shale, sandstone, limestone and coal. The soils were glacial till based and had a loam / silt loam texture. They also surveyed the land use pattern in the study area, finding it to be mostly agricultural (slightly less than two thirds), with just over one quarter of land area forested. The remaining one twelfth of the land area was used for residential, commercial, industrial, recreational, wetlands, and mining purposes. 293 stream sites were surveyed to identify sites
where there was homogeneous land use in the area draining to that site. 73 sites were chosen,
with the following results:

**Table 21: Boron Loading in Surface Waters in Western / South-Western Indiana, USA,
by Land Use. (from Wilber et al 1985, page 32)**

<table>
<thead>
<tr>
<th>Land Use Type</th>
<th>Glacial Province</th>
<th>No. of sites sampled</th>
<th>Median Boron load (mg/l)</th>
<th>Minimum Boron load (mg/l)</th>
<th>Maximum Boron load (mg/l)</th>
<th>Interquartile range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest</td>
<td>Wisconsin</td>
<td>2</td>
<td>0.045</td>
<td>0.030</td>
<td>0.060</td>
<td>0.030</td>
</tr>
<tr>
<td></td>
<td>Unglaciated</td>
<td>1</td>
<td>0.030</td>
<td>0.030</td>
<td>0.030</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>TOTAL</td>
<td>3</td>
<td>0.030</td>
<td>0.030</td>
<td>0.060</td>
<td>0.030</td>
</tr>
<tr>
<td>Agriculture</td>
<td>Wisconsin</td>
<td>11</td>
<td>0.050</td>
<td>0.020</td>
<td>0.110</td>
<td>0.210</td>
</tr>
<tr>
<td></td>
<td>Ilinonian</td>
<td>12</td>
<td>0.060</td>
<td>0.020</td>
<td>1.600</td>
<td>0.210</td>
</tr>
<tr>
<td></td>
<td>Unglaciated</td>
<td>9</td>
<td>0.030</td>
<td>0.020</td>
<td>0.100</td>
<td>0.030</td>
</tr>
<tr>
<td></td>
<td>TOTAL</td>
<td>32</td>
<td>0.040</td>
<td>0.020</td>
<td>1.600</td>
<td>0.040</td>
</tr>
<tr>
<td>Reclaimed</td>
<td>Wisconsin</td>
<td>1</td>
<td>0.120</td>
<td>0.120</td>
<td>0.430</td>
<td>0</td>
</tr>
<tr>
<td>Mining</td>
<td>Ilinonian</td>
<td>1</td>
<td>0.430</td>
<td>0.430</td>
<td>0.430</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Unglaciated</td>
<td>2</td>
<td>0.160</td>
<td>0.080</td>
<td>0.240</td>
<td>0.160</td>
</tr>
<tr>
<td></td>
<td>TOTAL</td>
<td>4</td>
<td>0.180</td>
<td>0.080</td>
<td>0.430</td>
<td>0.290</td>
</tr>
<tr>
<td>Un-reclaimed</td>
<td>Wisconsin</td>
<td>3</td>
<td>0.140</td>
<td>0.110</td>
<td>0.550</td>
<td>0.440</td>
</tr>
<tr>
<td>Mining</td>
<td>Ilinonian</td>
<td>19</td>
<td>0.140</td>
<td>0.010</td>
<td>0.570</td>
<td>0.180</td>
</tr>
<tr>
<td></td>
<td>Unglaciated</td>
<td>12</td>
<td>0.170</td>
<td>0.010</td>
<td>0.490</td>
<td>0.320</td>
</tr>
<tr>
<td></td>
<td>TOTAL</td>
<td>34</td>
<td>0.150</td>
<td>0.010</td>
<td>0.570</td>
<td>0.240</td>
</tr>
</tbody>
</table>

Wilber et al. observed that across all glacial provinces,

"Median concentrations of boron, nickel and zinc were significantly higher in streams
draining mined watersheds than in streams draining forested and agricultural
watersheds. The content of boron in Indiana coals is greater than that in the Earth's
crust. The average content of boron in 10 coal samples analysed by Gluskoler and
others (1977) was 142 ug/g, whereas the average in the earth’s crust is only 10 ug/g
(Taylor, 1964).” (Wilber et al 1985, page 39)

### 6.5.3 Boron in Surface Waters in Industrial Areas

In areas of a high industrial and population density, increased levels of boron concentration in
surface waters have been observed by Helmann and Schumacher (1977), who took
measurements along the River Rhine, the main river artery of western Germany. They
observed that boron is present at background (natural) levels in the river at a concentration of
0.1 mg/l. However, they found that the boron concentration in the river between Lake
Constance and Lobith increased from 0.1 mg/l to 0.15 and 0.25 mg/l. Measurements were
taken, they say, in areas of average effluent discharge. The increase they ascribe to
anthropogenic sources of boron such as detergents. (see Helmann & Schumacher 1977, page
324)

Earlier work by Graffinman et al (1974) in West Germany looking specifically at boron traces
in surface water and drinking water throughout the country had shown raised levels of boron
in the rivers. As part of their study they took 300 samples of surface water from sites
distributed along rivers throughout the Federal Republic and West Berlin over a period
between January 1973 and May 1974. They found that boron concentration in the Rhine lay
predominantly between 0.1 mg/l and 0.2 mg/l, that the Rivers Neckar and Main, both rivers
with high levels of waste pollution, had boron levels between 0.2 mg/l and 0.3 mg/l, and that near the mouth of the River Ruhr boron concentrations in the river were between 0.4 mg/l and 0.5 mg/l. It should be observed that while outflows from anthropogenic activity may have caused a substantial portion of this levels of boron, the Ruhr area has been a major coal belt in the Federal Republic, and may have similar geological contributions to those found in Indiana.

6.5.4 Discussion on Data for Surface Water Boron Levels
The data presented thus far, illustrating results of work into boron concentrations in water systems, suggest that many variables impact upon the level of boron in water. However, they show no clear consensus as to a final mean value of boron concentration in global surface waters. In 1973 Matthews suggested that surface waters contain boron at a concentration of 0.013 mg/l, a figure consistent with the conclusions of Mellor, writing in 1980, who suggested that for the USA and the USSR boron was present in surface waters at a mean concentration of 0.012 mg/l.

However, Sprague, writing in 1972, suggested that for the USA surface water boron concentration was approximately 0.1 mg/l, a value almost ten times higher than those used by Matthews and Mellor. Sprague suggested that surface waters in the Western Great Lakes of North America contained boron at concentrations of 0.02 mg/l while those near the Western Gulf Basin contained boron at 0.3 mg/l. This would be consistent with the work of Wilber et al. in 1985 who found mean surface water boron levels in Indiana, USA, to range from 0.03 mg/l to 0.18 mg/l depending on geology and land-use. Block, writing in 1980, reported values for Yoho National Park, Canada, with a lower detection limit for boron of 0.02 mg/l, a value which is greater than the mean values reported by Matthews and Mellor. Helman and Schumacher, writing in 1977, gave a natural background boron level in the River Rhine of 0.1 mg/l, consistent with Sprague’s mean concentration of 0.1 mg/l for the USA.

Reasons for the discrepancy between the values given are not known. It could be speculated that the differences could be due to a lack of accuracy in measurement systems, or poor experimental technique. The issue of quantity of data must also be addressed. A notable feature of much of the data presented in texts on surface water boron levels is that valuable information; such as frequency of sampling, duration of the sampling program, and river flow conditions associated with each sample, is not provided. The absence of such information precludes the determination of a global surface water boron level beyond a probable range of 0.01 mg/l to 0.1 mg/l.

At the local level, however, a Case Study examines the issues involved in the determination of accurate surface water boron levels. Particular attention is given to seasonal variations and the identification and quantification of boron sources. This case study is presented as Appendix 1 (see Vol. 4 APD1).
### 6.6 Boron in Ground Waters

Residence times for boron in ground water are much greater than those for surface water and thus there is greater potential for interaction with bedrock. Work by Edmunds et al. for the British Geological Survey (1989) in the United Kingdom examined element concentrations in ground waters in different bedrock zones from 1983 to 1988. They found a noticeable impact upon boron concentrations from bedrock, summarised in the following table:

<table>
<thead>
<tr>
<th>Aquifer</th>
<th>Median Boron Concentration (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Berkshire Chalk</td>
<td>0.056</td>
</tr>
<tr>
<td>London Basin Chalk</td>
<td>0.165</td>
</tr>
<tr>
<td>All Lincolnshire Limestone</td>
<td>0.104</td>
</tr>
<tr>
<td>East Lincolnshire Limestone</td>
<td>0.632</td>
</tr>
<tr>
<td>West Lincolnshire Limestone</td>
<td>0.033</td>
</tr>
<tr>
<td>Carboniferous Limestone</td>
<td>0.013</td>
</tr>
<tr>
<td>Lower Greensand</td>
<td>0.020</td>
</tr>
<tr>
<td>Wealden</td>
<td>0.150</td>
</tr>
<tr>
<td>Millstone Grit</td>
<td>0.009</td>
</tr>
<tr>
<td>Carboniferous Sandstone</td>
<td>0.044</td>
</tr>
<tr>
<td>Shropshire Triassic</td>
<td>0.011</td>
</tr>
<tr>
<td>West Lancashire Triassic</td>
<td>0.016</td>
</tr>
<tr>
<td>Carlisle Triassic</td>
<td>0.013</td>
</tr>
<tr>
<td>Moray Old Redstone and Triassic</td>
<td>0.018</td>
</tr>
</tbody>
</table>

Comparing values for millstone grit and carboniferous limestone in Derbyshire, Edmunds et al. observe that,

"Boron is low in waters from both the Millstone Grit and the Carboniferous Limestone and there appears to be little enhancement in concentrations above background due either to the mineralisation or to the contrast in the geochemical environment between both formations. The median values are similar in both aquifers and the baseline must therefore be due mainly to atmospheric inputs (thought to be 5±3 ug/l)" (Edmunds et al 1989, page 128)

Work by Ford et. al for Dames & Moore (1995) examined boron concentrations in groundwater and surface-water sources of drinking water in western Europe. They looked in detail at Denmark, France, Greece, Italy, and Spain, taking 342 samples from groundwater and surface water sources associated with a variety of bedrock conditions. They found boron present at concentrations between 0.017 mg/l and 1.904 mg/l.

Work by Goetz (1990) examined the possible impact of bedrock on concentrations of elements in wells filled by surface drainage in the Zuni River Basin in USA. This study examined an area of desert in southern USA, on the border between New Mexico and Arizona. This was an area of extremely sparsely populated tribal land, pentagonal in shape,
with sides of approximately 30 miles. This study examined over 170 wells, and characterised the parent material for each well’s primary source of water using 21 different aquifer codes. 36 measurements were taken for boron, of which 26 had aquifer information. Seven different aquifer types were represented in these sites. The values for the different aquifer types are shown below:

Table 23: Aquifer Geology and Dissolved Boron Levels, New Mexico Wells, (derived from Goetz 1990)

<table>
<thead>
<tr>
<th>Aquifer Geology</th>
<th>Number of wells</th>
<th>Minimum Dissolved B (mg/l)</th>
<th>Maximum Dissolved B (mg/l)</th>
<th>Mean Dissolved B (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mesozoic, Upper Cretaceous, Dakota Sandstone</td>
<td>8</td>
<td>0.390</td>
<td>1.900</td>
<td>0.850</td>
</tr>
<tr>
<td>Cenozoic, Quaternary, Alluvium, Surface Deposits</td>
<td>6</td>
<td>0.130</td>
<td>1.300</td>
<td>0.470</td>
</tr>
<tr>
<td>Mesozoic, Upper Cretaceous, Gallup Sandstone</td>
<td>8</td>
<td>0.180</td>
<td>0.980</td>
<td>0.480</td>
</tr>
<tr>
<td>Mesozoic, Upper Cretaceous, Mesaverde Group</td>
<td>1</td>
<td>0.380</td>
<td>0.380</td>
<td>0.380</td>
</tr>
<tr>
<td>Mesozoic, Upper Jurassic, Zuni Sandstone</td>
<td>1</td>
<td>0.040</td>
<td>0.040</td>
<td>0.040</td>
</tr>
<tr>
<td>Cenozoic, Quaternary, Pleistocene, Laguna Basalt Flow</td>
<td>1</td>
<td>0.030</td>
<td>0.030</td>
<td>0.030</td>
</tr>
<tr>
<td>Mesozoic, Upper Cretaceous, Dilco Coal Member of Crevasse Canyon Formation of Mesaverde Group</td>
<td>1</td>
<td>0.190</td>
<td>0.190</td>
<td>0.190</td>
</tr>
</tbody>
</table>

The data for Europe shows boron present at concentrations between 0.017 mg/l and 1.904 mg/l, while that for the southern United States shows boron present at concentrations between 0.030 mg/l and 1.900 mg/l, a close correlation. If these figures are applied to global groundwater volumes of approximately $8.4 \times 10^{18}$ kg, then boron is present in groundwater at a global level of between $1.428 \times 10^{11}$ kg and $159.9 \times 10^{11}$ kg B.
7. Calculating the Global Boron Mass Values

The objective for this section is to summarise the reservoirs and flows of boron in the environment which have been identified in the previous sections and to quantify these reservoirs and flows in terms of kilograms of boron. In previous sections boron has been discussed as either boron equivalent, or as boric oxide ($B_2O_3$) equivalent. In this section all values will be converted to boron ($B$) where necessary.

7.1 Reservoirs of Boron

The following reservoirs of boron have been identified:

7.1.1 Boron in the Continental Crust

The continental crust has been estimated to have a mass of approximately $2.985 \times 10^{22}$ kg, with boron present at an average concentration of 15 mg/kg (see Section 6.2, page 58).

From these figures, the continental crust represents a boron reservoir of: 

$$4.4 \times 10^{18} \text{ kg B}.$$ 

7.1.2 Boron in the Oceanic Crust

The oceanic crust has been estimated to have a mass of approximately $5.97 \times 10^{21}$ kg, with boron present at an average concentration of 10 mg/kg (see Section 6.2, page 58).

From these figures, the oceanic crust represents a boron reservoir of: 

$$5.97 \times 10^{16} \text{ kg B}.$$ 

7.1.3 Boron in the Oceans

Boron is present in the oceans at a mean concentration of 4.6 mg/l. According to hydrology texts there are between $1.31 \times 10^{21}$ kg and $1.4 \times 10^{21}$ kg of water in the world’s oceans (see Section 6.4, Table 17).

From these figures, the oceans represent a boron reservoir of: 

$$6.026 \times 10^{15} \text{ kg to } 6.44 \times 10^{15} \text{ kg B}.$$ 

7.1.4 Boron in Surface Deposits

Boron is present in the earth’s crust as borate minerals. There are between 99 million and 227 million tonnes of $B_2O_3$ in these deposits (see Section 4.3.1, page 18).

From these figures, surface deposits represent a boron reservoir of: 

$$3.075 \times 10^{10} \text{ kg to } 6.44 \times 10^{10} \text{ kg B}.$$ 

7.1.5 Boron in Coal

Boron is present in coal deposits. There are between 12.74 million and 148.13 million tonnes of boron in these deposits (see Section 6.1.3.1, page 51).

From these figures, coal deposits represent a boron reservoir of: 

$$1.274 \times 10^{10} \text{ kg to } 14.813 \times 10^{10} \text{ kg B}.$$ 

7.1.6 Boron in Soil

The total soil coverage on the earth’s surface is 13 billion hectares (see Section 6.3.6). Boron is present in the soil at concentrations ranging from 4 mg/kg to 98 mg/kg at a mean of 30 mg/kg. However, as discussed in Section 6.3.6, this information is not sufficient to calculate a value for boron held in the soil reservoir system.

7.1.7 Boron in Biomass

Boron is present in the biomass on earth at a mean concentration of 30 to 50 mg per kg biomass. The dry weight of the biomass of the earth is approximately 1 trillion tonnes (see Section 6.3.4, page 64).

From these figures, biomass represents a boron reservoir of:

\[ 3 \times 10^{10} \text{ kg to } 5 \times 10^{10} \text{ kg B.} \]

7.1.8 Boron in Ice Caps & Glaciers

The majority of ice on the earth’s surface is freshwater; ice deposits on Antarctica and Greenland are frozen snow, glaciers are freshwater based. The ice caps and glaciers represent between 1.5 \( \times \) 10^{19} kg and 2.9 \( \times \) 10^{19} kg of water, with boron present at a concentration of 0.01 to 0.1 mg/l (see Section 6.5.4).

From these figures, ice represents a boron reservoir of:

\[ 1.5 \times 10^{11} \text{ kg to } 29 \times 10^{11} \text{ kg B.} \]

7.1.9 Boron in Ground Waters

Boron is present in ground waters at concentrations of between 0.017 mg/l and 1.904 mg/l. Ground waters represent approximately 8.4 \( \times \) 10^{18} kg of water (see Sections 6.4 and 6.6).

From these figures, ground-water represents a boron reservoir of:

\[ 1.428 \times 10^{11} \text{ kg to } 159.9 \times 10^{11} \text{ kg B.} \]

7.1.10 Boron in Surface Waters

Boron is present in surface waters at a concentration of between 0.01 and 0.1 mg/l. Lakes represent between 2.8 \( \times \) 10^{16} kg and 3.4 \( \times \) 10^{16} kg of water (see Section 6.4 and Section 6.5.4).

From these figures, lakes represent a boron reservoir of:

\[ 2.8 \times 10^{9} \text{ kg to } 3.4 \times 10^{9} \text{ kg B.} \]
7.2 **Boron Flows to the Atmosphere**

7.2.1 **Boron From Marine Injection & Volatilisation.**
Boron is transmitted from sea surfaces to atmosphere through direct salt injection and volatilisation. Between $80 \times 10^{10}$ g and $400 \times 10^{10}$ g boron enter in gas phase, while $50 \times 10^{10}$ g enter as particulate each year (see Section 6.1.1, page 50).
From these figures, marine injection and volatilisation to atmosphere represent a boron flow of:

$$1.3 \times 10^9 \text{ kg to } 4.5 \times 10^9 \text{ kg B per annum.}$$

7.2.2 **Boron From Volcanoes**
Boron is transmitted from volcanoes to atmosphere at a rate of $30 \times 10^{10}$ g gas phase boron and $0.01 \times 10^{10}$ g particulate boron each year (see Section 6.1.2, page 50).
From these figures, volcanic activity represents a boron flow to atmosphere of:

$$3.01 \times 10^8 \text{ kg B per annum.}$$

7.2.3 **Boron From Forest Fires**
Boron is transmitted to the atmosphere as a result of forest fires, boron being present in organic matter, at a rate of $0.59 \times 10^{10}$ g gas phase boron and $0.06 \times 10^{10}$ g particulate boron each year (see Section 6.1.3, page 51).
From these figures, forest fires represent a boron flow to atmosphere of:

$$6.5 \times 10^6 \text{ kg B per annum.}$$

7.2.4 **Boron From Agricultural Burning**
The burning of organic material in agriculture contributes $13.5 \times 10^{10}$ g gas phase boron and $1.5 \times 10^{10}$ g particulate boron each year (see Section 6.1.3, page 51).
From these figures, agricultural burning represents a boron flow to atmosphere of:

$$1.5 \times 10^8 \text{ kg B per annum.}$$

7.2.5 **Boron From Coal Combustion.**
Boron has been calculated to be present in coal at a concentration range of 12.7 mg/kg to 135.95 mg/kg (see Section 6.1.3.1, page 51). When coal is burned, 50% of the boron present is volatilised to atmosphere, and between 5% and 10% of the remaining boron present is released in atmospheric fly ash. It has been calculated that 4440.9 million tonnes of coal are consumed annually.
From these figures, coal combustion represents a boron flow to atmosphere of:

$$(27.08639 \text{ to } 302.58129 \text{ kg } * 10^5) + (1.35432 \text{ to } 30.25813 \text{ kg } * 10^6)$$

$$= \sim 2.844 \times 10^7 \text{ kg to } \sim 33.284 \times 10^7 \text{ kg B per annum.}$$
7.2.6 Boron From Glass Production
A total of approximately 390,000 tonnes of B₂O₃ are used in the production of glass related products, per annum, with 0.068% of B₂O₃ lost as B₂O₃ dust, and 0.546% lost as B₂O₃ gas. From these figures, the production of glass based products represents a boron flow to atmosphere of:

2.395 * 10⁶ kg B per annum.

7.2.7 Boron From Ceramics Production
Annual production of glazed ceramic tile is approximately 1360 million m², with an upper possible 5500 mg boron released per m² tile produced (see Section 5.3.7.4.1, page 41). From these figures, the production of ceramic tiles represents a boron flow to atmosphere of no more than:

7.48 * 10⁶ kg B per annum.

7.2.8 Boron From Cellulose Insulation Production
A total of approximately 20,000 tonnes of B₂O₃ are used in the production of cellulose insulation per annum, with an upper possible process loss of 2.838% to atmosphere as dust (see Section 5.3.9, page 44). From these figures, cellulose insulation represents a boron flow to atmosphere of no more than:

1.76 * 10³ kg B per annum.
7.3 Flows To Soil Systems

Flows to the soil systems will include deposition from the atmosphere, disposal of commercial products to landfill, disposal of process wastes to landfill, application of fertilisers to soils, application of sewage sludge to soils, decomposing organic matter, manure, and desorption from clays, plus possible additions from weathering processes.

7.3.1 Boron From Atmospheric Deposition

Circulation of boron in the atmosphere is global. With the exception of combustion products from ineffective stack systems, boron released to atmosphere is concentrated evenly in the atmosphere (Clift 1996). Total sources of atmospheric boron (see Section 7.2) are in the range \(-1.796 \times 10^9\) kg to \(5.300 \times 10^9\) kg B per year. According to Barry (1971), 77% of precipitation falls over the oceans, with 23% falling over land (Barry 1971, page 1-1). According to Porteous (1993), the ratio is 75% over the oceans and 25% over land (Porteous 1993, page 186). Taking an average of 24% of precipitation falling over continental masses, it can be estimated that 24% of atmospheric boron will be washed out over land systems. From these figures, atmospheric washout represents a boron flow to soil systems of:

\[ 0.431 \times 10^9 \text{ kg to } 1.272 \times 10^9 \text{ kg per year.} \]

7.3.2 Boron From Primary & Secondary Processing Losses

Between 1.18 million and 1.33 million tonnes \(\text{B}_2\text{O}_3\) is removed from borate deposits each year. The following losses to land have been calculated (see Section 5.3.3):

- **Primary Losses to Gangue and Solar Pond:** ~118,000 to ~265,000 tonnes \(\text{B}_2\text{O}_3\),
  ~3.665 to ~8.231 \times 10^7\ kg B.

- **Boric Acid Production Losses to Tip:** ~73,000 tonnes \(\text{B}_2\text{O}_3\),
  ~2.267 \times 10^7\ kg B.

Currently, none of the process losses to solar ponds are recovered. Work is ongoing at US Borax to develop systems which will eventually recover approximately 50% of these losses at Boron, USA.

7.3.3 Boron From Perborate and Detergent Production

Approximately 190,000 tonnes \(\text{B}_2\text{O}_3\) is used in the production of perborate and detergents, between 0.17% and 3.1% of which is lost as solid waste. From these figures, the production of perborate represents a flow to landfill of:

\[ ~1 \times 10^2 \text{ kg to } 18.29 \times 10^2 \text{ kg B per year.} \]

7.3.4 Boron From Ceramics Production

Double firing ceramic systems produce ~70,720 tonnes of sludge per year, containing ~5438 tonnes of \(\text{B}_2\text{O}_3\), while single firing systems produce ~332,800 tonnes of sludge, containing ~15,442 tonnes of \(\text{B}_2\text{O}_3\).
From these figures, process losses from the production of ceramics represent a boron flow to landfill of:

\[ 6.485 \times 10^3 \text{ kg B per year.} \]

### 7.3.5 Boron From Bottom Ash in Coal Combustion

Boron has been calculated to be present in coal at a concentration range of 12.7 mg/kg to 135.95 mg/kg (see Section 6.1.3.1). When coal is burned, 50% of the boron is released as ash, between 90% and 95% of which is bottom ash. The majority of bottom ash goes directly to landfill, with the rest being applied directly to the soil as a form of fertiliser. Boron in landfill is highly mobile (see Section 6.1.3.1) and it is possible that much of the boron in landfill is leached into the soil system. It has been estimated that 4440.9 million tonnes of coal are consumed annually.

From these figures, coal combustion represents a boron flow to land or landfill of:

\[ -2.438 \times 10^7 \text{ kg to } 28.745 \times 10^7 \text{ kg B.} \]

### 7.3.6 Boron From Landfill of Discarded Product.

The assumption is made that the commercial product cycle for boron products is in balance. I.e. the global production of borosilicate glass, ceramic tiles, textile fibre-glass is used to replace discarded products, so that in a given year, the annual production of non-biologically active boron products is balanced by disposal of boron products to landfill. In 1994 the following product volumes have been calculated as a product of raw material inputs less process losses (see Section 5.3.4, Section 5.3.5, Section 5.3.7, and Section 5.3.9):

- **Glass-based Products:** ~387,605 tonnes B$_2$O$_3$.
  - \( 1.204 \times 10^8 \text{ kg B.} \)
- **Fritted Products:** ~2.334 * 10$^7$ kg B to 3.082 \( 10^7 \text{ kg B.} \)
- **Cellulose Insulation:** ~22,473 tonnes B$_2$O$_3$.
  - \( 6.980 \times 10^7 \text{ kg B.} \)

Final fate details for B$_2$O$_3$ sold to distributors and other applications is not known. For the purposes of these calculations it will be assumed that all such sales will reach landfill eventually.

- **Distributors and Others:** ~220,000 tonnes B$_2$O$_3$.
  - \( 6.833 \times 10^7 \text{ kg B.} \)

### 7.3.7 Boron From Fertiliser Application

A total of ~50,000 tonnes B$_2$O$_3$ are used annually in the production of fertilisers, of which approximately 49,750 tonnes are sold as product (see Section 5.3.8). From these figures the use of fertilisers represents a boron flow to soil of:

\[ 1 \times 1.545 \times 10^7 \text{ kg B.} \]
7.3.8 Boron From Rock Weathering

It is estimated that weathering processes mobilise 360,000 tonnes of boron per year into river sedimentary systems (see Section 6.3). A variety of processes, such as frost shattering, will mobilise insoluble boron into the soil systems. However, data has not been found to quantify such flows.
7.4 Flows To Aqueous Systems
Flows to aqueous systems will include atmospheric deposition, manufacturing process wastes as effluent, household wastes in the sewage stream (mainly food wastes and detergents), leaching from soil systems into ground waters and surface waters, additions to ground waters from bedrock weathering processes, surface run-off from soil systems.

7.4.1 Boron From Atmospheric Deposition
As discussed in Section 7.3.1, circulation of boron in the atmosphere is global. Total sources of atmospheric boron (see Section 7.2) are in the range $\sim1.796 \times 10^9$ kg to $5.300 \times 10^9$ kg B per year. Taking an average of 76% of precipitation falling over oceans, it can be estimated that 76% of atmospheric boron will be washed out over oceans (see Section 6.4). From these figures, atmospheric boron washout represents a flow to aqueous systems of:
\[1.365 \times 10^9 \text{ kg to } 4.028 \times 10^9 \text{ kg B per year.}\]

7.4.2 Boron Leaching From Soil Systems
Local mass balance work for the River Thames region suggests that the soil system is in balance, with net additions balanced by net removal into aqueous systems and a reservoir of predominantly insoluble boron present in the soil bound to clays or other minerals and unavailable to plants (see Vol. 4 APD2). Applying this at a global level, any atmospheric deposition on land will find its way into continental water systems. Total boron flows to atmosphere are $\sim1.796 \times 10^9$ kg to $5.300 \times 10^9$ kg B per year, of which approximately 24% falls on land (see Section 7.4.1). From these figures, atmospheric boron flows to soil systems which then balance in the soil to leach into continental water systems represent a boron flow of:
\[\sim4.31 \times 10^8 \text{ kg to } 12.72 \times 10^8 \text{ kg B per year.}\]

7.4.3 Boron From Detergent Production and Consumption
190,000 tonnes of B$_2$O$_3$ is used in the detergent industry each year. Between 182,400 tonnes and 188,043 tonnes is converted to product, which flows into aqueous systems through sewage streams, and between 1653 and 1710 tonnes is lost to aqueous systems through process losses (see Section 5.3.6). From these figures, flows to sewage streams and effluent from the detergent industry represent a boron flow of:
\[\sim5.665 \times 10^7 \text{ kg to } \sim5.841 \times 10^7 \text{ kg B per year in sewage.}\]
\[\sim5.134 \times 10^5 \text{ kg to } \sim5.311 \times 10^5 \text{ kg B per year in process effluent.}\]

7.4.4 Boron From Ceramics Production
The production of ceramics produces 21,080,000 m$^3$ of wastewater, with boron present at 0.055 kg/m$^3$ (see Section 5.3.7.4.2).
From these figures, flows to aqueous systems from the production of ceramics represent a boron flow of:
\[1.159 \times 10^6 \text{ kg B per year}.
\]

### 7.4.5 Boron From Fertiliser Production

Approximately 50,000 tonnes \( \text{B}_2\text{O}_3 \) are used in the production of fertilisers each year, of which less than 0.5% is lost to aqueous systems (see Section 5.3.8).

From these figures, losses to the aqueous system in the production of fertilisers represent a boron flow of:
\[7.765 \times 10^1 \text{ kg B per year}.
\]

### 7.4.6 Boron From Food Wastes

Crop removal for human consumption represents a removal of approximately \(2.599 \times 10^{12}\) kg mass each year. With boron present in biomass at concentrations ranging from 30 mg/kg to 50 mg/kg, boron removal in crop harvesting can be calculated to lie in the range \(7.797 \times 10^7\) kg to \(12.995 \times 10^7\) kg B per year (see Section 6.3.4). Approximately 94% of ingested boron is released into the sewage stream (where there is one) (see Vol.4 APD2).

From these figures, food waste flows represent a boron flow to the environment of:
\[7.329 \times 10^7\text{ kg to } 12.215 \times 10^7\text{ kg B per year}.
\]
7.5  Boron Flows Within Aqueous Systems

7.5.1  Boron From River Discharge to Oceans

It has been calculated that surface run-off represents a water flow of approximately \(3.2 \times 10^{16}\) kg per year (see Section 6.4). The boron concentration of surface waters has been calculated to lie in the range 0.01 mg/kg to 0.1 mg/kg (see Section 6.5.4).

From these figures, river discharge to oceans represents a boron flow of:

\[3.2 \times 10^8\] kg to \(3.2 \times 10^9\) kg B per year.

7.5.2  Boron From Ground Water Flow to Oceans

It has been calculated that ground water discharge represents a water flow of approximately \(4.0 \times 10^{15}\) kg per year (see Section 6.4). The boron concentration of ground waters has been calculated to lie in the range 0.017 mg/l to 1.904 mg/l (see Section 6.6).

From these figures, ground water discharge represents a boron flow of:

\[6.8 \times 10^7\] kg to \(7.616 \times 10^9\) kg B per year.
7.6 \textit{Mass Flow Schematic}

The boron flows and reservoirs have been assembled into a process schematic illustrated over-page. The major reservoirs are illustrated as solid boxes, with the width of border representing the relative size of the reservoir. Short term reservoirs, such as borate mines, power stations, factories, end-use locations are illustrated by the boxes marked ‘Mining and Processing’, ‘Coal Combustion’, ‘Industry’ and ‘Use’ respectively. Landfill is included as a reservoir, the residence time of boron in this reservoir is unknown.

Boron flows are represented by solid arrows, with a value for the size of the flow included mid-way along the relevant arrow. The greater the flow, the wider the arrow used. Where a flow has been identified but not quantified a dotted line is used. Mass values are represented in kilograms throughout. These reservoirs and flows will be discussed in Section 8, ‘Conclusions and Evaluation’.
Figure 20: Boron Mass Balance Schematic
8. Conclusions and Evaluation

8.1 Key Findings for Boron Reservoirs

The total boron identified in the global mass system exists in ten major reservoirs and in the flows between them shown in Section 7.6. Nine of these major reservoirs have been quantified. These are, in order of magnitude: the continental crust, the oceanic crust, the world ocean system, ground-waters, ice, coal reserves, surface borate deposits, boron in biomass, boron in surface waters. Given the presence of boron in continental structures, it is likely that physical weathering processes such as frost shattering will mobilise insoluble boron into the soil system, which may turn out to be a significant reservoir also.

The sum value of these identified reservoirs (to three decimal places) is:

$$4.466 \times 10^{18} \text{ kg B.}$$

Of this value, $4.4 \times 10^{18} \text{ kg B}$ is thought to exist in the continental and oceanic crusts. In the remaining reservoirs the boron mass present has been calculated to lie in the range:

$$6.026 \times 10^{15} \text{ kg to } 6.459 \times 10^{15} \text{ kg B}$$

There is a range in mass values between the maximum calculated reservoir mass and minimum calculated reservoir mass of $4.328 \times 10^{14} \text{ kg}$. It must be re-emphasised that these values do not include a value for boron present in the soil system. Nonetheless, these mass values lead to the following conclusions for boron reservoirs:

1. Over 99.87% of the boron present in the earth outside the core and mantle is held in the continental and oceanic crusts, structures so large that they may be considered, essentially, as a virtually homogeneous basaltic mass. These structures weather extremely slowly to move boron into the surface deposits, ground-waters, sea-waters, and soils.

2. Of the remaining boron present outside the core and mantle, over 99.99% is found in the oceans.

3. Borate deposits, of between thirty billion and sixty five billion kilograms of boron, represent approximately ten millionths of the boron present in the surface systems of the planet, and approximately ten billionths of the boron present outside the core and mantle.

4. Global biomass and coal deposits represent boron reservoirs of similar magnitude to the borate deposits.
8.2 Key Findings for Boron Flows

Several cycling systems exist between the reservoirs. For example, boron removed from the oceans through transmission to the atmosphere will return either through direct precipitation over the oceans, or by precipitation over land followed by passing through the soil into the continental drainage system. This system has been identified as the largest flow system, with $1.3 \times 10^9$ kg to $4.5 \times 10^9$ kg B moved into atmosphere from the seas and hence washed out over land and sea.

By far the most dominant quantified flows are those going to atmosphere. As the mass flow diagram shows, there are six major sources of boron flows to the atmosphere. These are, in order of magnitude: ocean transmission, volcanism, agricultural burning, coal combustion, industrial activity, and forest fires. The sum total of these flows lies in the range 1.796 to 5.3 billion kilograms per year.

Flows from the surface systems are less well quantified, with weathering from continental crusts unknown. However, coal mining and borate mining account for the removal of between 0.44 and 1.01 billion kilograms of boron per year.

Several conclusions can be drawn from the data on boron flows:

1. By far the most dominant flows of boron arise from the movement of boron into the atmosphere from oceans.
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 around four hundred million kilograms boron and volcanic eruptions estimated to represent a flow of around three hundred million kilograms per year.
3. Coal mining represents a boron flow from the ground of similar magnitude to boron mining and volcanoes, with between fifty and six hundred million kilograms boron removed in coal each year.
4. Anthropogenic activity 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 activity such as glass products production, ceramics production etc., represent flows of boron to atmosphere of approximately ten million kilograms, a small percentage of the total boron flows to the atmosphere of between one thousand eight-hundred million kilograms and five thousand three-hundred million kilograms per year.
5. Process losses from industry and the use of detergents represent flows to aqueous systems of approximately fifty three million kilograms per year. Drainage into the sea from rivers and ground-waters is estimated to represent anything from three hundred and ninety million kilograms to as much as ten billion kilograms of boron per year, much of which is boron which was previously moved into atmosphere from the seas by natural processes.
8.3 Appraisal of the Strength of the Data Used

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 is so speculative that the magnitude of boron in the crusts could vary by a factor of ten in either direction, an error which is larger than the sum of all the other reservoirs. The data for the continental and oceanic crusts is useful, however, in that it shows 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 the mass values presented that there is 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 is not available. The solubility of boron has meant that the hydrological cycle is one of the key drivers of boron mass flows in the environment. However, authors disagree as to the exact mass values of the components of the hydrological cycle, despite being in broad agreement over the orders of magnitude associated with the flows. Discussions with members of staff at the Department of Oceanography at Southampton University reveal that there are insufficient data, as yet, to be entirely specific on the hydrological mass values, although a major research program into the world oceanic systems is ongoing (Gymer & Briden 1996). The same issue applies to other reservoirs for boron, such as coal deposits. The exact mass of coal in the earth’s crust is unknown, but an order of magnitude can be estimated based on existing information.

Once a value for the size of a reservoir has been determined, further error is introduced by assumptions made about the concentration of boron present in the reservoir. Either data is only available for one specific location but has had to be taken as representative of global values, or the concentrations in any given location vary to such an extent that a specific value cannot be determined beyond a range of values. Thus values for the mass of boron in ground waters range from $1.428 \times 10^{13} \text{ kg}$ to $1.599 \times 10^{13} \text{ kg B}$, due to a lack of certainty in the data over boron concentrations in this system. There are many locations across the globe where data is not available for soils, borate deposits, vegetation, and coal deposits, for example, which creates difficulties in determining genuinely global figures.

The difficulties experienced in generating conclusive values for boron reservoirs were also found in identifying flows between the reservoirs. The data available were rarely sufficiently representative of global activity. Data for flows within the hydrological cycle, such as precipitation, will only be as accurate as the data for the reservoirs from which the flows arise. On the anthropogenic side of the balance, data tended to be either extremely specific information about one particular process, or non-existent. For example, in the case of borate mining activity: there are comprehensive data on process flows during primary processing of borates at Boron, USA. Data are not available for activities in Turkey where a large share of the world’s borates are mined. Data for activities in Argentina, China, and the former USSR
are unavailable also. To take information for one location and then attempt to apply it globally involves a high risk of inaccuracy.
8.4 Future Work

Several areas of work to improve the accuracy of this mass balance are possible, but may not be practical. For each of the reservoirs identified a research project to establish global boron levels and movements would be possible. In the case of coal, samples from throughout the globe could be analysed for boron content. The combustion techniques for coal throughout the globe, in terms of flows and temperatures would need to be known and work carried out to calculate the global proportion of boron in coal going to atmosphere and to bottom ash.

Landfill is an area where very limited information is available. It has been possible, within this project, to establish that boron in ash is extremely mobile in landfill, but it is not known to what extent boron is leached out of the landfill into the soil system. A great deal of work is possible on the anthropogenic movement of boron. Information on mining and processing is commercially sensitive and in an industry with only two major operators; Borax and Etibank, any information which does exist is closely protected.

Accurate data on the movement of boron in biomass would also be needed to improve the overall mass balance. The exact composition of global biomass in terms of different organic species would need to be established. Data does exist on the concentration of boron present in different plants which could then be used to gain a more accurate understanding of the true value of boron present in biomass. This could be followed by work into examining the flows of boron into and out from the biomass; flows such as boron in decomposing organic matter and the mechanisms by which the biomass interacts with the soil.

The major area of uncertainty, however, is the soil system. It has not been possible, within this work, to establish a value for global soil boron levels. The analysis of a local system; the River Thames region, has suggested that the system is in balance, with net additions offset by net removal from the system, but further data within this region would be necessary to give greater validity to this suggestion. A possible way to do this would be to isolate a part of such a system, an individual slope or field for example. If underlying geological conditions were known and soil boron levels measured, biomass calculated and boron content determined, rainfall measured and analysed for boron, if leaching patterns were determined and boron in leachate measured, one could make progress towards determining mass flows of boron within the soil system.

Much of the discussion in these closing sections has focused upon the accuracy of data used to generate mass values, with reservations expressed regarding the extent to which the data can be regarded as truly representative of the global system. Nonetheless, the work carried out to date, in general terms, remains representative of the scale of the reservoirs and flows which exist. For example, the key findings from this work are associated with the relative size of the reservoirs and flows rather than the accuracy to as many decimal places as possible of the actual values used. Crusts, for example, are such a large store of boron that the slightest error in terms of boron concentration could give an error for mass which will outweigh the sum of the boron present in all the other reservoirs. A more useful finding is that the movement of boron associated with borate mining and conversion are outweighed by movements associated with combustion of organic material and coal, by tectonic activity such as volcanism and sub-
oceanic plate boundary movements, and, particularly, by ocean-to-atmosphere movements. Ocean to atmospheric movement could represent a flow of boron as much as ten times larger than the movement of boron mined, each year.
8.5 Overall Evaluation of the Project

The objectives of this project have been, broadly, three fold. The first objective has been to identify the global reservoirs for boron and, where relevant, where they are. The second objective has been to identify the mechanisms by which boron moves between these reservoirs. The third objective has been to attempt to quantify these mass reservoirs and mass movements wherever possible. Where such an attempt has been unsuccessful, the objective has been to offer an explanation regarding why such a quantification has been unsuccessful, and to specify the data which would be required to make such a quantification possible.

An upper time limit of six months was established for the completion of a global mass balance for boron. The justification for imposing such a deadline on this work relates to the depth of information required. As emphasised in Section 8.3, there are many areas where data is incomplete. To generate a comprehensive mass balance for boron could take many years, as it would involve a data gathering exercise of a much greater scale than was possible for this project. In this project, where data is not available for a region or operation, assumptions based on information available for proximate regions or operations have been made. For example, as explained in Section 6.2, to discover the true construction of the continental crusts is beyond the capabilities of existing technology.

Nonetheless, the broad objectives of this project have been met within the time-frame specified. The global reservoirs for boron have been established. It is possible that oil reserves and oil consumption may represent a reservoir and flow for boron, but Mellor (1980) argues that the concentration of boron in oil approximates to 0.466 mg/kg. With global oil reserves estimated at $1.373 \times 10^{14}$ kg (BP 1995), the boron present in these reserves will be approximately $6.398 \times 10^7$ kg B, approximately 0.1% of the size of the boron reservoir in coal. Considerable effort and time was required to generate a value for coal and it was felt that similar effort for oil would not be justified; effort would better be focused elsewhere. Coal combustion may leave more boron in bottom ash each year than is present in all global oil reservoirs.

The mechanisms by which boron is moved between the global boron reservoirs have been identified and quantified wherever possible. Where quantification has not been possible the limitations of the data available have been discussed. This applies particularly to soil flows and surface water run-off. River boron must be evaluated almost on a case-by-case basis to build up a global picture, and the same is true for soils, the complexity and variety of factors influencing the flows being so great. This notwithstanding, the work carried out is intended to represent a scheme of data to illustrate the global picture for boron mass reservoirs and flows. Where there are omissions, the discussion is intended to show the reasons for such omissions and how much data of the data needed is available as well as suggesting specific areas where further knowledge is required.
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