Integrated Waste Management:
A Knowledge Based Decision Support System Prototype for Developed and Developing Countries

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A Decision Support Prototype

Abstract

A prototype knowledge-based decision support system was developed to compare the components and parameters of the inputs and wastes of different industries and determine the potentials for reuse, recycling or disposal and the treatments required for recycling or disposal. The specific number and the order of required treatments was termed a treatment train and was determined through exhaustive searching. The knowledge base included the input limits for each parameter and the formulae that define the parameters of the outputs for 25 treatments. The parameters depend upon the state of the waste and a total of 29 parameters were included. The system also determined the quantity of the secondary wastes produced by each treatment.

To test the system, inputs, products and wastes from four industries on the Point Lisas Industrial Estate, Trinidad were incorporated into the database. For the 73 wastes, the program produced over 4,600 treatment trains, with seven wastes which could not be treated to match an input or a standard. By selecting the treatment train which produced the lower volumes of secondary wastes, matching treatment trains for co-treatment and selecting the shorter trains, final options for treatment were determined. Economic data were not incorporated into the system, although a mechanism for such an incorporation has been included in the developed prototype.

This research provided the following contributions:

a) Development of a prototype knowledge based decision support system for determining all possible treatment options for successfully treating a waste for reuse, recycling or disposal;

b) Development of a model for selection of treatment options for each waste;

c) Incorporation of different types of wastes from different producers into the prototype;

d) Determination of the input limits and formulae to define outputs from treatments;

e) Development of an approach that considers the concerns of developing countries.

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1.0 Introduction

With the advent of sustainable development as the overlying philosophy of the international community, we must rethink past practices and initiate new policies. Achieving sustainability requires that the concept of the consumer society must be replaced by a conserver society, in the hope that resources will be available for future generations (Ekins, 1991). The production of disposable goods, the discarding of waste materials and the disposal of wastes into the nearest uncontrolled dump or water body are no longer acceptable. Instead production systems must be designed with sustainable and environmental concerns as priorities. This design concept, termed "design for the environment" (DFE), links total quality management with environmental management and includes environmental policies, life cycle analysis, environmental auditing, waste management, emergency planning and prevention (Côté et al., 1994). According to Côté et al. (1994) the objectives of this approach would include:

> "conservation of natural resources
> conservation of financial resources
> reduction of production costs relative to volume of product
> reduction of raw material costs
> reduction of treatment costs
> reduction of energy costs
> reduction of environmental liability and insurance costs
> improvements in operating efficiency
> potential income through sale of wasted materials
> improvements in quality control
> improvements in public image with customers
> improved health for ecosystems and populations using the area."

A significant portion of those objectives can be met by implementing a waste management program which incorporates waste reduction, material reuse and recycling and disposal with minimal environmental impacts. The implementation of these waste management practices are intrinsic to achieving sustainable development (Saraswat and Khanna, 1989).

Waste disposal is a problem faced by all societies. Waste handling and disposal practices in the past have created expensive and damaging legacies throughout Europe and North America (Schneider, 1991; Somlyody, 1991; Russell, 1992). The effects of these poor waste management practices will have repercussions for decades to come, damaging ecosystems and negatively affecting human health (Somlyody, 1992). The costs of remediating sites contaminated by improperly discarded wastes is extremely high, estimated at $750 billion in the U.S. (Russell, 1992). Some areas, most notably in the former Soviet Union, have been rendered uninhabitable through contamination with hazardous wastes (French, 1991).

Pollution controls are now found in most industrialized countries and have become more stringent (Davis, 1988). Such measures have not reduced the quantities of wastes being produced and the disposal of wastes in general has become a concern, as landfills reach capacity and the siting of new facilities encounters increasing opposition (Young, 1991). Consequently, some governments are now moving towards a waste management strategy that incorporates waste reduction, reuse, recycling and disposal (Morse, 1989: Allessie, 1989). However, it is the reduction of waste that must be the major emphasis in such a strategy.

The problems facing governments in drawing up a sustainable waste management strategy include:

a) the political environment - waste management is such a controversial issue that many politicians are unwilling to take the issue to task; in addition, there is political inertia towards change resulting in the continued use of traditional waste management methods such as landfilling and incineration (Michael, 1991);

b) the interdisciplinary nature of the problem - waste management affects environmental and human health and the associated problems are defined by regional geology, ecology, climate, geography, hydrology; the solutions encompass management, planning, legal, economic and engineering aspects;

c) the global context - the impact of waste management policies in one country can have both a negative and a positive impact upon surrounding countries; global problems such as air, water and land contamination, global warming and the decreasing ozone layer are a direct result of poor waste management (Bingham, 1991);

d) lack of information - we still have a poor understanding of the effects, both individual and cumulative, of waste disposal on both the environment and on human health (Contant and Wiggins, 1991) and of the volumes and types of wastes, especially fugitive wastes such as solvent vapours, which are generated;

e) lack of education and trust - a poor understanding of toxicity and a lack of trust by the general public towards politicians and industries has resulted in a general public wariness of many waste disposal technologies and many industries;

f) the economic environment - economic problems, particularly during recessionary periods, tend to take political precedent over environmental considerations (Michael, 1991), despite the public's continuing concern (World Environment Report, 1992) and the fact that the environment and economy are linked (Hirschhorn and Oldenburg, 1991).

Of these concerns, the greatest obstacle may be the political environment. However, as waste management problems become more pressing, political attitudes are changing (Allessie, 1989; Morse, 1989). As a result, governments are reconsidering legislative means of controlling pollution and are seeking cooperation with industry in reducing waste.

With government encouragement (Morse, 1989), with the implementation of increasingly stringent pollution control standards, with the increasing costs of waste disposal (Crittenden, 1992) and with stringent measures being implemented for infractions of environmental legislation (Jeffery, 1992), waste management within industry is moving from an end-of-pipe technology to the incorporation of changes in designs, processes and management methods to reduce waste production up front (Jacobs, 1991). As a result, environmental risk management is now becoming as important as cost management to some companies (Winter, 1991), and waste management is now playing a significant role in reducing the environmental risk (Smart, 1992).

Industrial ecology is a concept that has developed as a result of this movement from end-of-pipe technologies towards a sustainable system of waste management. The term 'industrial ecology' was coined by Frosch and Gallopoulos (1989), although the underlying concepts had been in existence since the 1970s (Côté and Plunkett, 1994). Frosch (1992) states:

"The idea of an industrial ecology is based upon a straightforward analogy with natural ecological systems. In nature an ecological system operates through a web of connections in which organisms live and consume each other and each other's waste. The system has evolved so that the characteristic of communities of living organisms seems to be that nothing that contains available energy or useful material will be lost. There will evolve some organism that will manage to make its living by dealing with any waste product that provides available energy or usable material. Ecologists talk of a food web: an interconnection of uses of both organisms and their wastes. In the industrial context we may think of this as being use of products and waste products. The system structure of a natural ecology and the structure of an industrial system, or an economic system, are extremely similar. This may be a somewhat trivial and banal idea but when consciously addressed it can help us to discover extremely useful directions in which the industrial system might develop."

Jelinski et. al. (1992) have taken the concept further, describing linear material flows where there are abundant natural resources and energy sources as a Type I ecosystem, analogous to ecosystems that could have existed when life was first developing on earth. A Type II ecosystem is semicyclic, requiring energy and resources input and producing some wastes, but cycling some waste and energy between ecosystem components. Some industries are now moving towards this level, particularly with easily recycled materials such as metals, water, paper and cardboard. The third level, Type III ecosystems, requires some energy but produces little or no waste as waste materials are reused or recycled within the ecosystem. It is in this direction that we must move, possibly creating an economic environment that will encourage industries to knowingly or unknowingly embrace the principles of a Type III ecosystem.

There are, however, significant barriers that exist at present which prevent industries from moving in the Type III ecosystem direction. These include:

a) Legislation - Legislation is often written to deal with linear industrial processes, with little recognition of the inherent value of waste materials as potential raw materials for other processes. Moreover, most legislation is based on penalties while incentive programs tend to be more effective (Henrichs, 1992). Legislation and policy are also hampered by public perceptions of risk which are often far removed from reality (Pariza, 1992) but often are influential in formulating legislation and policy (Henrichs, 1992). Voluntary, cooperative programs between industry, government and communities, especially industry-driven approaches, combined with legislated targets would be effective mechanisms for promoting movement towards industrial ecology (Côté and Plunkett, 1994).

b) Tradition and convention - Many plant managers and operators are reluctant to change processes that have been producing quality products out of concern that the quality of the product will suffer. Wastes have not been an issue in the past and management were more concerned with the product quantity and quality. Increasing waste disposal costs and liabilities have changed the priorities, but managers are still more comfortable dealing with end-of-pipe technologies that will not affect the quality of the product. It is only when upper management recognizes that the risk of affecting product quality will be balanced or outweighed by the benefits of reducing waste production that process changes will be fully implemented. This also applies to changes in feedstock - using a raw input material is perceived as being better than a waste material, even though processing requirements and material costs may be reduced.

c) Cost considerations - With a traditional linear system, costs were relatively easy to calculate and economic feasibilities of equipment upgrading could be readily determined. However, with the incorporation of waste minimization, reuse, recycling and product life-cycle concerns, the economics become much more complex. The potential to sell a waste material versus the cost to minimize or eliminate its production versus the inherent risk due to any hazardous components in the waste material versus the changes in legislation, life-cycle material and energy concerns and market needs mean that a web of economic potentials must be evaluated and compared to assess future directions of a specific industry or plant. Many of the cost factors have yet to be recognized by economists and business managers, yet is these factors that industries will have to take into account for future success (Duchin, 1992).

d) Technological considerations - Two questions arise when faced with the technological concerns inherent in industrial ecology - those of 'who' and 'how'. The former is the more important question since we must define those who can develop the technology. The major problem lies in our present educational system which is highly focused on specialized fields of study (Lynch and Hutchinson, 1989). Although the concept of inter-disciplinarity is popular, few academic groups have put it into practice and there are still barriers to those wanting to move from one discipline to another. Yet in order to understand the needs of industries, professionals will have to have a broader education and be capable of understanding management, economics, law, engineering and social and environmental risks and impacts.

All options must be examined and carefully assessed to ensure that wastes and costs are minimized by the final options selected (Freeman, 1990). These options can include changes in raw materials, in processes, in equipment, in product design, in plant management methods and in waste treatment and must be balanced against time frames and costs. Waste minimization primarily occurs within a specific plant, involving an examination of all aspects of plant operation, including maintenance, inventory supply and storage, material delivery, product processing and waste handling and treatment. A number of management programs have been proposed to enable companies to examine their operations and identify possible waste reducing measures (Freeman, 1990).

In many cases, it may prove feasible to sell wastes as a feedstock for other industry processes (Smee, 1992). When considering the options that may be available for minimizing, reusing or recycling wastes for one plant, an engineer must have an understanding of the specific plant operations, both from a mechanical as well as a chemical perspective. When attempts are made to tailor a waste for resale to a market, the engineer must also know the requirements of the market as well as the treatments that are available for refining the waste, if necessary. Much of the work that has been done in waste recycling has examined specific waste streams and treatments to enable engineers to make these decisions. Limited work has been done on integrating different industrial waste materials and treatments to produce comprehensive packages for treating waste materials to saleable materials.

Waste management in most industries in North America today is primarily an individual plant or company activity although waste exchange programs have attempted to provide links between waste producers and industries requiring raw materials. Large companies such as 3M, Dupont and Dow have been able to successfully initiate waste exchange within their own operations (Smart, 1992). However, even within industrial estates, there have been few attempts to actively engage separate industries in cooperatively reusing, recycling, treating or disposing of waste materials. In Kalundborg, Denmark, an industrial ecosystem is already operating, where all plants interact to utilize discarded or unused energy, water, chemicals and organic materials (Côté et al., 1994). An industrial park in Nova Scotia is currently being used to test the concepts of industrial ecology and determine the benefits and costs that would accrue through symbiotic relationships established between businesses (Côté and Plunkett, 1994).

Within the tenets of industrial ecology, the manager of an industrial estate must examine the potential of all waste materials produced by industries of the estate to be used as inputs by other industries or as saleable materials. Industrial plants often produce a variety of wastes which were traditionally mixed and discarded. However, recognizing that wastes are easier to treat and recycle when kept as 'pure' as possible, the individual waste materials must be evaluated for potentials for reuse or recycling. It may be possible that wastes can be co-treated and a treatment facility can be constructed to handle a larger volume of waste with a potential saving in construction and operation and maintenance costs. Consequently, the estate manager must consider all waste materials produced by the estate plants, potentials for reusing or recycling wastes, both on the estate and elsewhere, treatments required to refine the 'wastes', the acceptability of wastes for specific treatments and the possibility of co-treating waste materials.

When seeking advice on waste management, companies primarily look to traditional methods for treating waste or turn to consultants experienced in waste management. Considering the number of treatments available for treating wastes and the knowledge required to determine which treatments are appropriate for a specific waste, few consultants can provide the broad expert knowledge that would be required to treat the variety of materials produced by a group of industries. Instead, most consultants are familiar in detail with a few treatment processes, usually dealing only in one material state (e.g. liquid, solid, sludge or gas) and have some knowledge of a variety of others. Moreover, few consultants are familiar with the range of wastes that could be produced by the variety of processes in industries that can be found on an industrial estate.

Woods (1994a) has produced a comprehensive manual on determining the treatments that are suitable for treating materials under specific conditions. A further volume will provide cost data. For an industrial manager, however, these manuals will not provide a simple means of determining treatments for the large variety of wastes that an industrial estate can produce. Moreover, they do not provide all the input specifications for each treatment, nor do they specify the characteristics of the outputs or indicate the mass balances inherent in each treatment.

The number of parameters that an industrial waste management planner or manager must consider is substantial, and this is exacerbated by legislation, the variation in surrounding industries and communities and potential recovery, treatment or disposal facilities. Many waste management plans consider only a limited number of parameters and thus are limited in scope. As discussed in section 2.8, computer models and knowledge based decision support systems (KBDSSs) are being developed to assist in understanding and incorporating the parameters into waste management planning, but no systems yet exist to provide managers with a mechanism to determine options for integrated waste management planning.

Faced with stricter legislation and negative reactions to waste disposal from communities, industries are attempting to site waste disposal facilities in developing countries (Suite, 1991; White, 1991). The Basel Convention (1990) has attempted to reduce the importation of industrial wastes into developing countries from affluent, developed countries. However, the Convention does not prohibit the exporting of hazardous waste or the location of waste-producing industries in developing countries nor does it prevent hazardous waste treatment facilities from being built in those countries to dispose of out-of-country wastes (Rabe, 1991). Consequently, developing countries are facing the same problems as developed countries but with limited technological, political, legal or economic resources.

The majority of waste is produced by industrialized countries (Young, 1991). However, developing countries face similar waste problems that threaten to increase as they strive to industrialize and as countries become more affluent (Singh, 1990). Most small, developing countries have a range of industries, from small, traditional, labour-intensive operations to large, technology-intensive industries (Singh, 1991). All of these industries produce industrial wastes, both hazardous and non-hazardous, but usually little has been done to provide environmentally-acceptable means of treating and disposing of such wastes (Bowonder, 1987). In most cases, there is a paucity of legislation in place to control production of wastes from an industry or the disposal of such wastes and enforcement of any existing standards is often lax (Wilson and Balkau, 1990). Most wastes are discarded into the air, nearby streams or the ocean or into the closest available landfill which is often located in the poorer areas of these countries (Durning, 1990, Bowonder, 1987). The damage to air, water, soil, ecosystems and human health in Eastern Europe are the effects of uncontrolled industrialization on the surrounding environment (French, 1991) and these conditions may be duplicated in developing countries in the near future.

The management of wastes, particularly those produced by industries, is only now being addressed in most industrialized countries (Saraswat and Khanna, 1989). In a survey of 23 Commonwealth countries, only eleven countries were able to report the quantities of hazardous wastes they produced per year and only eight countries had national standards and specifications for treated wastes before discharge for disposal, although eleven countries stated they had some acts or regulations in place (Hasan, 1991). Information on enforcement of those regulations was not determined.

One of the primary reasons for the lack of waste management is that pollution control, especially end-of-pipe technology, has a significant cost but no short term benefit (von Weizäcker, 1994; Ugelow, 1994). Consequently, companies that can stall introduction of such controls will have an advantage over companies required to meet environmental standards. Legislation involves costs for administration, enforcement, education and litigation so that less affluent countries are reluctant to pass such legislation. Yet with the lack of water treatment facilities and the denser populations found in those countries, any level of pollution can have a significant effect on the health of the people (El-Ashry, 1993).

Islands are at a greater risk from such wastes due to their small, essentially closed ecosystems and finite assimilative capacities (Singh, 1990). Water is limited and the groundwater that is available may be shallow and easily contaminated. Surrounding waters, which are usually exploited for food, are quickly degraded, resulting in a contaminated food source and, since those coastal resources are usually the primary tourist attraction, loss of an important economic source. Land and natural resources are very limited and any degradation results in hardships to the inhabitants and the island ecosystem. Those who usually suffer most are those living in poverty and pregnant women and children whose health is more susceptible to environmental contaminants (Durning, 1990). It is therefore even more important to ensure that wastes are properly managed on small, developing islands. Yet the same factors that prevent effective waste management from being implemented in developed countries also occur in developing countries, with the added concerns of lack of environmental legislation, lack of environmental knowledge and education and a lack of funds to maintain plants at acceptable safe operating levels, let alone to minimize waste production.

Industrial managers require a decision support system that would determine waste management options for all types of wastes, giving priority to recycling and reuse and minimizing cost and environmental impacts. Ideally, the system would require a minimum of analytical information and input of information would be simple. The output would provide the optimum treatments necessary to treat all the wastes produced, ideally recycling or reusing them or, if necessary, disposing of them and providing data on costs or savings for each treatment and for the treatment system overall.

Such a system would require much more information than is currently readily available and more than could be obtained for this project. There are still discrepancies regarding input criteria for many treatments, including the most common treatment systems such as aerobic wastewater treatment (Grady and Lim, 1980; Metcalf and Eddy, 1979). Cost data are not readily available for many treatments and treatment outputs and efficiencies often depend upon a variety of factors, including operator experience, temperature, type and age of equipment and process control facilities. A complete model for such a decision support system is considered beyond the scope of this research. However, a model for determining waste treatment options for a variety of waste types can feasibly be developed, although there must be some recognition of the limitations of the input criteria and the output formulae and efficiencies. Such a system would not optimize the treatments; it would list the options available for treating the wastes and indicate if there were any wastes that could not be treated by the treatments in the system. A manager could then select a treatment option that would be common to most wastes and examine other options for reducing or eliminating non-treatable wastes.

By providing a decision support system that can act as a tool to educate and assist managers in making waste management decisions, it may be possible to encourage industries to recognize the potential markets for their waste materials. Moreover, industrial estate managers will be able to determine if the current waste treatment system can treat wastes from a new industry or if additional treatments will be required. Some of the factors that must be recognized when defining a model for developing countries include: a lack of legislation, a lack of funds, a lack of expertise and a lack of sophisticated facilities such as high temperature incinerators for treating wastes. It must also be recognized that, although the model may be designed for developing countries, it could also be applied to industries in developed countries, as long as the applicable legislation was incorporated into the data base.

1.1 Research Objectives

This research produced a prototype which would be the basic component of a larger knowledge based decision support system (KBDSS) to determine options for integrated management of wastes from a variety of sources and industries. The KBDSS could provide decision support to government or industry representatives for the development of an integrated waste management plan for a number of plants within a defined geographical area such as an industrial estate. The system was developed with the concerns of developing countries in mind, recognizing the urgent requirements of many such countries for adequate waste management. The following were the research objectives:

1.1.1 Development of a prototype knowledge based decision support system for determining the treatment trains necessary for successfully recycling a waste as an input (recycling or reuse) or treating it for disposal. The system will:

a) include a simple user interface to obtain the required data;

b) require a minimum amount of analytical data for inputs, products and wastes;

c) allow the user to input, change or specifically select industry data for assessment;

d) incorporate a number of treatment options, sufficient to treat a variety of waste types such as gases, liquids, sludges and solids;

e) provide data on final masses after treatment;

f) include a framework to incorporate and calculate cost data;

g) enable the user to include regulations for disposal of wastes and incorporate those into the system;

h) enable the user to change or add to the list of treatment options;

i) examine all possible treatment options for each waste ;

j) determine all potentials for reuse or recycling wastes as inputs;

k) determine all potentials for treating wastes for disposal;

l) provide a list of successful treatment options for each waste;

m) assess the treatment options for potentials for co-treatment;

n) select final treatment options for each waste that have the fewest treatments, produce the lowest secondary wastes and/or allow for co-treatment of wastes;

o) determine the quantity of secondary wastes produced from each successful treatment option;

p) list those wastes which cannot be treated or disposed of using the included treatments and disposal options and;

q) run on a 486 personal computer using readily available, inexpensive software.

1.1.2 Determination of the input limits and formulae to define outputs from treating a material with a specified treatment, including secondary wastes from the treatments, using published data from a variety of sources;

1.1.3 Consideration of the concerns of developing countries, regarding cost, equipment, expertise and legislation, for integrated resource management planning.

1.1.4 Collection and analysis of data from industries located on the Point Lisas Industrial Estate, Trinidad to be used as a case study application for the prototype system.

1.2 Dissertation Structure

The remainder of the dissertation is structured as follows:

Chapter 2 - Literature Review

A review of the pertinent literature, including a discussion of wastes as resources, waste management planning, integrated waste management, waste minimization and disposal, waste management in developing countries and knowledge based decision support systems;

Chapter 3 - Knowledge Based Decision Support System

Outlines the prototype system and how it works, including a flow chart of the system, the internal verification and external validation required, system outputs and limitations and future system developments;

Chapter 4 - Knowledge Base - Treatments, Input Criteria and Output Formulae

Discusses the treatments selected, the input criteria for the treatments and the formulae for treatment outputs as well as the regulations selected and upgrading of the knowledge base by users;

Chapter 5 - The Case Study - Waste Management at the Point Lisas Industrial Estate, Trinidad

Overview of the field data obtained from Trinidad in terms of waste management concerns, including environmental law, health and safety issues, waste disposal and available data on plant inputs, products and wastes, as well as application of the plant data to the prototype KBDSS and the results from the prototype system;

Chapter 6 - Conclusions and Recommendations

Presents the conclusions and recommendations for future developments in the program, KBDSS and industrial ecology, particularly with relevance to developing countries;

Appendices - flow charts and program listings for the prototype system, user input forms and data and knowledge tables.

2.0 Literature Review

The implementation of a sustainable industrial ecosystem requires that wastes must be viewed as resources rather than as materials to be discarded. The principles of integrated waste management, including reduction, reuse and recycling, must be employed. Some of those principles, such as waste reduction, can only be implemented at a plant level. Others can be implemented through co-operative efforts between plants and include reuse, recycling and co-treatment of wastes. However, to implement such a program will require knowledge and understanding of the input, product and waste parameters as well as process input limits and output quality. This chapter will review the literature on waste management, implementation of industrial ecology and the developments in knowledge based decision support systems to assist in implementation of integrated waste management principles.

2.1 Waste Management

Only a few years ago the emphasis in waste management lay in waste treatment and disposal as waste prevention was considered possible only in the long term (Huisingh, 1989; Robinson and Bazelmans, 1991). However, the volume of waste being produced is beyond the capacity of present waste disposal facilities (Kreith, 1992) and public concern over such facilities is making their siting and construction difficult (Linnerooth and Wynne, 1988). In addition, it has been recognized that continued consumption of natural resources and disposal of manufactured products is not sustainable (MacNeill, 1989; Ruckelshaus, 1989; Ekins, 1991). Consequently, waste minimization is now recognized as the most effective and economical means of managing wastes (Fujita and Maltezou, 1991, Freeman, 1990).

The purposes of waste minimization, from society's perspective, are:

a) reduction of discharge of pollution;

b) reduction of waste for disposal; and

c) reduction of demand on natural resources (Matilla, 1989).

From an industrial point of view, however, minimizing waste offers the following benefits:

a) improvement in economic return;

b) compliance to regulations ;

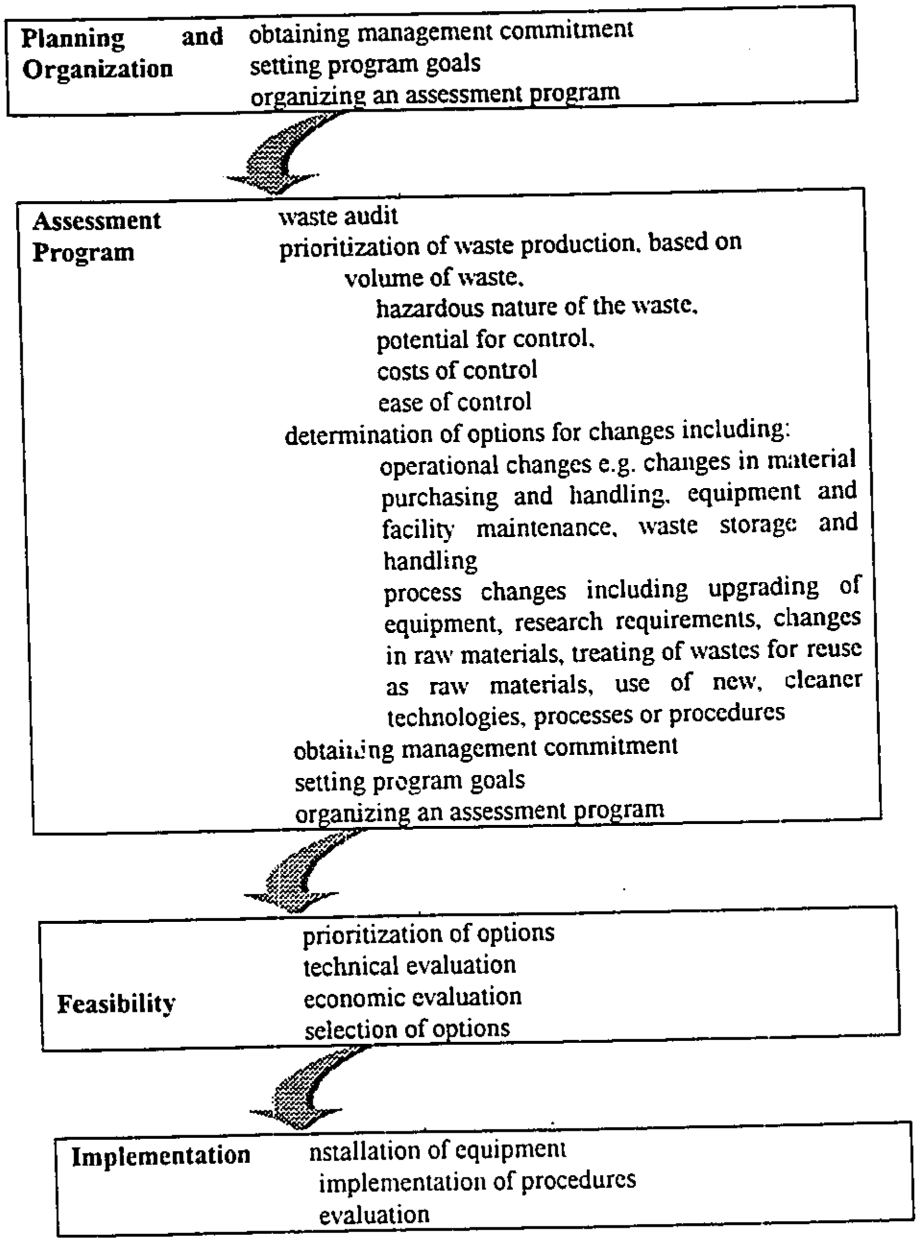
c) reduction in liability; and

d) improvement in community/public relations (Ehreth, 1991).

Regardless of the perspective, the results are the same - waste is minimized. A number of large corporations, notably 3M, Polaroid Corporation, E.I. DuPont and de Nemours and Company, have initiated waste minimization programs, with significant economic savings and reductions in waste (Ehreth, 1989). A survey of waste reduction programs in large U.S. manufacturing firms found that 66% had initiated a formal waste reduction program and most respondents expected to reduce wastes by 50% or more through switching raw materials, internal recycling and increased efficiencies (Environmental Information Ltd., 1992). The steps involved in a waste minimization program for an industrial plant are outlined in Figure 2.1.

A waste audit involves an initial survey of the facility to determine the wastes that are being produced, stored on-site or that may have been dumped historically on the plant site. Since continued contamination of the site may only increase costs and could have a bearing on the company's viability or on other changes, it is important to ensure that even old wastes are taken into consideration. The storage of wastes may be contaminating water, soil or air and will require action. The volumes of stored wastes may also provide some indication of the amounts produced. In addition, a waste audit will also be able to focus on wastes that may not be recognized as such, e.g. air contamination by evaporating solvents.

Following the plant survey, manifests for waste disposal, emission and effluent licenses and quantitative and qualitative data on all wastes produced over the last several years are accessed to determine the characteristics and volumes of wastes produced (Huisingh, Siljebratt and Backman, 1989). Any quantitative data on materials use and composition is also needed. A plant process flow diagram is also necessary and should identify inputs, including water, and outputs, thus providing a means of



Planning and Organization

- obtaining management commitment
- setting program goals
- organizing an assessment program

Assessment Program

- waste audit
- prioritization of waste production, based on
  - volume of waste,
  - hazardous nature of the waste,
  - potential for control,
  - costs of control
  - ease of control
- determination of options for changes including:
  - operational changes e.g. changes in material purchasing and handling, equipment and facility maintenance, waste storage and handling
  - process changes including upgrading of equipment, research requirements, changes in raw materials, treating of wastes for reuse as raw materials, use of new, cleaner technologies, processes or procedures
- obtaining management commitment
- setting program goals
- organizing an assessment program

Feasibility

- prioritization of options
- technical evaluation
- economic evaluation
- selection of options

Implementation

- nstallation of equipment
- implementation of procedures
- evaluation

Figure 2.1 Steps in waste minimization (adapted from Freeman 1990 and Hazardous Waste Engineering Research Laboratory, 1988).

balancing materials and, hence, identifying wastes (Ontario Waste Management Corporation, 1987). It is important to be able to determine the waste production in quantities that are comparable, such as waste per volume of product or by product line. Some wastes, particularly maintenance wastes, are generated on a time, not a product, basis (Rittmeyer, 1991).

A number of waste minimization techniques have been proposed (U.S. EPA, 1988; Chemical Manufacturers Association, 1989; Freeman, 1990; Katin, 1991; Gujer, 1991). The major focuses have been on inventory management, raw material substitution, process design and operation, volume reduction, recycling and chemical alteration (Katin, 1991).

Huisingh (1989) evaluated 500 case studies and found the major approaches used were combinations of the following:

a) replacement of chemical processes with mechanical processes;

b) replacement of single-pass rinse processes with counter-current processes;

c) replacement of single-pass rinse processes with closed loop processes;

d) replacement of solvent-based materials with water-based compounds;

e) replacement of heavy metals with less toxic materials;

f) replacement of halogenated with non-halogenated compounds;

g) installation of new technologies to separate components from the waste stream;

h) installation of low or non-waste technologies (LNWT);

i) installation of more accurate monitoring and modulating equipment.

Using waste minimization, Allessie (1989) expects significant changes in waste streams in the Netherlands by the year 2000, including:

- an increase in reuse and useful application from 35 to 60%;
- a decrease of 5% in the total volume of waste;
- a decrease in waste requiring ultimate disposal from 65 to 35%;
- a decrease in the percent of waste being landfilled from 55 to 10%.

The components of waste minimization are waste reduction and waste recovery. Energy recovery from wastes may also be included, although only as a last option since the waste is lost as a raw material, and waste treatment is also a consideration since treatment is often required to enable wastes to be recovered and reused.

a) Waste Reduction

Waste reduction involves reducing the wastes from the plant through operational and process changes. The utilization of wastes as by-products for sale or reuse as raw material is termed reuse or recycling. Since reduction requires no concern about material markets and has no further treatment which may also produce waste materials, it is an effective means of waste minimization.

Operational and management changes are important in reducing wastes, especially maintenance wastes, accidental spills or out-of-date materials (Freeman, 1990). Since changes to reduce these wastes are often minimal but serve to promote the concept of waste reduction among management and employees and can result in cost savings, these changes are usually implemented initially. At this point, employees are often solicited to provide innovative concepts for waste management (Rittmeyer, 1991).

Once the waste streams and their volumes have been identified, options for minimization can be determined. Low and non-waste technologies (LNWT) are currently being developed to reduce waste volumes. LNWT is defined as 'the practical application of knowledge, methods and means so as, within the needs of man, to provide the most rational use of natural resources and energy and to protect the environment' (UN ECE, 1978). According to Saraswat and Khanna (1989) most research and development on LNWT has been restricted to minor process modifications, resource conservation and waste recycling while issues such as transfer of technology through developmental assistance and ranking of production technology based on resource and environment considerations have yet to be researched.

A number of sources for possible LNWT options are available, most notably the UNEP International Cleaner Production Information Clearinghouse and the U.S. EPA Pollution Information Clearinghouse, which provide a LNWT database accessible through any computer with access to a modem or to Sprintnet. The International Association for Clean Technology is especially concerned with the problems of developing countries and technology transfer between industrialized and developing countries (Sutter, 1989) and India has set up a LNWT database specifically to meet its needs (Choudhari and Modak, 1989). In addition, a number of government agencies in both Europe and the U.S. are offering subsidies for research into cleaner technologies.

Waste reduction is primarily an individual plant process. Although waste reducing technologies can be incorporated into many plants, the incorporation of the technologies is an individual plant management decision. Moreover, many waste reduction measures involve changes in material handling processes, operation and maintenance management, all of which are plant-specific.

b) Waste Reuse and Recycling

Waste reuse and recycling are integral to a waste minimization program and may provide some of the more economical benefits. Reuse and recycling treat former waste materials as products for either external sale or reuse within the plant. Reuse is generally considered to be the direct reuse of a material without any treatment while materials which require treatment are recycled, but the distinction between the two may blur, especially for wastes requiring minimal treatment.

It is important to balance waste reduction against market potentials for by-products. It may be more feasible to reuse a former waste product as a raw material than to switch to a different raw material which results in lower quantities of waste that cannot be reused. It is also important to consider the hazardous nature of any materials, as reducing the hazards in the work place will improve working conditions for employees.

Waste exchanges have been set up across Canada, in the U.S., in Japan and in some European countries to promote reuse of waste materials (Kreith, 1992). Companies list the composition and volume of their waste materials, enabling a company which may have a use for that material to negotiate a suitable exchange with the waste producer. In the U.S., with a larger manufacturing base, such exchanges have saved companies millions of dollars in waste disposal and raw material costs (Woolard, 1990; Smee, 1992). Yet these are, in many ways, passive mechanisms, where waste producers merely advertise their wastes, hoping a market will be found. No attempts are made to specifically match wastes to a saleable market and there is a concern regarding material quality.

In developing countries, especially island countries, where resources are scarce, reuse is often a way of life. In cities in these countries, the collection and reselling of waste materials is common and provides a valuable sources of income and resources for poor residents (Uriarte, 1991; Jensen, 1990) although it is often not controlled and the potential for disaster does exist especially where infectious and hazardous wastes are routinely disposed of with other municipal waste. However, recycling facilities do not often exist and transportation costs can be high. In addition, it may be more economical to utilize labour-intensive systems in developing countries rather than the technology-oriented systems commonly used in industrialized countries.

c) Energy Recovery

Some organic wastes contain enough energy to act as an energy source and are used as fuel sources for other processes, such as cement kilns. Penner and Richards (1989) estimate that, even with 30% recycling, incineration of municipal solid waste could provide 1 to 2% of the energy needs of the U.S. by 2000. Tires, which pose a serious technical problem for disposal, contain a high heating value and, with the correct technology, could be used as an energy source (Kreith, 1992). Used oil is also reprocessed as a fuel in both the U.S. (Kreith, 1992) and Europe (Allessie, 1989).

Incineration, even for energy recovery, has a number of concerns. Heavy metals accumulate in bottom and fly ash (Reimann, 1989), while if the temperature and residence time in the incinerator are not sufficient, organic compounds may not be sufficiently degraded or other compounds such as dioxins may be formed. Concerns regarding ash residue management, production of toxic gases and the loss of natural resources still exist (Kreith, 1992). A long-term build-up of dioxins and furans has been found in milk from dairy farms near incinerators in Europe (Schneider, 1991). The increase in greenhouse gases, contributed to through incineration, is also a global concern (Fuwa, 1991). The loss of the material as a useable resource is also a concern, especially with limited resources. Consequently, if incineration of a specific waste is selected as a treatment option, the benefits must be carefully weighed against the concerns.

d) Waste Treatment

Mechanical, chemical, biological or thermal treatments are applied to wastes to render them into a form that can be used, or one that is more acceptable for disposal (reduced in volume or hazardous nature). Mechanical processes usually entail phase separation or solidification but do not change the nature of the compound itself. Chemical processes are used to change the nature of a compound through the addition of chemicals, heat and pressure while biological processes use living organisms, usually bacteria, to break down organic compounds or to accumulate heavy metals. Thermal processes, such as incineration, use heat to combust a material, thus converting it to carbon dioxide and other gases, particulates and ash. When designing a waste management system, treatment processes are selected on the basis of the initial waste characteristics, the required product characteristics, production of wastes from the treatment, other environmental considerations, cost, energy consumption, feasibility and availability of the process (Batstone, Smith and Wilson, 1989).

2.2 Waste Disposal

Regardless of the improvements made in waste minimization, waste disposal will still be required and will pose a concern. It must be recognized that there is, at present, no method of permanently disposing of wastes - disposal facilities usually provide only long or short term waste storage (landfilling) or dilution (effluent or emission release). Land treatment is a mechanism of disposal of biodegradable materials which are then degraded by soil micro-organisms. Incineration is a waste treatment which results in residual material that requires further disposal and has been previously discussed. There is always the potential for discarded wastes to escape into the surrounding environment (Young, 1991).

It must be recognized that the costs of materials and goods do not usually include the full cost that is inherent in the disposal of wastes from the manufacture of the product or the disposal of the product when it is ultimately discarded (Hirschhorn, 1985; El-Ashry, 1993). The cost of actually constructing and decommissioning a waste disposal facility, including the cost of an environmental assessment, has not been included in the cost of disposal in the past (Jain, 1988).

a) Landfilling

Landfills, the most common means of disposing of waste materials, act as long-term, uncontrolled waste storage facilities, with subsequent anaerobic decay of wastes, producing methane gas and leachate. Today, many new landfills are highly engineered and, to obtain approval for construction, often must be designed with a non-porous base material such as clay, up to three plastic liners, a leachate collection system, gas vents, surface run-off control and a specified decommissioning plan (Braithwaite, 1992). Newer landfills in the U.S. are incorporating systems to prevent wind from blowing garbage off-site and to control odour. Even with these improvements, local opposition makes it difficult to site such facilities, and the full cost of landfilling (indefinite loss of land, indefinite leachate removal and treatment, gas venting, indefinite monitoring requirements, possible groundwater contamination requiring treatment) is rarely paid by the taxes allotted to waste collection and disposal (Hirschhorn, 1985).

There are three potential long term effects from landfills - contamination of groundwater, surface water or soil from leachate, contamination of the surrounding air from produced gases and the loss of the land for future productive purposes. The extent of concern is site dependent, but all three concerns exist for any landfill. It is generally recognized that a landfill will eventually leak, despite the technological advances that have been made (Yong, 1991). Leachate collection systems are required and facilities for treatment of the leachate must be available (Krieth, 1992). In addition, methane emissions from anaerobic decomposition of waste must be collected and burned. Due to these concerns, it is difficult to develop former landfill sites with any assurance that health hazards will not arise.

b) Land Treatment

Land treatment involves the application of a degradable waste to active soil, where micro-organisms, heat, cold and light break down the material. The waste material must be applied at a sufficiently low rate not to damage organisms or the process will not be effective; moreover if applications are being repeated, there must have been sufficient time for the initial application to have degraded to prevent overapplication and loss of micro-organisms. Application rates are highly dependent upon the waste material and its concentration. Trace contamination by materials resistant to degradation such as heavy metals and some pesticides can cause contamination of the soil, preventing its availability for future use. The application site must be properly chosen and prepared to prevent runoff of contaminated liquids into surface water and seepage into ground water. Careful research and management is necessary to successfully landtreat waste materials (Boyle, 1992).

c) Ocean Discharge, Effluent Release

This is a common disposal method for municipal wastewater and for liquid industrial wastes in developing countries (Singh, 1990; Sammy, 1992) and still occurs in Canada and other countries. The prevailing arguments for ocean discharge involve the apparently unlimited assimilative capacity of oceans (Botes and Russell, 1992) while those against argue that local conditions can be overwhelmed by discharges and that the system is much less infinite than previously suspected (Morita, 1991). The dependence by many developing countries on fishing as a food source suggests that erring on the side of caution would be prudent (Bowonder, 1987). In addition, the poor condition of many coral reefs, caused in many cases by ocean discharges, would point to a more conservative approach being required (Risk, 1992).

Standards exist in most developed countries that limit the levels of specific contaminants that can be released. Problems with the assimilative capacity of rivers, cumulative effects, increased industrialization and allowing "grandfathering" for older plants have resulted in severe pollution of many rivers despite the standards. Moreover, many countries are concerned that they cannot afford the cost of pollution standards, both from an industrial competitiveness and an enforcement perspective (von Weizsäcker, 1994).

d) Emission Release

Emissions of gases previously thought to be harmless, such as CFCs and CO_2, are changing the way we view the world, as those releases are now recognized to potentially cause changes that will affect the globe. Substances such as acid gases which contribute to acid rain and heavy metal particulates and solvents which can affect human health are also of concern. Most of these are regulated by standards in developed countries, but few developing countries have set standards (Wilson and Balkau, 1991).

2.3 Disposal Regulations

The major means of controlling pollution or disposal of wastes into the environment has been through the implementation of restrictive legislation, where limits on the release of specific contaminants are set and plants are licensed to release specified amounts. There have been many criticisms regarding the present method of regulation (Williamson, 1992; Brunner and Baccini, 1992; Kreith, 1992; Vos, 1993) but changes in legislation, regulation policy and standards have been slow. Moreover, pollution standards differ significantly from country to country and, in Canada, even from province to province. Consequently, there is little consent on what constitutes acceptable releases in setting standards.

When evaluating disposal from an industrial estate, basic standards need to be set, as well as total releases from the estate into the ecosystem. However, few estate managers have the knowledge to set such standards if the country has not already set them. Standards from other countries may be used, although the limits of these standards must be recognized. These limits include the following:

1. different ecosystems are differently affected by pollutants;
2. cumulative effects of low pollutant levels may cause serious impacts;
3. some standards have been set based on public risk perception, usually the perceptions of the standard-setting country;
4. climatic conditions may affect releases, impacts and plant operations and standards may reflect those conditions;
5. enforcement of standards has been difficult.

The setting of standards, however, is primarily used to effect the reduction of environmental impacts from waste disposal. Incorporating sustainability into waste management requires more innovative concepts.

2.4 Wastes as Resources

Traditional waste management practices such as treatment and disposal constitute a Type I ecosystem. Moving towards a Type II or the longer term goal of a sustainable, Type III industrial ecosystem requires significant changes in thinking about products, processes, wastes and waste treatments and disposal. Products must be examined to determine their necessity, durability, life span, reuse or recycling potential and whether the product is an efficient use of its component resources. Processes have to be redesigned to reduce by-product generation (including heat), reduce resource and energy requirements, minimize hazardous material usage and maintain quality standards. Wastes must be recognized as by-products, with an inherent positive or negative value - they have to be minimized or examined for their potential as a product and reused or recycled. Disposal becomes acceptable only when other options have been fully implemented and must be minimized. Industrial processes and plants must be examined holistically to determine possible linkages, redundancies and potential improvements in sustainability and efficiencies (Shaw and Öberg, 1993). Planners and managers must move from short-term to long-term management planning and policies, incorporating sustainability as a fundamental component of the planning process (Ugelow, 1994). However, attempts to implement most of these concepts have just begun (Keoleian and Menery, 1994)

Consequently, waste management has evolved from short-term, end-of-pipe technology solutions to more complex, integrated resource management plans initiated prior to plant design. These plans involve waste reduction, reuse and/or recycling as illustrated in Figure 2.2 (Allessie, 1989) and the plant design may be modified to incorporate new designs to allow for effective reduction, reuse or recycling of materials. Recovery of energy from waste material may also play a role in the process although this does not promote material resource recovery.

The value of waste materials may be determined through Life Cycle Analysis (LCA). LCA examines the total effects of the product development, both direct and indirect. Direct effects include disposal or recycling of waste products and the sustainability of such an action. Indirect effects are less obvious, however, and include the maintenance requirements of the product after it is sold or the methods used to produce the energy to produce the product. Life cycle analysis allows a company to improve design of a product to increase its sustainability or may assist consumers to make purchasing decisions (White and Shapiro, 1993). Thousands of numbers may be used to calculate the LCA and some effects, such as environmental impacts of hydroelectricity, may not be included because of difficulties in quantification (Hunt, Sellers and Franklin, 1992). In some cases, numbers may not be available; in others, weighting factors are used to reflect renewable vs. non-renewable resources. The resulting analysis provides some indication of the ultimate impact of the product on the environment.

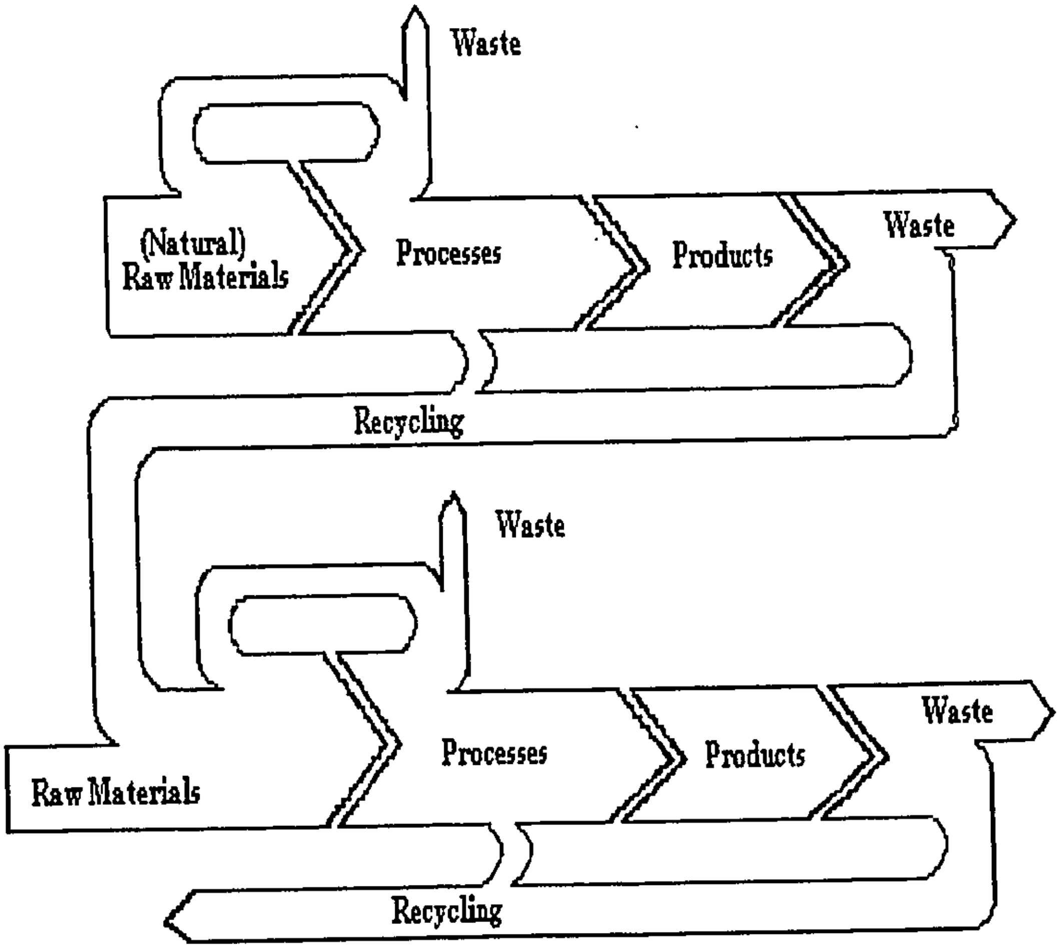


Figure 2.2 Waste production, from raw materials to waste, incorporating waste recycling (Allessic, 1989).

LCA has some significant drawbacks. One LCA alone required 600,000 data points and much of the data were unavailable or proprietary (Nash and Stoughton, 1994). Moreover, there are few conventions to guide assumptions or develop weighting factors and, as a result, it may not be possible to compare one LCA to another. Consequently, calculating the full LCA of a product may become chaotic in scope, due to the numerous indirect influences. LCAs are also technology dependent and can change significantly with minor changes in equipment or improvements in maintenance. As a result, LCAs can provide an indication of where major impacts are occurring. For example, one study determined that consumer maintenance of an item consumed more resources than producing the item, indicating that the design of items to reduce such maintenance requirements would significantly improve the overall impact of the item (Nash and Stoughton, 1994).

A significant component within an LCA is the reuse or recycle of process by-products, both as input materials from other processes and as materials produced by the process under examination. Although this is only one component of an LCA, it becomes important when the volume of waste produced and the impact of disposal of those wastes are considered. Moreover, the reuse of a resource reduces pressure on resource stocks, moving towards sustainable use of those resources.

Another tool in industrial ecology thinking is cascade chaining, which "attempts to evaluate the appropriateness of resource exploitation from a resource efficiency point of view, throughout the entire life cycle of a resource." (Sirkin and ten Houten, 1994, pp vi). Resources are seen to move down a cascade as they are used, reducing in quality over utilization time and improving in quality when energy and additional resources are added to improve the resource. This theory contains four principles of resource utilization, which are (Sirkin and ten Houten, 1994) :

a) <u>Appropriate fit</u>

matching the quality of the resource to the scope and demand of the use;

b) <u>Augmentation</u>

improving the quality of the resource to prevent decline over utilization time;

c) <u>Consecutive relinking</u>

recycling of resources to higher cascade levels;

d) Balancing resource metabolism

achieving sustainable use of resource materials.

Both life cycle analysis and cascade chaining are valuable tools for designing processes and products which will be sustainable and for improving resource management planning to ensure effective use of resources. One of the primary concepts is the change from classifying used materials as wastes to recognizing their potential as resources which have an inherent quality and which should be used to the extent of that quality. This change in thinking is only slowly filtering down to industry where sustainable resource management planning is still a relatively innovative concept. In countries where there are few or no environmental regulations, such as developing countries, industry has not yet considered the economic incentives in considering wastes as resources.

2.5 Integrated Waste Management Planning

Although governments may promote and legislate cleaner technologies and better management of wastes, it is at the corporate and individual level that the most effective action is taken. The recognition that economics of production can be improved by implementing pollution prevention measures has drastically affected the attitude of government and industry (Davis, 1988), especially in countries such as the U.S. and Europe where pollution standards are strict and waste disposal is increasingly expensive.

Table 2.1 points out the actions that need to be taken at different management or political levels to promote waste management. The concepts of industrial ecology are primarily implemented at the plant, management and community levels although they have implications for all levels.

At the industry level, it requires a strong commitment from corporate management to implement an effective waste management plan (Freeman, 1990). In every industrial process, there are means to reduce waste, whether it is by operational and inventory changes or through changes in technology. However, many industries operate by traditional methods and routines, and it is difficult to introduce change. Furthermore, many managers are suspicious of changes in their operation, particularly if it is perceived that the quality of their product may be affected. Huisingh (1989) lists a number of constraints, both internal and external, that must be addressed when implementing a waste management program (Table 2.2).

Table 2.1 Example actions required at different management or political levels to assis in waste minimization.

Level	**Example Actions**
plant	implementing good housekeeping practices; changing maintenance procedures, material storage and product design; controlling fugitive emissions, leaks and spills; use of recycled or reused materials; co-operating with other plants to reuse or recycle material
manufacturers (equipment, chemical)	changing equipment design and operation to reduce waste, recycle materials, to use less hazardous materials and to improve recycling and treatment equipment; producing chemicals which are less hazardous or more effective
management	initiating waste minimization programs within the company to facilitate plant, material and equipment specific changes
industry	changing standards to promote resource conservation, waste minimization and use of recycled materials; testing and approving recycled materials; changing processes to reduce waste production; endorsing and encouraging waste reduction practices and principles
community	determining waste materials that can be used by other local industries as raw materials; co-treating wastes for either recycling or disposal
region	defining local zoning and environmental standards; co-treating municipal and industrial waste; managing regional waste exchange programs
country	educating and promoting waste minimization; enacting legislation to clearly define standards for waste discharge into the environment; initiating and managing waste exchange programs
international	initiating international agreements on transboundary movements of waste and discharge of industrial wastes into international waters and air

Table 2.2 Internal and external constraints addressed when implementing a waste management program (Huisingh, 1989).

Internal Constraints	**External Constraints**
- product quality	- customer demands
- expenditure of capital	- governmental mandates
- reluctance to change	- regulatory approaches
- awareness of and availability of technically sound alternatives	- environmentalist pressures
	- awareness of and availability of technically sound alternatives

Palmer (1982) found that scarce financial resources only accounted for 10% of the reasons for companies not implementing waste minimization programs. Considering the present economic situation, this has probably increased but the message remains; financial constraints may be a relatively minor concern when introducing waste management programs.

Many waste management programs consider only a single category of waste such as industrial or municipal solid waste, hazardous or non-hazardous waste, liquid waste or air emissions, or wastes from a specific process or plant. This concept of waste management sets sharp boundaries between the types of wastes, ignoring the fact that there may be no clear distinction between the types of wastes. Management methods feasible for one type of waste may be acceptable for another and, in fact, combining wastes may be more efficient, economically and/or technically (Vaananen, Pouttu and Kulmala, 1992). Most industries and governments must deal with all types of waste.

Many strategies deal specifically with hazardous wastes, especially in the U.S. where legal definitions and high costs of disposal for designated hazardous wastes ensure that they receive special attention (Wassersug, 1992). Examples are found in Hazardous Waste: Detection, Control, Treatment (Abbou, 1988) and Batstone, Smith and Wilson's discussion of disposal of hazardous wastes for developing countries (1989). A number of company strategies deal primarily with industrial waste minimization (Galil and Rebhun, 1992; Spearman and Zagula, 1992; Shieh and Sheehan, 1992; Chemical

Manufacturers Association, 1989) and many government strategies deal with either industrial waste, municipal solid waste or wastewater (O'Gallagher, 1990; U.S. EPA, 1988; MacLaren Engineers, 1989; Krieth, 1992; Davis, 1988).

Some waste management programs, both corporate and government, are beginning to deal with all types of waste (Shubert, 1990; Allessie, 1989). The Dutch approach (Allessie, 1989) is perhaps the most comprehensive since it considers all types of wastes and their effect on the environment and recognizes the value of wastes as resources. Since the Netherlands is a small country with limited resources, it is perhaps easier for an overall plan to be incorporated since the number of environmental parameters would be manageable. However, their small size, limited resources and the variety and quantity of materials they produce also requires the serious consideration of integrated resource management since any pollution could have a major effect in their country (Schneider, 1991). Such considerations are also valid for islands states such as the Caribbean.

Integrated waste management has been used to refer to a waste management plan that constitutes "cradle-to-grave" waste management, as opposed to waste minimization or waste disposal (Shieh and Sheehan, 1992). In order to be comprehensive and effective, any waste management plan should incorporate such an approach (Allessie, 1989). Such plans usually also manage only a specific plant's, company's or community's wastes and most plans consider by-products to be wastes, not resources.

Within the tenets of industrial ecology, integrated waste management planning acquires a different meaning. Rather than being a plan for managing all different types of wastes at one plant only, industrial ecology looks at waste production at a number of plants and attempts to find optimum solutions for managing all wastes in an economical and environmentally sound manner. Moreover, considering the concepts presented by cascade theory, it is more appropriate to use the term 'integrated resource management', which recognizes the value of process by-products. Therefore, within this research, integrated resource management assesses a wide range of resource types, including gas, liquid, sludge and solid wastes, and attempts to determine the most economical and effective methods for managing resources, including reduction, recovery, treatment and disposal of process by-products. This management concept is fundamental for the implementation of sustainability within industry. Moreover, for countries with rapidly depleting resources and few environmental standards as exists in many developing countries, the implementation of such practices would assist in reducing impacts on the environment, potential threats to human health and pressure on the resources.

2.6 Waste Management and Developing Countries

Developing countries range from those which are experiencing a rapid industrialization and consequent economic development (e.g. Mexico, Malaysia, Philippines, Thailand) to those which still rely primarily on agriculture, tourism and small, light industry as an economic base (e.g. most small islands in the Caribbean, Brunei, Darussalam and Maldives). The former are facing waste management problems similar to those faced by industrialized nations in the early 1950s and 1960s (Uriarte, 1991), including problems with municipal solid waste, wastewater and industrial waste management and disposal. The latter countries contend with municipal solid waste, wastewater and a limited volume of industrial and non-point source agricultural pollution. Some developing countries have set environmental standards, but few have the enforcement capabilities to ensure that the standards are met (Wilson and Balkau, 1990; Saraswat and Khanna, 1989).

Industries in developing countries include highly technical operations, incorporating combinations of old and new technologies (e.g. the petroleum industry) and producing large volumes of wastes but many are small operations, following traditional means of production (many textile and metal-working companies operate in this manner) and produce less than 100 kg of waste per annum (Wilson and Balkau, 1990). The traditional production methods may have evolved their own methods of waste disposal, which may not be environmentally acceptable; in addition, some wastes may be recycled or reused in a grassroots waste exchange program (Jensen, 1990).

In developed countries, government approaches to waste management policy and legislation range from the traditional pollution standard with a minimal commitment to waste minimization to a long term objective of maximum reduction in discarded wastes and minimal negative impact from those wastes (as found in the Netherlands; Allessie, 1989). The U.S. EPA has initiated a Pollution Prevention Office which includes among its objectives the incorporation of pollution prevention into EPA policy, the supplying of tools and mechanisms to prevent pollution and the marketing of pollution prevention as a new environmental ethic (Morse, 1989).

It must be recognized that it is difficult for developing countries to limit industrial development through environmental controls and restrictions as there is often an emphasis on short term gain (Bowonder, 1987). Consequently, many developing countries have few standards or limits which industries must meet and, even if such legislation is in place, the problems of enforcement often prevent such legislation from being effective (Pareek, 1992; Wilson and Balkau, 1990). In addition, disposal of municipal and sewage waste is often haphazard and uncontrolled (Uriarte, 1991; Vlugman, 1991). The price of industrialization without environmental controls is illustrated in the conditions now found in Eastern Europe, where water, air and soil are polluted to such an extent that lifespans have been affected and villages have required evacuation (Wassersug, 1992; French, 1991). Effective policies, legislation and enforcement must be in place to effectively manage waste production (Ehreth, 1991; Biswas, 1988).

Wilson and Balkau (1990) outlined the steps involved in the evolution of a hazardous waste management system for developing countries (Figure 2.3). However, they noted that the sequence of steps will vary from country to country and that management methods must be adapted to specific local needs and circumstances. Using case studies, they determined some of the differences between developed and developing countries:

a) small generators are the norm, not the exception in many small countries;

b) non-industrial sources of waste may be important;

c) the environmental and health impacts may vary between industrialized and developing countries;

d) climatic differences may require changes in waste handling and design or handling of wastes;

e) transportation networks may be inadequate, requiring local solutions;

f) government bureaucracy may make complex control systems difficult to implement.

Most of their recommendations involve bureaucratic changes that are necessary to initiate a management program, such as implementing controls over pollution, designating and training people to resolve problems. However, initiating waste minimization practices, promoting public, media and industry education and obtaining independent advice are measures that can be taken independent of government action and therefore are appropriate for industrial participation.

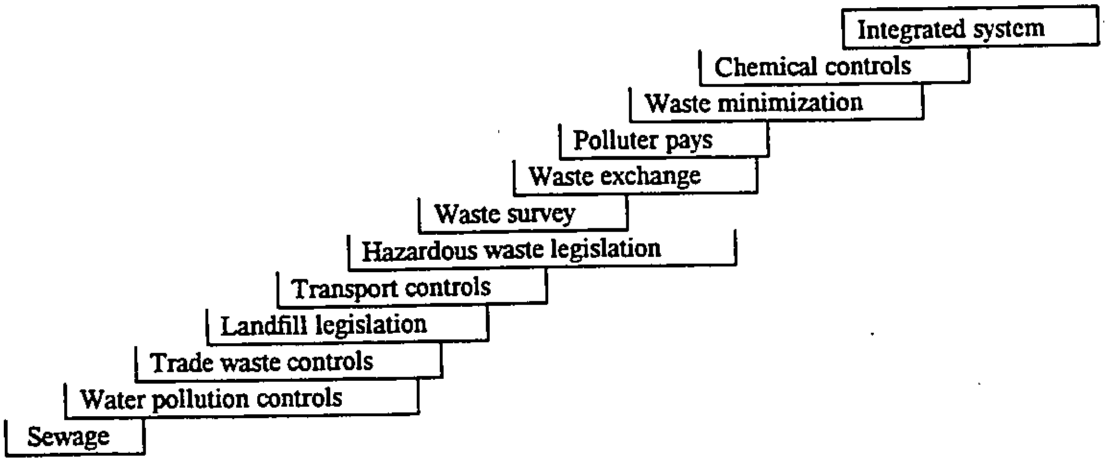


Figure 2.3 Steps in the evolution of waste management systems (Wilson and Balkau, 1990).

When considering sustainable development, assimilative capacity, or the ability of a system to assimilate pollutants, becomes an important concept since the assimilative capacity would be a primary factor restricting development. Singh (1990) points out that assimilative capacity is more important for small, developing island states since the assimilative capacity of such islands is lower than for larger, more geologically and ecologically diverse continental countries. The use of sustainable development concepts, protection of the environment and proper management of wastes is, therefore, vital to those small island states. The state of waste treatment plants in developing countries (Vlugman, 1991) indicates the necessity of ensuring that technology fits the culture or that attempts are made to ensure that the level of skilled, trained labour available is consistent with the requirements of the technology (Armstrong, 1989).

An integrated resource management planning decision process for a developing island state could assist in:

a) sensitizing waste generators, both industrial and non-industrial, to waste management issues and the need for policy;

b) increasing the potential for selling waste products and potentially improving the economic return for companies;

c) reducing the number of waste recovery, treatment and disposal facilities that are required, thus reducing the potential impacts of such facilities on a limited ecosystem;

d) enabling the costs of waste recovery, treatment and disposal facilities to be co-funded by industries and municipalities, thus making them more affordable;

e) improving the efficiency of resource use and increase resource conservation.

Implementation of an integrated resource management plan, however, requires a significant level of expertise in a number of disciplines. Wastes can be divided into a number of categories; biodegradable, non-biodegradable, heavy metal or salt bearing, liquid, gaseous or solid, water-soluble, etc. The type and volume of wastes define the possible reduction, recycling, treatment and disposal methods. However, the evaluation of waste management options that will be most effective requires a knowledge of chemistry, biology, geology, engineering, ecology and environmental policy which few managers have. Managers need direction to assist them in determining the most effective waste management options. In many cases, consultants provide that direction, but often at a high cost, which would be unaffordable and possibly unavailable in developing countries. However, knowledge-based decisions support systems (KBDSSs) can be developed to provide assistance to managers in making decisions about waste management at much less cost. Considering the lack of expertise available in developing countries and the multitude of parameters that must be considered when examining options for waste reuse, recycling and co-treatment, a KBDSS could greatly assist industries in these countries in initiating integrated waste management programs.

It must be recognized that, considering the lack of funds, the input requirements for the KBDSS must also be limited as analyses of waste materials can be extremely expensive. Technical limitations, such as power and water fluctuations or shortages which often occur in developing countries, point out the necessity of introducing processes which can reduce water or power requirements.

2.7 Knowledge Based Decision Support Systems

The main goal of a decision support system (DSS) is "to provide decision makers with tools for interactively exploring, designing and analyzing decision situations in a manner compatible with their mental representations" (Angehrn and Lüthi, 1990). A DSS is, traditionally, a system that provides tools to managers to assist them in solving semistructured and unstructured problems (Parker and Case, 1993). O'Brian (1990) classifies DSSs as computer-based information systems that provide interactive information support to managers during the decision-making process and may include analytical models, specialized databases, a decision maker's own insights and judgments and an interactive, computer-based modelling process. Controversy exists as to whether DSSs are a broad group of systems that encompass spreadsheets to knowledge-based and expert systems (Angehrn, 1993) or are a specific, separate type of system (O'Brian, 1990). Angehrn (1993) defines two broad types of DSSs. The first, vehicle DSSs, are vehicles for conveying an expert's problem solving strategy for resolving a specific problem to a decision maker. These would include expert systems and knowledge-based systems and are guidance mechanisms. The other, toolbox DSSs, provide loosely coupled sets of flexible tools, such as modelling functions, statistical functions, graphic packages and simulation and optimization subroutines.

A knowledge-based system (KBS) adds a knowledge base to a computer-based information system (O'Brian, 1990), representing and manipulating knowledge about non-structured problems to find a solution (Guida, Marchesi and Basaglia, 1992). Adding a knowledge base to the database and model base of a decision support system results in a knowledge-based decision support system (KBDSS). Van Weelderen and Sol (1993) term this an expert support system, discerning that computers should provide a support function in solving problems rather than act as experts.

Expert systems imitate the reasoning processes of human experts and provide decision makers with the type of advice they would normally receive from human experts (Parker and Case, 1993).

O'Brian (1990) classify expert systems as KBDSSs which act as expert consultants to end users about specific, complex applications. The knowledge base includes both facts and heuristics that express the reasoning procedures of an expert on the specific subject. O'Brian differentiates between DSSs and expert systems by a number of factors as listed in Table 2.3. For the purposes of this dissertation, decision support systems that utilize knowledge bases will be referred to as knowledge based decision support systems (KBDSSs).

Table 2.3 Differences between DSSs and expert systems (O'Brian, 1993).

Attribute	**DSS**	**ES**
Objectives	Assist human decision maker	Replicate a human adviser
Recommendation/decision maker	Human and/or system	System
Major orientation	Decision making	Transfer of expertise, rendering of advice
Major query direction	Human queries machine	Machine queries human
Nature of support	Personal, groups, institutional	Personal, groups
Data manipulation method	Numerical	Symbolic
Characteristics of problem area	Complex, broad	Narrow domain
Type of problems treated	Ad hoc, unique	Repetitive
Content of database	Factual knowledge	Procedural and factual knowledge
Reasoning capability	No	Yes, limited
Explanation capability	Limited	Yes

Within a KBDSS, the user defines the problem to be considered; the system then prompts the user for information. KBDSSs often incorporate IF..THEN statements to provide answers, using a database. Such systems allow users to deal with many possible solutions, including what-if scenarios, may incorporate uncertainty and can provide both numerical and written solutions (Mollenkamp, 1989; Merry, 1985). In designing such systems, a series of questions must be considered and answered: "why" (organizations, organizational structures, problem classes, individuals, tasks), "what" (tasks, including the information needed to solve the problem, the information from solving this problem, the expert's problem solving behaviour and the support structure or inference engine of the engine), "how" (information grouping and processing) and "with what" (hardware and software) (van Weelderen and Sol, 1993).

There are a number of inherent limitations found in all KBDSSs:

i) Relevance of Material

Despite all efforts, KBDSSs reflect the data that are available when the system is written. As new information becomes available, decisions may be made on a different basis or using new factors. Probabilities may also change. Although most systems contain some methods to upgrade the system, time and effort must be spent to ensure that the system is upgraded.

ii) Knowledge

The system is only as good as the knowledge that is incorporated into the system. Although systems are usually evaluated by a number of users and by some experts, such validation may be expensive and, consequently, may not be extensive. In addition, even experts differ on their interpretation of data, their method of making decisions and their ultimate decisions (Clark, P., 1990). Furthermore, the knowledge or expertise to solve the problem must be available (Yurman, 1990).

iii) Objective

The ultimate goal of the system will affect how the decisions are made. If the ultimate endpoint of the system is to provide the most economical method of remediating a site, then methods that comply with the standards of the law and minimize the cost will be proposed. However, if the goal of the system is to ensure that the environment is protected then the system may go beyond the letter of the law and propose solutions that may be more expensive but will better protect the local environment.

iv) Data Limitations

Information and data must be supplied by the user and, if the information supplied is inaccurate or has been misinterpreted, then the results of the system will be of limited use. For example if results of an analysis are required to provide basic information, then the system depends upon the accuracy of the analysis.

v) User Expertise

Although many systems provide explanations of technical jargon or specific terms, some knowledge on the user's behalf is expected. Verification and validation of the system should reduce the probability that the system results will be misinterpreted or that the system will produce unacceptable answers (Stunder, 1990).

KBDSSs are being produced to solve a number of problems. It is important that the user recognize the limitations of the system and how the decisions are made. Most systems provide some mechanism to enable the user to follow the decision making process (Gevarter, 1987). That process should be examined to determine the basic assumptions that are used to solve the problem. Without this understanding, systems can be misapplied and the results used to promote incorrect courses of action. In addition, it is important that the decisions made also incorporate an ethical consideration which should not be dictated by the decision support system.

KBDSSs have the capability to be widely abused. Inexperienced employees may rely too heavily on a decision support system and not try to understand the process involved in the decision making process (Ostrowsky and Swezey, 1989). Employees may actually not gain expertise as they rely on the computer to provide all answers (Dreyfus and Dreyfus, 1986).

Finally, most professionals tend to use in their diagnoses or decisions, a strong mixture of knowledge, information, experience and some intuition (Ostrowsky and Swezey, 1989). The factor of intuition is most difficult to incorporate in a decision support system. It is that intuition that could incorporate the additional factors that make a program successful or points it in the correct direction. Some aspects may be incorporated into the probability component of the system, but some require experience and insight (Dreyfus and Dreyfus, 1986). Michie (1990), however, has found that using computer analysis of movement and behaviour patterns may provide some models of expert physical behaviour (such as driving a vehicle), and this may be applicable to expert thought processes, although this has yet to be explored.

As a result, some problems may not be suitable for decision support system application. According to Yurman (1990), some of the criteria that must be met to ensure successful application of an decision support system include:

a) the problem must be solvable by conventional means;

b) the problem must have recognized bounds and be clearly defined: and

c) the problem must be solvable by an expert, preferably within a week.

Although there may not be solutions yet for all waste management problems, most are solvable by conventional means. The problem boundaries are clearly defined for this research. Finally, most waste management problems are solvable by experts, although more than a week is usually required. Much of this time is spent in initiating and organizing the program and gathering data (Freeman, 1990). The time required for actual problem solving is probably within a week, although there is little information in the literature about such time requirements.

In developing a decision support system, shells are frequently used to provide the basic framework for the system. The features of shells available on the market must be assessed to assist in selecting a shell for the proposed decision support system. In addition, existing KBDSSs for waste management must be examined to determine the current state of development in the field and to determine if any aspects of those systems could be integrated into the proposed system.

a) Knowledge Based Decision Support System Software

KBDSSs can be developed through three approaches:

a) a custom-built system using an AI development language such as LISP or Prolog;

b) a prewritten expert system shell without a knowledge base; and

c) a prewritten application package which can be fine-tuned.

Writing a custom-built system is the most expensive and time-consuming approach but allows specific tailoring to the application, while application packages, if available and applicable to the problem to be solved, can be the least time consuming. No application packages were found that could be used for the problem defined in this research.

Decision support system shells facilitate the construction of an decision support system, acting as a building tool (Mackerle, 1989). Since different shells offer different features, such as backwards or forwards chaining, explanation functions for the user, rule-based or object oriented programming, ability to interface with database management systems, etc., can vary in price from hundreds to tens of thousands of dollars and have varying rule limitations, run speeds and memory requirements, it is important that the shell be selected carefully (Mettrey, 1992; Mackerle, 1989). Some shells are designed for solving specific types of problems, thus increasing their reliability and efficiency (Bradshaw, 1991; Marcus and McDermott, 1989).

Mackerle (1989) reviewed 86 decision support system development tools or shells, identifying the computational and memory requirements, the cost, language, knowledge representation, inference engine capabilities, interfaces and integration capabilities of each. The time required to learn the system is also a concern. All of these aspects and more must be considered when selecting an decision support system shell for a specific purpose.

b) KBDSSs Developed for Waste Management

In 1991 there were about 70 KBDSSs presently on the market that deal with environmental problems (Erhle, 1991), a significant increase over the 21 available four years earlier (Hushon, 1987). About 20 systems had been produced in Canada, Germany and a few other countries while the majority were produced for the U.S. market (Erhle, 1991). A number of these systems tackled the problems inherent in waste management.

One system, TSDSYS, selects treatment or recycling facilities for wastes in the U.S. (Hushon, 1990) while XUMA, a German system, evaluates hazards of chemicals and identifies disposal options (Geiger, Osterkamp and Weidemann, 1991). Systems developed by the U.S. EPA support data sampling, analysis and validation (Olivero and Bottrell, 1990), predict aquatic toxicity of contaminants (Hickey et al., 1990), aid hazardous waste site investigations (Goldblum, Clegg and Erving, 1992; Cross, Flores-

Pineda and Hindin, 1990; Fang, Mkroudis and Panukcu, 1990), develop and cost remedial actions for Superfund sites (Chenu and Crenca, 1990) and perform risk assessments for hazardous waste (Schaum, et al., 1990). The Multimedia Environmental Pollutant Assessment System (MEPAS) integrates source-term, transport and exposure models to estimate potential health impacts from toxic chemicals (Whelan et al., 1992). A number of systems deal with control, cost modeling and problem solving for wastewater treatment systems (Galil and Levinsky, 1991; Laukkanen and Pursianen, 1991; Collins and Bristol, 1992) and an optimization method for liquid industrial wastewater treatment has been outlined by Ellis, McBean and Farquhar (1985). There are numerous other systems, many of which are listed in Hushon (1990), Foster (1992) and in UNEP Industry and Environment volume 14, nos 1 and 2. None, however, deal specifically with problems in developing countries.

Most of the waste management software deals specifically with purchasing, tracking, shipping and regulatory compliance, waste site investigations and determination of toxicity of chemicals. One system, RESREC, assists in evaluating resource recovery options, using waste characteristics and cost, while the Environmental Assessment System (EASY) evaluates environmental impacts and implications of LNWT (Hushon, 1990).

A knowledge-based prototype system was developed by Evenson and Baetz (1994) to select and sequence treatments for hazardous wastes. The system used NEXPERT on a Sun Sparcstation, and suggested potential treatment sequences to reduce contaminants to treatment objective levels.

Barnard and Olivetti (1990) have developed an decision support system which allows prediction of industrial waste production within an area. The system contains a database of known types and quantities of waste arising from manufacturing industries and bases the predictions on waste production per employee in other locations. The system does not provide any advice on waste management options or on environmental impacts.

In conjunction with their Pollution Prevention program, the U.S. EPA has developed an decision support system, the Strategic WAste Minimization Initiative (SWAMI) which identifies waste minimization opportunities, prioritizes and devises a strategy to take advantage of those opportunities

(Peer Consultants, P.C. and University of Dayton Research Institute, 1992). The system uses mass balance calculations, generates graphic process flow diagrams and identifies strategies such as resetting controls or making major equipment changes to reduce waste production. It does not provide information on waste recovery, treatment or disposal options, nor does it consider environmental impacts.

Some models can be used as the basis for KBDSSs and numerous environmental models have been developed. Piazza et al. (1992) use costs and process modeling to analyze manufacturing waste generation and effectively design process control systems to minimize consumption of reactants while meeting other process constraints. The computer models were developed for each specific process examined to illustrate where wastes were being generated. Although they termed it a methodology for characterizing the environmental impact of manufacturing processes and operations, this work only examined the internal manufacturing processes and costs for manufacturing and waste disposal, not the environmental impacts.

An economic analysis model for hazardous waste minimization (EAHWM) has been developed to enable users to evaluate life cycle costs for waste minimization practices and compare them to current operating costs (Dharmavaram, Mount and Donahue, 1990). This model is applicable to other wastes and compares costs of waste reduction, recovery and treatment. The approach provides information on waste management methods for solvents, paint stripping, metal plating, industrial wastewater treatment plant wastes, used oil and batteries, which are the primary processes of concern to the U.S. Army. Default values can be used for calculating costs for options to those processes, but the user can input alternative estimates and estimates for other options and processes. Another economic model has been developed by Karam, St. Cin and Tilly (1988) for providing economic evaluations of hazardous waste minimization options, using user-inputted cost estimates, and incorporating user-defined confidence ranges. Neither model considers environmental parameters within its analysis.

A decision support system for assisting industrial waste management has been developed by a consortium of industry, consulting, research and government partners to find efficient methods of waste treatment and disposal, taking environmental regulatory criteria and economic constraints into consideration (Pintér, 1993). The system, Environmentally Sensitive Investment System (ESIS), only considers wastewater management options and is currently designed for the pulp and paper industry, although its scope could be broadened.

A specific wastewater treatment optimization model has been written for developing countries which considers environmental, cultural and social factors as well as economics and selects optimal wastewater treatment systems for a developing country (Ellis and Tang, 1991; Ellis and Tang, 1994). Models for integrated pollution control dealing primarily with end-of-pipe technology (Munshi, 1990), air and water pollution and soil interactions (Chen, 1991; Pictet, Giovannoni and Maystre, 1992) have also been written. Pictet's model uses a multibox system utilizing load factors and mass balance equations to produce a final ranking showing environmental impact.

c) System Verification, Validation and Evaluation

Any KBDSS requires some means of determining correct performance or verification and a number of strategies have been developed (Landry, Malouin and Oral, 1987; O'Keefe, Balci and Smith, 1987; Renard, Sterling and Brosilow, 1993). Evaluation is the process of determining if the system can solve real-world problems while validation has been defined as "the process of determining that an expert system accurately represents an expert's knowledge in a particular problem domain" (O'Leary, Goul, Moffitt and Radwan, 1990, pp 51) and includes verification and substantiation. Verification is confirmation that the system contains the entire problem and will provide a credible solution while substantiation determines that a model or system is accurate within the limits of the system.

Both consistency and completeness of the knowledge base, as well as logical correctness of the rule set are part of verification. Nazareth (1989) has detailed the errors that may occur in the logic of KBDSSs and these include:

a) redundancy

b) conflict

c) circularity

d) missing rules

e) missing facts.

Typographical mistakes, input error (omitting part of a rule, reversing direction of a rule), errors introduced when upgrading a system and overreaching the boundaries of the initial system are also errors that may occur in expert systems. In addition, scientific and technical limits to the data also introduce errors. Finally, improper application of the system also will result in errors.

Systems can include verification mechanisms to prevent a number of errors from occurring in a system but the system must still be assessed to determine if the data itself are applicable and accurate for the specific problem the system purports to solve. Finally the system must also be evaluated using case studies to ensure that it can solve real-world situations.

d) KBDSSs and Developing Countries

According to the literature, there have been no KBDSSs or expert systems written which recognize the concerns of developing countries. Ellis and Tang (1991, 1994) have developed models for optimization of wastewater treatment in developing countries but most KBDSSs or expert system were designed with the concerns of developed countries as a priority. Although each developing country has its own set of unique problems, three problems are likely common - a lack of funds, a lack of expertise in treatment processes and a lack of environmental legislation. The lack of funds means that any system must be able to run on a micro-computer system, rather than a larger, more expensive system such as a Sun workstation. In addition, if a shell or supporting software system is being used, it must be inexpensive and readily available.

2.8 Summary

In response to stricter waste disposal and pollution control legislation, higher waste disposal costs and increased penalties for non-compliance, waste management in industrialized countries has moved from end-of-pipe technology to focusing on waste minimization and recovery in the last five years (Crittenden, 1992; Jacobs, 1991; Jeffery, 1992). A variety of mechanisms for incorporating this waste management philosophy into government and industry programs have been proposed (Allessie, 1989;

Freeman, 1990; Hazardous Waste Engineering Research Laboratory, 1988). A number of companies have undertaken waste minimization programs and have realized significant financial benefits within a few years of the programs' inceptions (Ehreth, 1989). Most of these programs, however, only take one waste type, e.g. hazardous or non-hazardous, industrial or municipal, into consideration. As a consequence, these programs do not incorporate potential co-recovery or co-treatment options that could be economically and technically efficient, with industry and municipalities sharing costs for equipment, facilities and transportation (Vaananen, Pouttu and Kulmala, 1992). A program with these type of characteristics would be described as incorporating integrated resource management principles.

Few developing countries, however, have undertaken waste management in any form, with many having no environmental or pollution standards or the enforcement capabilities to uphold any such legislation (Wilson and Balkau, 1990; Saraswat and Khanna, 1989). In addition, they face pressure from industry in developed countries to dispose of hazardous wastes (Suite, 1990; White, 1991). Consequently, developing countries require assistance in promoting waste reuse and recycling and in the proper management of wastes in general (Singh, 1990).

KBDSSs are used to provide expertise that is not readily available, and over 70 environmental KBDSSs have been written, some of which consider waste management concerns (Erhle, 1991). The majority of these deal with chemical toxicity, site remediation, data sampling, and some are specific to wastes such as municipal wastewater or hazardous wastes (Hushon, 1990). Models have also been developed to assist in determining waste minimization options and costs (Peer Consultants, P.C. and University of Dayton Research Institute, 1992; Dharmavaram, Mount and Donahue, 1990; Karam, St. Cin and Tilly, 1987) and for determining integrated pollution control options (Munshi, 1990) and air, water and soil interactions (Chen, 1991; Pictet et al., 1992). However, from a review of the existing literature, no KBDSSs have yet been developed to provide advice on options for integrated industrial waste management planning, including different waste types (e.g. hazardous and non-hazardous wastes) or different waste producers (e.g. a range of industries). In addition, limited KBDSSs or models have recognized the specific requirements of developing countries, and none acknowledge the problems inherent in waste management planning for small island applications.

This chapter focused on literature which discusses the concepts of industrial ecology and integrated waste management, how they can be implemented and the possible benefits the application of these concepts could have for developing countries. The role of knowledge-based decision support systems in implementing effective waste management practices was also discussed and the contributions of this research were defined. Chapter three will discuss the development of a prototype KBDSS for integrated waste management.

3.0 Development of a Knowledge Based Decision Support System Prototype

By matching the major components and parameters of a waste material with the requirements needed for an input, the potentials for reuse or recycle can be determined. Changes which are needed to match the input requirements can be effected by a series of treatments, each of which change the parameters of the waste material. The series of required treatments is termed a treatment train. Once all treatment trains have been defined for a group of wastes, the final selection of treatment options can be made to provide an optimal waste management system. This chapter describes the system model in detail, the selection of the software, inputting of the data and the inference engine.

3.1 The System Model

A typical plant operation involves inputting a raw material or input into a process which then produces outputs which may be either a product or a waste material (Figure 3.1). Processes can include many of the operations at a plant - the manufacturing process (which produces the product), the cooling process or the maintenance process, while inputs can include raw materials such as iron ore or water as well as manufactured items such as filters. Inputs usually have to meet certain specifications to optimize the process and to produce a quality product. These specifications include the percent of the major components and their chemical composition as well as the ranges acceptable for the parameters of the input material such as the pH, the trace contaminants or the amount of suspended solids. Products also have to meet quality specifications but waste materials are usually treated according to the common characteristics they display, such as the TOC or pH.

In order to reuse waste materials, a number of criteria has to be met. First, the input must not be a manufactured item such as a filter. Used manufactured items usually require specific treatments or inspection and replacement of worn parts for recycling. Second, the waste material must contain the major components and the percent required in the input. Third, the parameters of the waste must lie

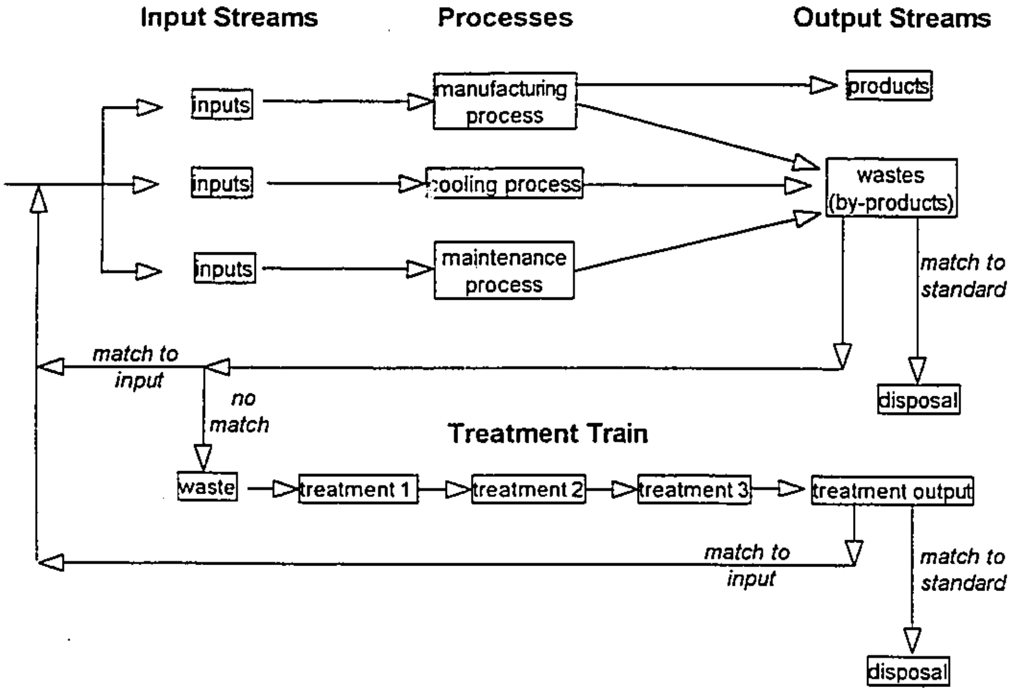


Figure 3.1 Movement of materials through processes and treatments for reuse, recycling and disposal.

within the acceptable range required for the input. Once these criteria have been met, the waste material can be considered for reuse.

To recycle a waste material, treatments are usually required. Since the treatments and refitting of new parts is specific to the item and would require an expert system in itself, manufactured items were not considered within this model for recycling. The waste material must still contain the major components required by the input, but the percent in the waste can be changed through treatment. Similarly the parameters of the waste can be changed by treatments.

Treatments usually have a primary effect on one or two parameters, but that change may affect the characteristics of other parameters. For example, removing oil from a waste will then change the percent of water in the waste material. Moreover, since the parameters can affect the efficiency of the treatment, the parameters of a material that a treatment can effectively treat must lie within a range specified by the treatment. Even if a material lies within the acceptable range, bench testing is still necessary to ensure that the treatment is efficient, since each waste is unique and its combination of parameters may reduce the effectiveness of the treatment.

The output of the treatment is also defined by its parameters and these can be determined by calculating the changes that have occurred. Treatments usually produce more than one output and an output is selected by the degree to which it matches the required parameters. The other outputs are termed secondary wastes. Both input parameters and the determination of treatment output parameters are discussed in detail in Chapter 4.

Once the inputs and outputs of a treatment have been defined, it then is possible to determine the treatments required to recycle a waste material or to meet disposal regulations. The parameters of the waste material are compared to the input requirements; treatments which primarily affect those parameters which do not fit the range but will accept the material are then selected. The output is then calculated and compared to the input requirements; if they do not match, another treatment is then selected (Figure 3.2). This sequence of *waste* → *treatment1* → *treatment 2* → *treatment 3* → *input* is termed a treatment train.

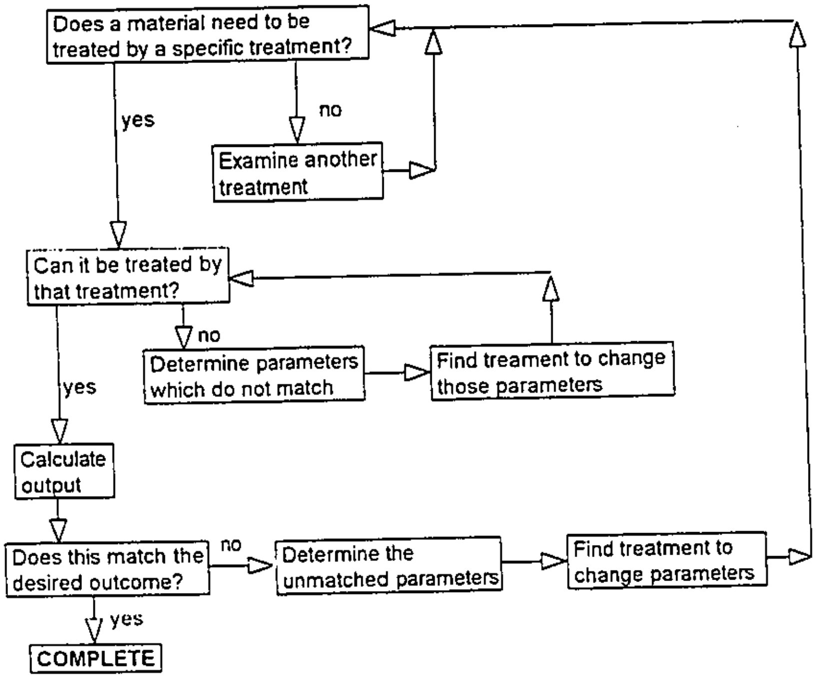


Figure 3.2 Determination of treatments for the treatment train.

To optimize the final selection, costs of materials and treatments would have to be included and this is beyond the scope of this present research. However, by allowing the user to select shorter treatment trains, or trains which produce low volumes of secondary wastes from treatments, costs may be reduced. By determining all the possible means of treating wastes from a group of plants for reuse, recycling or disposal, possibilities for treating wastes with the same treatment can be determined which can also significantly reduce costs. Using one or more of these criteria, possible options for treatment of all the wastes can be determined.

3.2 The Programming Software

A number of potential expert system shells were examined to determine which was suitable for the purposes of this research. The criteria that were considered were:

1. system flexibility;
2. capable of handling significant volumes of data;
3. cost (< $500);
4. capable of producing a user friendly interface; and
5. easy to learn and program.

Of the systems that were examined, most were expensive, not easy to learn or were insufficiently flexible. Most systems required that the system interface with a separate database system and few had flexible, user friendly interfaces. Discussions with a number of individuals familiar with expert system shells prompted the use of Paradox, a database program compatible with Windows or DOS. This inexpensive program (~$200 for Paradox for Windows, 1995) is essentially a database but also incorporates an object-oriented programming system. Within this program, interactive forms can be designed which can accept data directly into tables. Moreover, checks on the data to ensure that they are in the correct format or within acceptable levels can be included with each object for verification purposes.

Paradox is not set up as a rule-based shell. However, it was determined that, rather than using IF..THEN rules, for the purposes of this application, it would be more effective to use tables to store and compare parameters. Since Paradox is a database, this capability was readily incorporated into the program. Paradox is not a spreadsheet, however, so calculation formulae cannot be readily stored in tables except as strings, although it can be linked to a spreadsheet or to a language compiler (e.g. C). Paradox will also incorporate or translate DBase files.

Paradox does not contain an inference engine so a major task was the development of an inference engine that will accept the tabled data, compare it with the knowledge base, calculate an output and determine the suitability of those outputs.

3.3 User Interface, Data Storage and Data Handling

The user interface operates through a series of menus, where the user makes choices, and forms, which the user completes. As data are entered into forms, they are placed into tables in the database. A complete set of the data input forms is found in Appendix 5. The current system does not provide the user with explanations of the data required but this feature could be incorporated into the system in future developments. Figure 3.1 illustrates the flow of materials through processes and treatments for reuse, recycling and disposal and the terms that are used in this section.

Level 1

Step 1

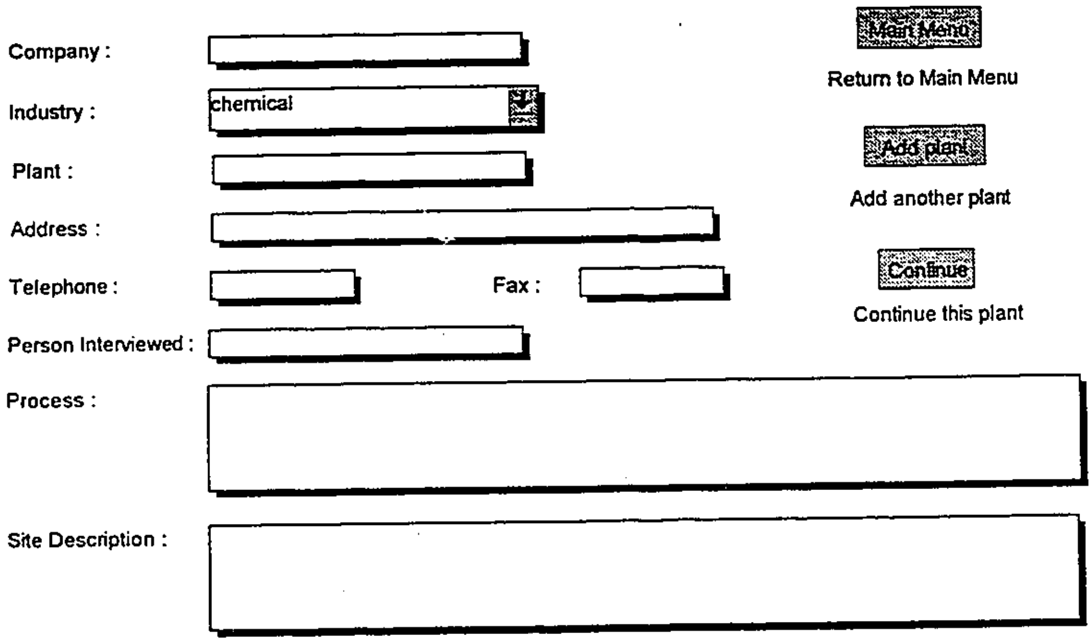
At level 1 (Figure 3.3), the user must enter data about the plant, identifying the company, plant name, industry type, contact person, telephone and fax number and a description of the plant.

Step 2

A specific plant process (e.g. manufacturing, maintenance, cooling etc.) is then selected and the composition and characteristics of the inputs are obtained. If the selected process produces a product, a basic mass balance must be completed for the process by the user.

The general data forms for inputs (Figure 3.4, Figure 3.5) obtains the following data:

a) the state of the input (gas, liquid, sludge or solid);



Company :

Industry : chemical

Plant :

Address :

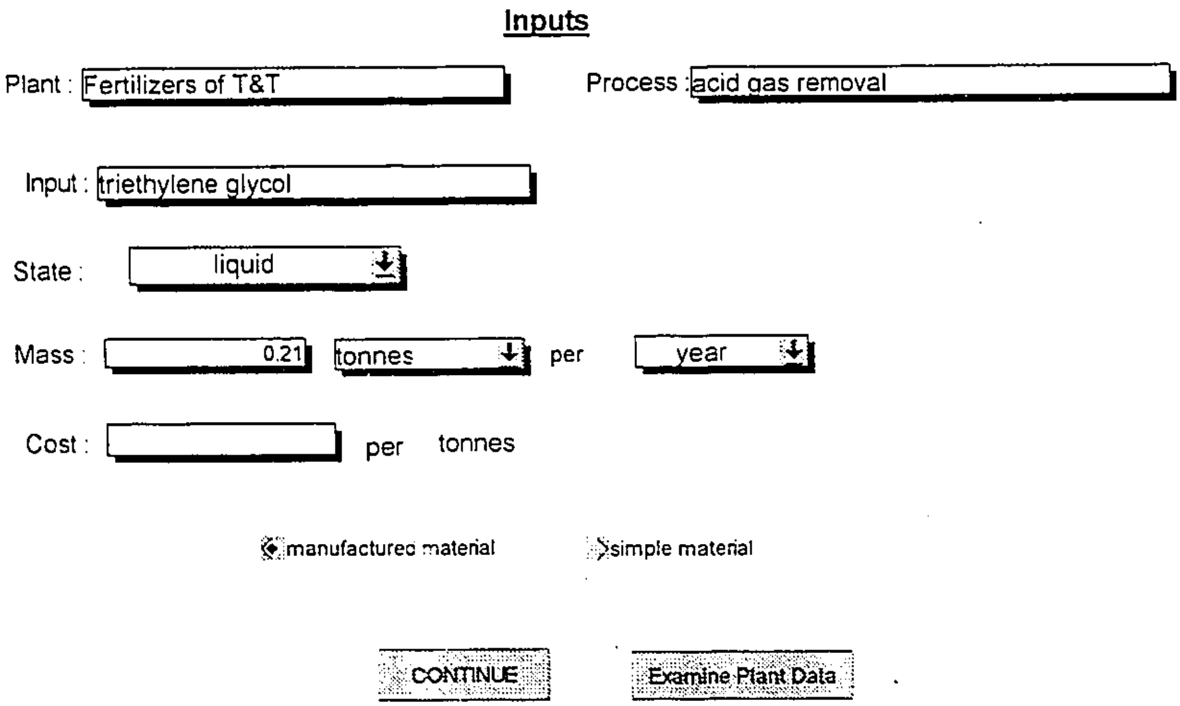
Telephone : Fax :

Person Interviewed :

Process :

Site Description :

Figure 3.3 Data required about the plant.



Inputs

Plant : Fertilizers of T&T

Process : acid gas removal

Input : triethylene glycol

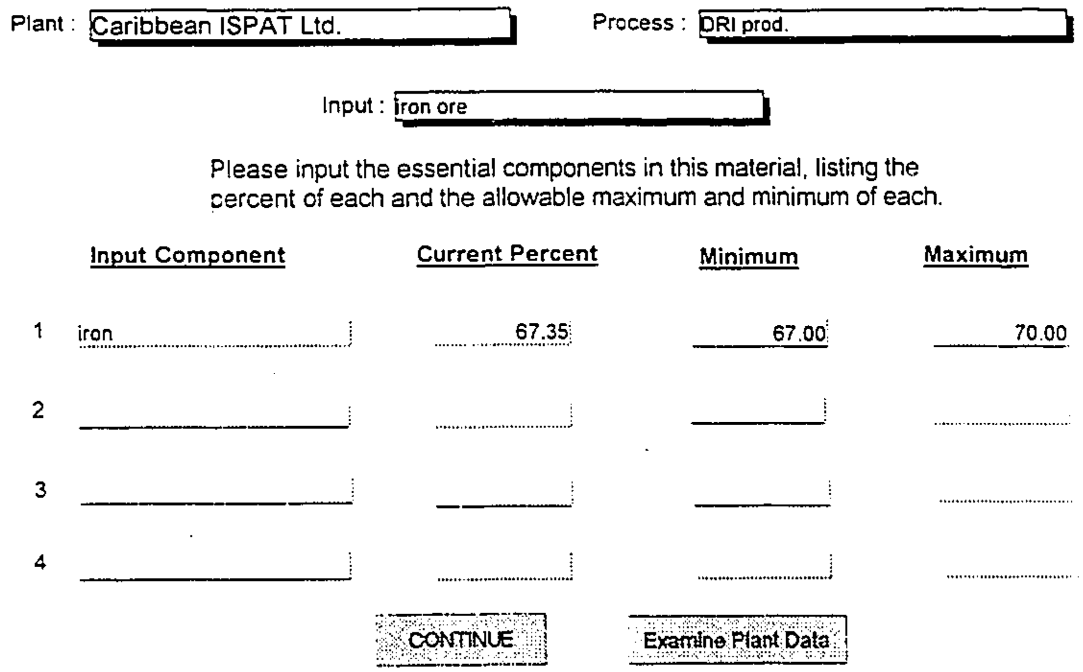
State : liquid

Mass : 0.21 tonnes per year

Cost : per tonnes

● manufactured material ○ simple material

Figure 3.4 General data form for inputs



Plant : Caribbean ISPAT Ltd.

Process : DRI prod.

Input : iron ore

Please input the essential components in this material, listing the percent of each and the allowable maximum and minimum of each.

	Input Component	Current Percent	Minimum	Maximum
1	iron	67.35	67.00	70.00
2				
3				
4				

Figure 3.5 General data form for inputs - obtaining input component data. The components may not equal 100% since only four major components are necessary.

b) if the input is simple (a raw material such as iron ore or a non-complex material such as white spirit which contains four or less major components), or complex (a material such as a cartridge filter or a specific mixture of chemicals which contains more than four major components);

c) the mass of the input per period (this is translated into mass per annum);

d) the four main components of the input and the average, minimum and maximum percent of each component; and

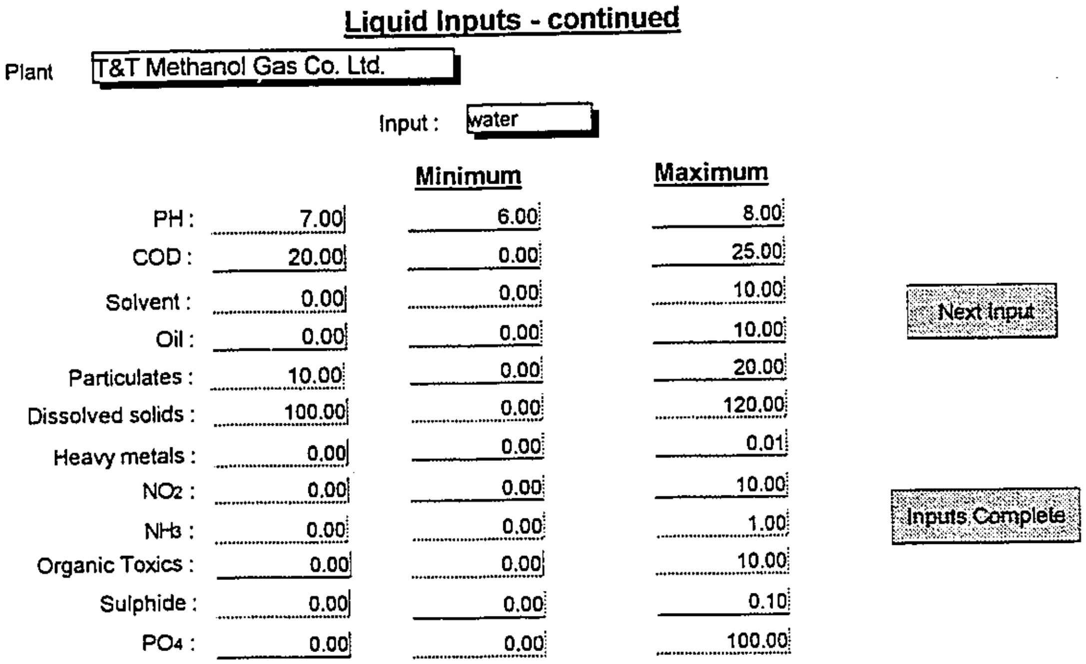
e) the cost of each input.

The form does not allow a minimum greater than the average or a maximum less than the average to be entered and the average total must be less than or equal to 100%.

The system requires mass estimates to calculate the mass balance. Some materials, however, are not commonly measured in mass, particularly gases, liquids and manufactured items such as filters. The user is required to provide mass and must make any required calculation to provide a mass estimate. In many cases, masses of waste produced are only estimates and any mass balance using such figures becomes only a very approximate estimate.

Step 3

If the input is simple then the next form (Figure 3.6) obtains information about the input parameters; otherwise information about the next input is obtained. If all inputs have been obtained, then, if the process produces a product, product data are obtained (Step 4). Otherwise the user moves to Step 5.


Liquid Inputs - continued

Plant: T&T Methanol Gas Co. Ltd.

Input: water

		Minimum	Maximum
PH :	7.00	6.00	8.00
COD :	20.00	0.00	25.00
Solvent :	0.00	0.00	10.00
Oil :	0.00	0.00	10.00
Particulates :	10.00	0.00	20.00
Dissolved solids :	100.00	0.00	120.00
Heavy metals :	0.00	0.00	0.01
NO_2 :	0.00	0.00	10.00
NH_3 :	0.00	0.00	1.00
Organic Toxics :	0.00	0.00	10.00
Sulphide :	0.00	0.00	0.10
PO_4 :	0.00	0.00	100.00

Figure 3.6 Form for obtaining input parameters.

Step 4 (processes producing products only)

The product data form (Figure 3.7) obtains the following information:

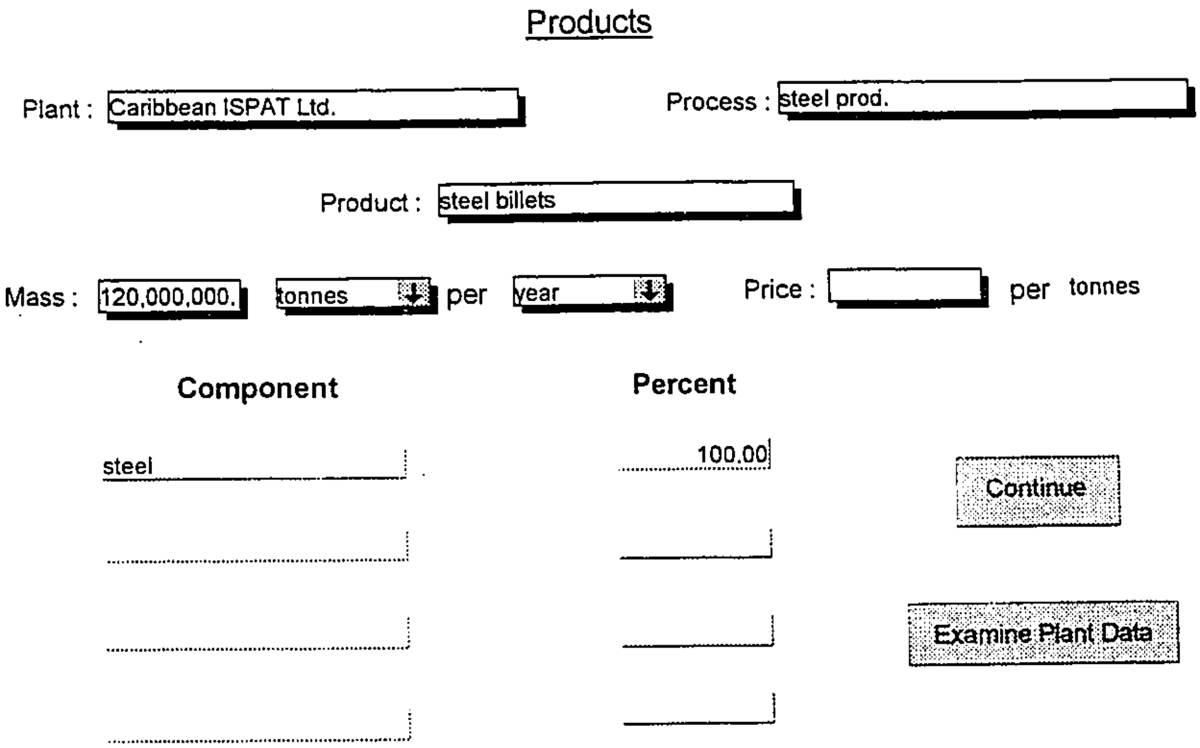
a) the state of the product;

b) the mass of the product per period;

c) the four main components of the product and the average (average percents must add up to equal to or less than 100%), minimum (must be less than or equal to the average) and maximum (must be greater than or equal to the average) percent of each component; and

d) the cost of the product.

The user then moves to Step 5.



Products

Plant : Caribbean ISPAT Ltd.

Process : steel prod.

Product : steel billets

Mass : 120,000,000. tonnes per year

Price : per tonnes

Component	Percent
steel	100.00

Figure 3.7 General data form for products.

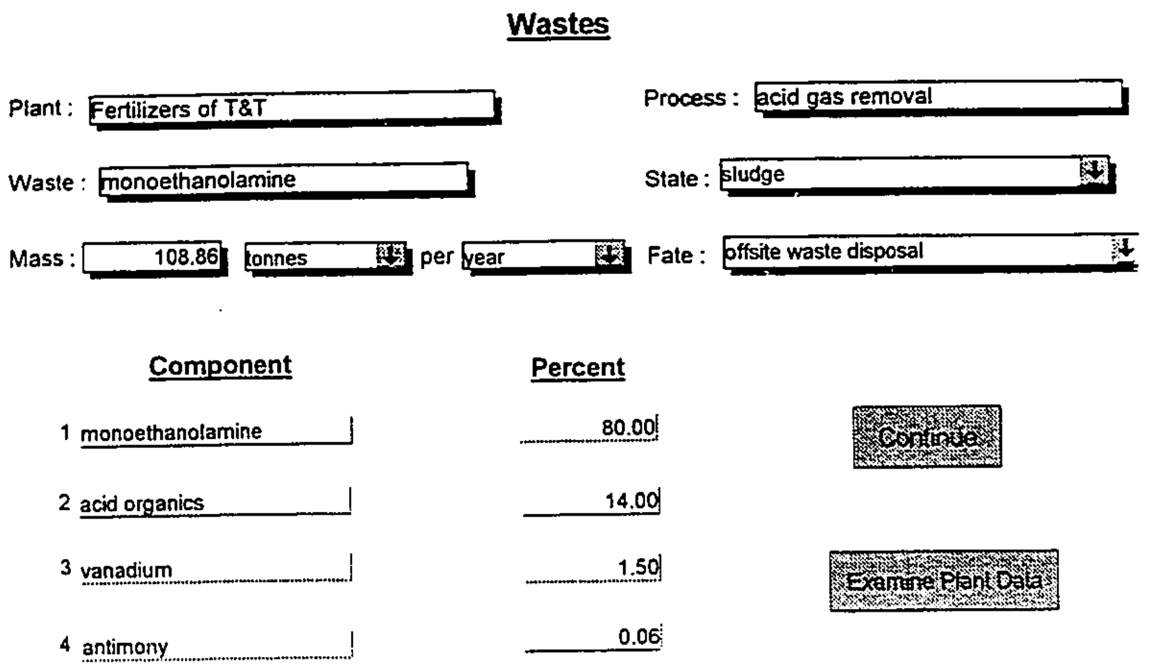
Step 5

General waste data are then obtained for each waste from that process. The information obtained for wastes (Figure 3.8) includes:

a) the state of the waste;

b) the mass of waste produced per period; and

c) the four main components of the waste and the average percent of each component.



Wastes

Plant : Fertilizers of T&T

Process : acid gas removal

Waste : monoethanolamine

State : sludge

Mass : 108.86 tonnes per year

Fate : offsite waste disposal

Component	Percent
1 monoethanolamine	80.00
2 acid organics	14.00
3 vanadium	1.50
4 antimony	0.06

Figure 3.8 Form for obtaining general waste data. Component percents may not add up to 100 since only four major components are required.

The specific parameter information required for simple inputs and for wastes depends upon the state of the input (see Table 3.1) and is measured in parts per million (ppm), unless such a measurement does not apply (i.e. pH). The parameters were selected for three main reasons - their discharge into the environment is regulated; they specify limits to treatments or they specify recoverable materials. Other factors such as human health and/or environmental impact and possible effects on material used for equipment construction were also considered. Since many regulations limit parameters at the ppm level, this was considered to be the most effective means for recording the parameters. The user must remember this however and, at present, must translate any percentages into parts per million.

An attempt was made to lump parameters (e.g. all heavy metals) together to reduce the number of inputs the user would have to make. This may lead to some inadequacies in the system since, for example, different heavy metals have different properties and may not react to treatments in the same manner.

However, it was felt that the increase in convenience for the user would outweigh the inadequacies; otherwise the user could be inputting over 50 parameters for each material.

Table 3.1 Parameters required for different states of inputs or waste materials, and reasons for selection of those parameters. R - regulated; H - health hazard; EN - environmental concern; T - required for determining treatment; M - required for determining material for construction; RR - recoverable for recycling (Woods, 1994a, 1994b; Amdur, Doull and Klaassen, 1991; Ontario regulations)

Gas	**Reason**	**Liquid**	**Reason**
corrosivity	R, H, EN, T, M	pH	R, H, EN, T, M
organic content	R, EN, T	organic content	R, EN, T
volatiles	R, H, EN, T, RR	volatiles	R, H, EN, T, RR
oil	R, EN, T, RR	oil	R, H, EN, T, RR
water	T, RR	water	T, RR
heavy metals	R, H, EN, T, RR	heavy metals	R, H, EN, T, RR
particulates	R, H, EN, T, RR	particulates	R, H, EN, T
particulate size	H, T, RR	particulate size	T
CFC	R, EN, T, RR	dissolved solids	R, H, EN, T
CO_2	R, EN, T	NO_3	R, H, EN, T
SO_2	R, H, EN, T, RR, E	NH_3	R, H, EN, T, RR
NO_x	R, EN, T	sulphur	R, H, EN, T, RR, M
		toxics	R, H, EN, T

Sludge	**Reason**	**Solid**	**Reason**
pH	R, H, EN, T, M	leachate pH	R, H, EN, T, M
organic content	R, EN, T	organic content	EN, T
volatiles	R, H, EN, T, RR	volatiles	R, H, EN, T, RR
oil	R, EN, T, RR	oil	R, H, EN, T, RR
water	T, RR	water	R, EN, T, RR
heavy metals	R, H, EN, T, RR	other metals	R, RR
particulates	R, H, EN, T, RR	soluble solids	H, EN, T
dissolved solids	H, EN, T, RR	iron	T, RR
NO_3	R, EN, T, RR	toxics	H, EN, T
NH_3	R, EN, T	paper	RR
sulphur	R, H, EN, T, RR, M	cardboard	RR
toxics	R, H, EN, T	plastic	RR
ash	T	ash	T

For processes which produce products, once all inputs, wastes and products of a process have been entered, an approximate mass balance is calculated to determine if inputs and outputs balance using the following equation:

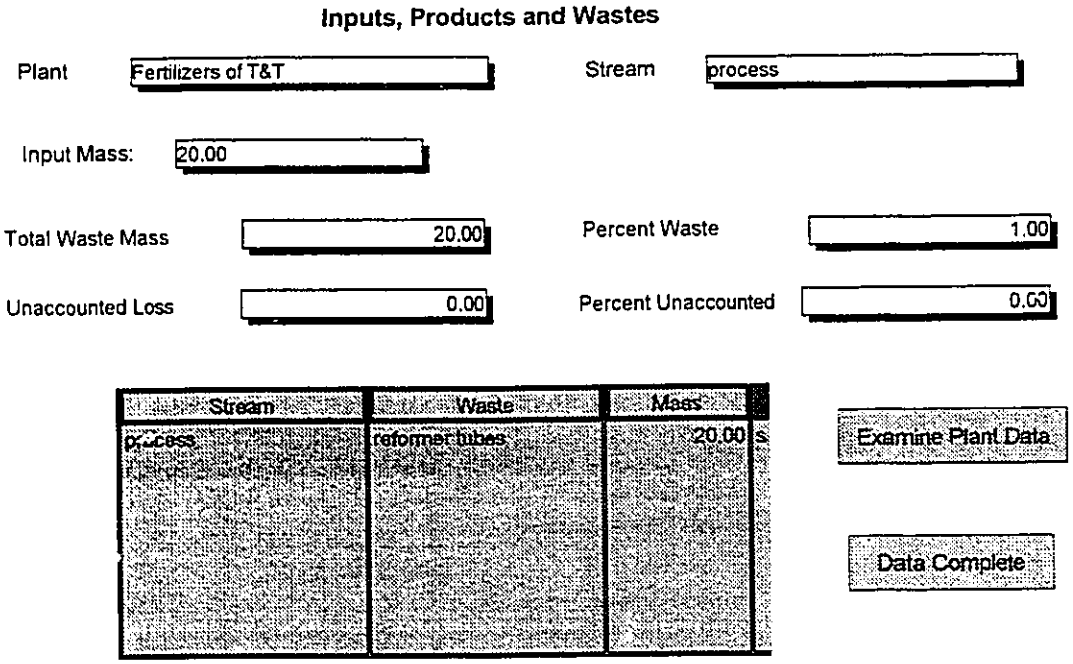
$$\Sigma M_i = \Sigma M_p + \Sigma M_w \qquad (3.1)$$

where M_i = input mass

M_p = product mass

M_w = waste mass.

The user is then provided with a breakdown of the number and quantity of inputs and outputs that have been entered (Figure 3.9). It must be recognized that this is only a simple mass balance and, when using data estimated for a year, there can be major discrepancies in the balance. However, these discrepancies serve to inform the user that more accurate information should be obtained or that there are inputs or wastes that are not being included, which is particularly important in the case of fugitive emissions.



Inputs, Products and Wastes

Plant: Fertilizers of T&T

Stream: process

Input Mass: 20.00

Total Waste Mass: 20.00

Percent Waste: 1.00

Unaccounted Loss: 0.00

Percent Unaccounted: 0.00

Stream	Waste	Mass
process	reformer tubes	20.00

Figure 3.9 Form showing mass balance of the inputs, process products and wastes.

Once all the information has been entered for one process another process is selected and the user returns to Step 2; if all processes are complete for a plant, another set of plant information is entered (Step 1). When data for all the plants have been entered, the user is returned to the main menu or to the second level where the inference engine is located.

3.3.1 Internal Verification of Data

The system itself applies certain constraints to verify the data being input into the system. As mentioned for inputs and products, the average of components and parameters must lie between the maximum and the minimum. The mass balance provides some verification of the component data by indicating that the inputs, products and wastes do not balance. The user cannot input numbers for parameters that are outside the range allowed for the specific parameter (e.g. for pH the number must lie between 0 and 14). The user can review the data at any time and revise it.

3.3.2 Determining possible treatments

Level 2

Step 1

The user is first requested to select the plants to be evaluated.

Step 2

Standards are then selected by the user.

Step 3

The system then begins to determine potentials for reuse, recycling and disposal and the treatments required. A flow chart of this system can be found in Appendix A4, together with the inference engine program.

Step 3a

First the major components of a waste are compared to those of a simple input; if one component matches then the potential for recycling that waste as the input exists. This is discussed in detail in section 3.4.2 and 3.4.3.

Step 3b

The parameters for the waste are compared with those of the input and, if they match, then the waste can be directly reused as the input and the system moves to Step 3f. If not, then treatments are required to match the waste with the input parameters for recycling (Step 3c).

Step 3c

A treatment which changes the unmatched parameters for a material is selected. The input limits of this treatment are compared to the parameters of the waste; if they fit, the treatment is accepted and the parameters of the output from the treatment (treatment 1) are calculated.

Step 3d

The parameters of the treatment output are then compared to the input parameters to determine if the parameters match.

Step 3e

If not, another treatment (treatment 2) which changes the unmatched parameters of treatment 1 output and will accept treatment 1 output is determined and the system cycles back to Step 3d (treatment 2 outputs are compared with the input). The cycle continues until either a match to the input is found or 10 treatments have been reached.

Step 3f

The resulting successful chain of waste→Treatment 1→Treatment 2→Treatment 3→...→output is termed a treatment train. Another starting treatment is then selected to determine another treatment train. Once all treatment trains have been assessed, another simple input is selected; when all inputs have been compared, the standards for disposal are then assessed in the same manner.

3.4 The Inference Engine

Many KBDSS use IF...THEN rules to control the flow through the decision-making process. These rules are effective when dealing with a small knowledge base or a system where the parameters considered at each branch are different. Such a system could potentially have been used for this program. However, the developed system was designed to take specific information about a set number of parameters and use that information to define which treatments could be appropriate. The parameters are similar for a specific state of a material. Consequently, rather than a series of IF...THEN rules, tables were used to store the knowledge base and the inference engine was designed to compare the fields in the knowledge base with those in the database. The inference engine is depicted in a flow chart in Figure 3.10.

In generating treatment trains, it is possible that an optimization method could be used. Ellis, McBean and Farquhar (1985) used a stochastic optimization method for selection of their treatments. However, they also noted that the results depended upon the order in which treatments were listed. As a result, if a large number of treatments and wastes were being considered, the results would not indicate the most efficient treatment trains possible unless the treatments were sorted in a preferential order. This may be possible when costs are included or if a relative environmental impact can be incorporated. The least preferred treatments (e.g. the most expensive treatments or those with the highest impact) would be placed at the end of the list and be selected only after other options have been evaluated.

Dynamic programming cannot be used to provide a solution since the selection of final options incorporates the potential for co-treatment of wastes and this potential can only be determined if all possible treatments are known. Integer programming may potentially be used, but it was considered to be beyond the scope of this research to incorporate an integer programming model into the system. Moreover, the time, program cost and hardware requirements necessary for running an optimization model for this type of problem may push the overall system beyond the financial capability of plants or industrial estates in developing countries. Thus it was decided to use exhaustive searching to generate the

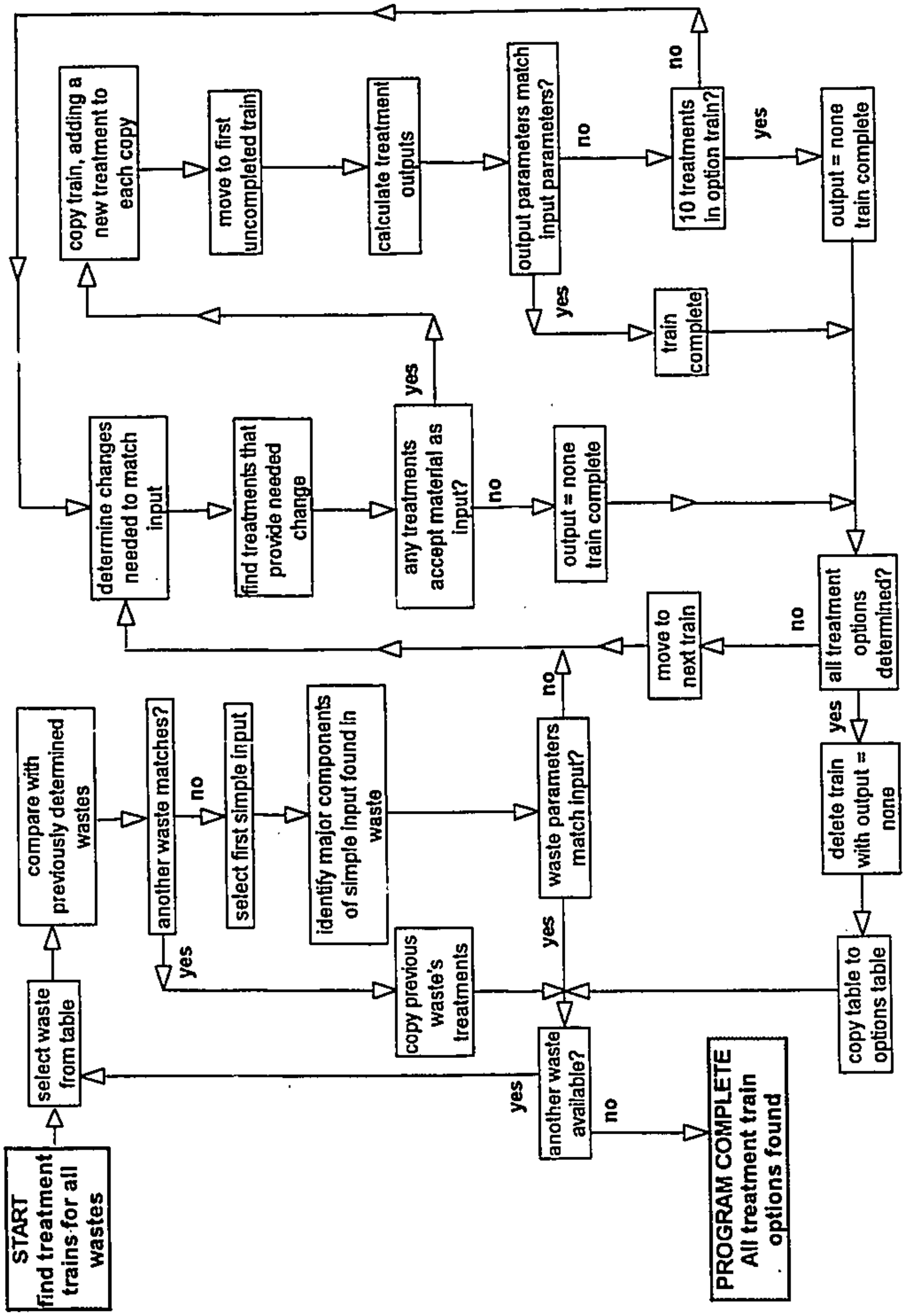


Figure 3.10 A flow chart of the inference engine.

treatment options, use multiple sort mechanisms for defining final options and to propose a model for the calculation of costs for the final options.

3.4.1 Initial Comparisons

The program first compares the major components and characteristics of the selected waste (Wn) with previously assessed wastes. If they are the same, the treatment options for the assessed waste (Wa) are copied into a temporary option table. The new waste name and its plant and mass are placed in the correct field. Masses are then calculated for each treatment using a mass ratio from the assessed waste:

$$M_{Wn2} = (M_{Wa2}/M_{Wa1}) * M_{Wn1} \qquad (3.2)$$

where M_{Wn2} = Mass of new waste for treatment 2

M_{Wa2} = Mass of assessed waste for treatment 2

M_{Wa1} = Mass of assessed waste for treatment 1

M_{Wn1} = Mass of new waste for treatment 1.

A final output mass can thus be determined. This table is then added to the final option table.

3.4.2 Evaluation of Outputs for Reuse or Recycling

The selected waste is compared with each 'simple' input. If the main components of the input are found in the waste, then the parameters are compared; otherwise another input is considered. If the waste parameters lie within the maximum and minimum of the input parameters, then the waste is considered to be directly reuseable as the input. If not, then some treatment is necessary.

The selected waste is compared with each 'simple' input. If the main components of the input are found in the waste, then the parameters are compared; otherwise another input is compared. If the waste parameters lie within the maximum and minimum of the input parameters, then the waste is considered to be directly reuseable as the input. If not, then some treatment is necessary.

The needed treatments are defined by those parameters which did not match the input parameters. Therefore, treatments which change those parameters and treat materials in the state of the waste (i.e. gas, liquid, sludge or solid) are then selected and stored in a temporary table (Figure 3.11).

Waste	**Treatment 1**	**Treatment 2**	**Treatment 3**	**Output** Match to Input 1
waste	*treat(1)*			
	treat(2)			
	treat(3)			
	treat(4)			
	treat(5)			

Figure 3.11 First cycle of a treatment system with a maximum of 3 treatments per treatment train.

Once all the treatments are placed in the temporary table, the system moves to the first, uncompleted train. The parameters of the output from that treatment are then calculated and compared with the input parameters. If the parameters match then no further treatments are required. Otherwise, treatments which change non-matching parameters are selected. If their input limits accept the output from the first treatment then they are placed as treatment 2 in the temporary option table (Figure 3.12). Again these are compared and the cycle is continued until:

a) no treatments are found to fit the parameters to be changed;

b) 10 treatments have been assessed or;

c) the treatment output matches the input parameters (Figure 3.13).

Once a treatment train has been completed, the system moves down a record in the temporary table and follows this train to the end in the same manner (Figure 3.14). The cycles continue until all treatment trains have been found. An exhaustive search for treatment trains to treat the waste to the input has been completed and another input can be considered.

To determine which output from a treatment is selected for recycling, the calculated outputs are compared with the selected input. The output with parameters which match the input parameters most closely is then selected. The mass of the second output, which is then termed a 'secondary waste', is then added to other secondary waste masses for that train. The completed record would include the total mass of secondary wastes produced by all treatments in that train.

Waste	**Treatment 1**	**Treatment 2**	**Treatment 3**	**Output** Match to Input 1
waste	*treat(1)*	*treat(2)*		
		treat(3)		
		treat(4)		
		treat(5)		
	treat(2)			
	treat(3)			
	treat(4)			
	treat(5)			

Figure 3.12 Second cycle - no treatment trains have been completed yet.

Waste	**Treatment 1**	**Treatment 2**	**Treatment 3**	**Output** Match to Input 1
waste	*treat(1)*	*treat(2)*	*treat(3)*	*yes*
			treat(4)	*no*
			treat(5)	*yes*
		treat(3)		
		treat(4)		
		treat(5)		
	treat(2)			
	treat(3)			
	treat(4)			
	treat(5)			

Figure 3.13 Third cycle in a train which allows a maximum of 3 treatments - the bold outputs indicate the completed treatment trains. Those which match the input are listed as 'yes'.

As each treatment output is calculated, the output mass is also calculated and stored separately in the table, as is the state of the output. When costs are included they would also be calculated and stored at this point.

Once all inputs have been evaluated, selected standards are then evaluated. These standards dictate the parameter limits that must be met to release gaseous emissions, liquid effluents, to dispose of material in a landfill or to apply material to land for land treatment. They can therefore be treated as were the inputs in this system. At present the system does not include a mechanism to list all the parameters which are restricted by each standard but that could readily be incorporated within future developments.

Waste	Treatment 1	Treatment 2	Treatment 3	Output Match to Input 1
waste	*treat(1)*	*treat(2)*	*treat(3)*	*yes*
			treat(4)	*no*
			treat(5)	*yes*
		treat(3)		*yes*
		treat(4)	*treat(2)*	*yes*
			treat(3)	*yes*
			treat(5)	*no*
		treat(5)	*treat(2)*	*yes*
			treat(3)	*yes*
			treat(4)	*no*
	treat(2)			
	treat(3)			
	treat(4)			
	treat(5)			

Figure 3.14 Ninth cycle of the treatment system. Those which match the input are listed as 'yes'.

Upon evaluation of all standards, the total treatment train options for the specific waste have been determined. If none have been found, the waste is placed in a no-treat table. The next waste is then assessed. Once all wastes have been evaluated, the final treatment train table should contain all possible treatment trains for the wastes. These then have to be sorted according to the criteria selected by the user.

3.4.3 Selection of Final Options

The user is given a choice of criteria for sorting the treatment trains. Cost will eventually be included but at present the criteria are:

a) a maximum train length equal to the shortest, second shortest or third shortest train for each waste;

b) a maximum mass of secondary wastes equal to the lowest, second lowest or third lowest masses of secondary wastes per treatment train for each waste;

c) the maximum number of matching treatments for all wastes.

The user can select more than one criterion, although the third criterion can only be selected as the final one as it produces the final lists of treatment trains. The first option determines the shortest, second shortest or third shortest (as selected by the user) treatment train for each waste and selects all trains that length or shorter for that waste (Figure 3.15). The second option sorts the trains for each waste according to the total mass of secondary waste and selects all trains with secondary wastes equal to or lower than the lowest, second lowest or third lowest (as determined by the user) secondary waste (Figure 3.16).

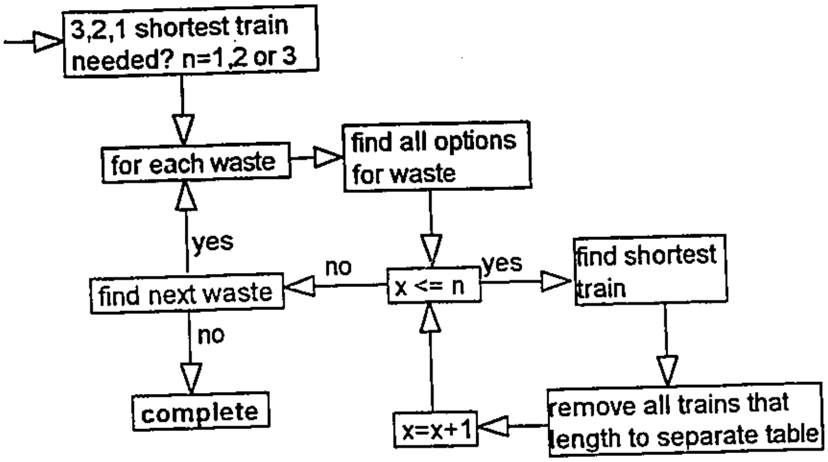


Figure 3.15 Flow chart for selection of trains equal to or shorter than the shortest, second shortest or third shortest treatment trains.

For matching treatments, trains which reuse wastes were automatically selected. Treatments were matched by first examining all trains which recycle wastes. Those which had the greatest number of matching last treatments and final outputs were then selected; these were then selected for the maximum of matching second last treatments, then the matching third last treatments etc. until the trains had been matched and sorted as in Figure 3.17. Once the treatments have been sorted, all of the trains for the selected wastes are deleted from the main list and the remaining trains are then matched (Figure 3.18).

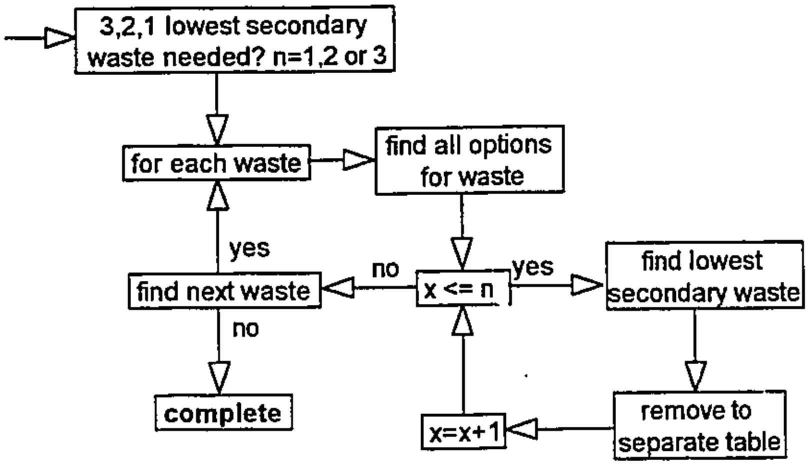


Figure 3.16 Flow chart for selection of treatment trains producing secondary waste masses equal to or lower than the lowest, second lowest or third lowest secondary wastes.

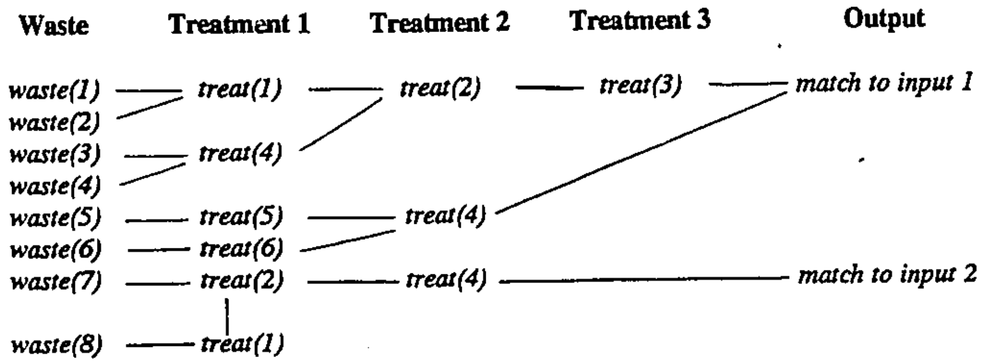


Figure 3.17. Matching treatments for a 3 treatment train.

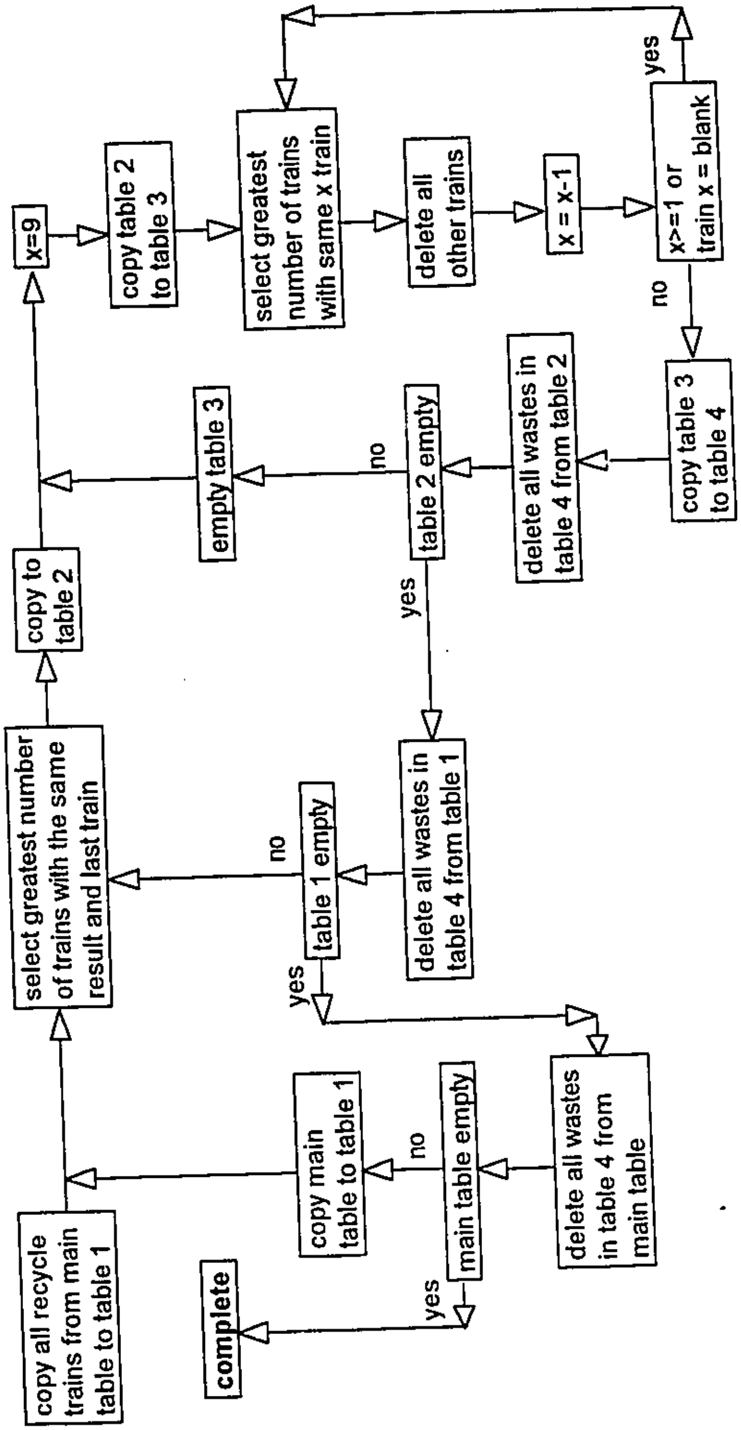
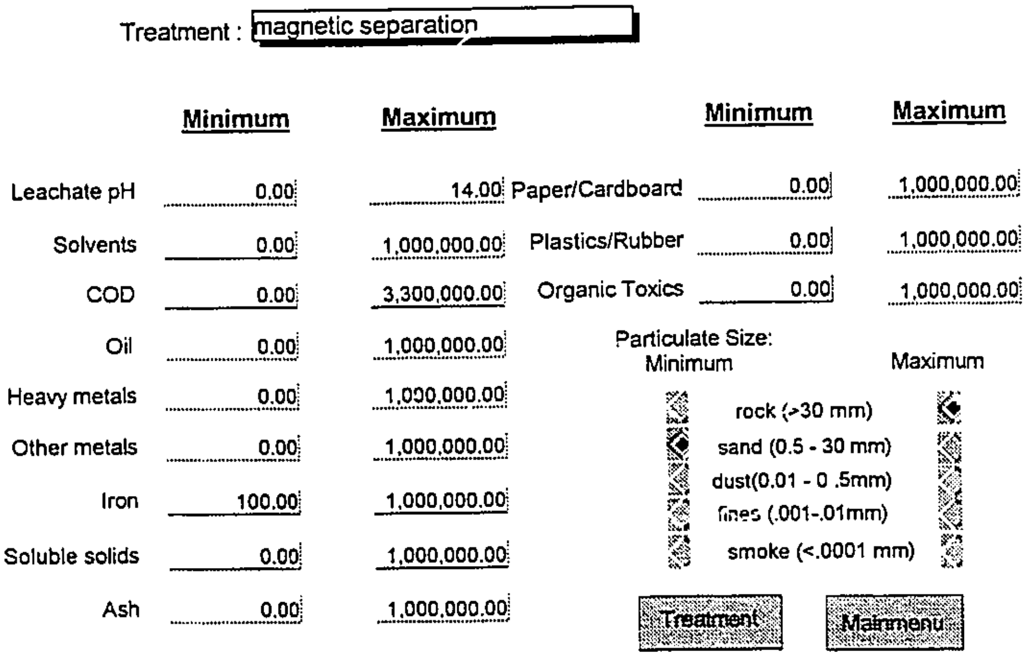


Figure 3.18 Flow chart for matching treatment trains

3.5 Treatments and Standards

The treatment and standard database contains information from the literature, experts, manufacturers and other sources and is the main database used to determine the treatment options available for treating a waste. Level 3 allows a user to change or input new data into this database. If a specific treatment exists on site, this flexibility allows the user to input the known input limits and output formulae for that treatment, thus ensuring a more accurate determination of acceptance of the material and of the parameters of the output material.

The data are held in two main tables. The first table contains the minimum and maximum input values for each treatment. The fields in this table include all the parameters for all states of a material. The user first defines the input state that a treatment will treat, then inputs data through forms specific to that input state (Figure 3.19). A field can be left blank - the program will fill it with 0 (a minimum) or 1000000 (a maximum) (except for pH, maximum = 14 and COD, maximum = 3000000). The data are input in ppm (except for pH) and values less than 0 or greater than 1000000 are not allowed, except for COD where the limit is 3000000 ppm.



Treatment : magnetic separation

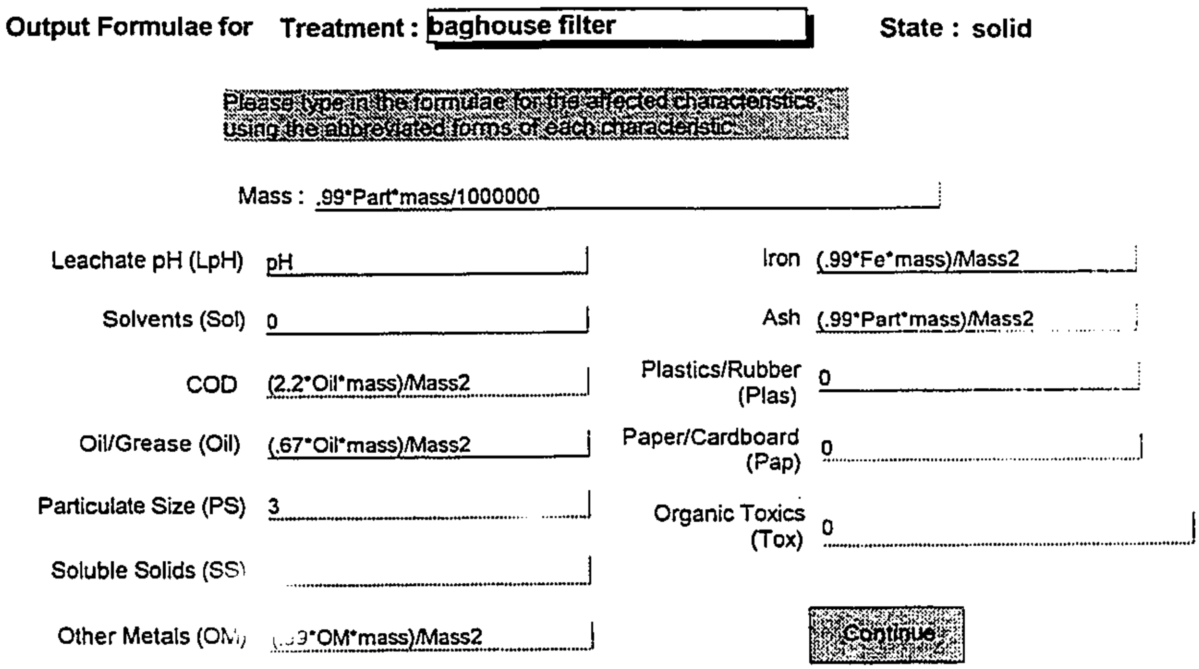
	Minimum	Maximum		Minimum	Maximum
Leachate pH	0.00	14.00	Paper/Cardboard	0.00	1,000,000.00
Solvents	0.00	1,000,000.00	Plastics/Rubber	0.00	1,000,000.00
COD	0.00	3,300,000.00	Organic Toxics	0.00	1,000,000.00
Oil	0.00	1,000,000.00			
Heavy metals	0.00	1,000,000.00			
Other metals	0.00	1,000,000.00			
Iron	100.00	1,000,000.00			
Soluble solids	0.00	1,000,000.00			
Ash	0.00	1,000,000.00			

Particulate Size:

Minimum		Maximum
○	rock (>30 mm)	●
●	sand (0.5 - 30 mm)	○
○	dust(0.01 - 0 .5mm)	○
○	fines (.001-.01mm)	○
○	smoke (<.0001 mm)	○

Figure 3.19 Form for obtaining input parameters for a treatment.

The second table defines the outputs for a treatment and contains formulae for all parameters. The user is first asked how many outputs a treatment has and what state those outputs are; the appropriate form is then provided for the user to complete (Figure 3.20). The user inputs the formulae as a string using defined codes for parameters - e.g. 'particulates' is coded as Part, 'volatiles' is coded as Vol. The user must recognize certain concerns - mass must include a conversion from ppm while the ppm of a substance in a material will change as the mass changes so that all treatment parameters will require some formulae. The output can be either a formula or a number. A subroutine is used to calculate the results of the formulae string.


Output Formulae for Treatment : baghouse filter

State : solid

Please type in the formulae for the affected characteristics, using the abbreviated forms of each characteristic.

Mass : .99*Part*mass/1000000

Leachate pH (LpH) pH

Solvents (Sol) 0

COD (2.2*Oil*mass)/Mass2

Oil/Grease (Oil) (.67*Oil*mass)/Mass2

Particulate Size (PS) 3

Soluble Solids (SS)

Other Metals (OM) (.99*OM*mass)/Mass2

Iron (.99*Fe*mass)/Mass2

Ash (.99*Part*mass)/Mass2

Plastics/Rubber (Plas) 0

Paper/Cardboard (Pap) 0

Organic Toxics (Tox) 0

Figure 3.20 Form for obtaining output formulae for treatments.

3.6 External Validation

Both the system and the data require some form of external validation. The system was first examined on a stepwise basis, examining the data and results at each step to ensure that it was functioning correctly. Data from the case study (Chapter 5) were then used to further verify that the program functioned accurately and represented the case study situation in a reasonable manner.

Selection of the parameters plays a critical role in the functioning of the system. Three errors can occur with regard to selection of the parameters:

a) a treatment is accepted although it will not actually treat a waste;

b) a treatment is not accepted although it will actually treat a waste;

c) the output from a treatment is not properly calculated since a parameter datum is not available or the treatment is less or more efficient than expected.

The more parameters available in the system, the less the chance that the system will cause these three errors. In discussion with Woods (1994b) the other major parameter that could be included for gases and liquids is temperature, necessary for some treatments (baghouse filtration) and for energy recovery. Since few treatments would require this parameter and energy recovery has not been included in this system, the temperature parameter was not included.

The trade-off with selection of more parameters is the cost requirement for the analysis and the time required for data input by the user. It must also be recognized that most materials must be tested to determine how effectively the treatment will treat them. Moreover, this program is designed to provide treatment suggestions, not definitive solutions, to users. Consequently, the parameters selected were considered to be an acceptable trade-off between data input requirements and potential errors in the suggested solution sets.

3.7 System Applicability

The system was initially designed for plants located on industrial estates in developing countries where there would be a requirement for knowledgeable advice, a limit to computer technology and availability, limits to disposal options and few environmental regulations. However, it is potentially usable by plants in developed countries and can incorporate waste from municipalities, allowing the potential for even greater cost savings.

The parameters should be able to incorporate most types of waste materials. However, it may be necessary to change the parameters to accommodate different wastes. Further testing would be required to determine how the wastes from different industries are handled by the developed system.

3.8 Limitations of the System

The system has a number of limitations and further development of the system could correct some of these concerns. Other issues may relate to a deliberate limit placed on the system to simplify the problem.

3.8.1 Number of Treatments

A limit of ten treatments was allowed in the treatment trains which may mean that some materials may not be treated within that limit. However, it was considered that most treatment trains would require fewer than ten treatments and this level was a reasonable upper boundary. With more than 10 treatments, the number of permutations would be extremely high and require additional computer time to determine acceptable trains.

3.8.2 Chemical Changes

When selecting the parameters, it was assumed that any change in major components would be reflected in the parameters and vice versa. Therefore, if the material parameters met those of the input and the main components of the waste match the input, then the final treated output should match the desired input. The system does not consider the complex chemical reactions that may occur, possibly yielding a result that does not match the desired input or producing some hazardous by-products. To include such a database within this system would require significantly more research. Moreover, the program is a compromise between a very specific, large and complex expert system and a general system which allows the user to make decisions. In the former case, each different type of treatment could be included. For example, instead of precipitation being classed as a treatment, it could be separated into the different types of precipitation: ferrous, alumina, etc. The same could be done to determine possible membrane treatments. Each treatment could easily require an expert system to determine if the material is acceptable for that treatment and if the treatment will perform the function described by the system. Consequently, it must be recognized that with this system, although the parameters may match, the components of the resulting material may not match the components of the input.

In addition, the efficiency of the treatments may not be as high or as low as the output formulae dictates. Very few materials will act exactly as those studied in research for a variety of reasons:

a) they are probably different than the studied material;
b) it is not uncommon for waste parameters to vary widely;
c) the operator may not follow the same procedure in handling and treating the material;
c) environmental conditions and equipment materials may differ;
e) larger vessels may create different treatment conditions; and
f) supplementary materials may not be of the same quality (e.g. distilled water vs untreated water).

It is important that the user recognize that the suggested treatment trains must be tested to determine the efficiency of the treatments and the quality of the results. Finetuning will be required to ensure that a standard product can be produced for reuse or recycling. Industries must also recognize that materials that are to be reused or recycled have to meet quality standards. Improving the quality of these former waste materials may reduce the need for treatment.

Another factor that must be considered is that the parameters included in this system are only a few of the parameters that characterize wastes. Although all of the parameters included in the system may match, other parameters, important to a specific treatment or for recycling to a particular input, may not lie within the treatment or input specification and the waste may require further treatment.

3.8.3 Costs

As previously mentioned, although there are mechanisms included in this system for incorporating costs, insufficient data are currently available to readily incorporate costs. When costs are included, those that must be considered include:

a) capital;

b) operating/maintenance;

c) transportation of final product.

3.8.4 Offsite By-product Resale

At present the system does not allow for entry of possible products for sale to industries outside the specified industries. However, incorporating such entries would be relatively simple and could be incorporated at present as inputs to a new 'plant'.

3.9 Summary

A model was developed to determine the potentials for reuse and recycling of waste materials and select the treatments needed to recycle waste or treat them for disposal. The knowledge based decision support system was then developed, using this model. This chapter described the prototype model, the developed knowledge-based decision support system, the input and storage of data within the system and the inference engine developed for the system to determine the treatment options for the wastes. Options for sorting and selecting treatment options or treatment trains were also described as were the limitations and future developments needed for the system.

Chapter four outlines the treatment processes included in the database of the prototype KBDSS and their input limitations and output characteristics.

4.0 Knowledge Base - Treatment Inputs and Outputs

The knowledge base for the developed KBDSS includes input criteria and output formulae for a number of treatments. Selection of these treatments depended in part on available information, the treatments required for basic treatment of all material states and treatments required for treatment of the case study wastes. The input criteria and output formulae for each treatment were determined, where possible, from published literature and can be found in Appendix 1. This chapter provides a short overview of each treatment and of the regulations that exist in Ontario and are incorporated into the program. A copy of the regulations is included in Appendix 2.

4.1 Treatments

The applicability of a treatment for a specific waste often depends upon the specific parameters of the waste and on the results of bench testing. For many treatments, the factors governing the action of the treatment on the material are specific to the treatment, and may include physical, chemical and biological characteristics of the material. The chemical characteristics of the material will affect the physical and biological properties, thus influencing how the treatment affects the material. In addition, many process byproducts cannot be completely characterized as they may contain unknown compounds, produced by reactions with heat, cold, pressure and other materials (Boyle, 1992). Consequently, although parameters such as those in Table 3.1 may be used to define suitable waste materials for a particular treatment, bench testing is still often necessary to determine the effectiveness of the treatment.

Byproducts from a treatment are also not often defined, primarily due to past focusing upon products and end-of-pipe technologies. Consequently, the parameters of all outputs of a treatment are often poorly defined in the literature. Moreover, the effect of one treatment is often focused upon a specific parameter or group of parameters; the effect on other parameters may not have been considered.

Bench testing is again necessary to clearly define the results from treating a material with a specific treatment. However, sufficient data were available to provide estimates of the output parameters for the treatments included in this research. The selected treatments treat all of the parameters chosen for this system and all of the material states. Treatments selected for this research are listed in Table 4.1. The treatments will be discussed by input state.

Table 4.1 Treatments included in this research, indicating the type of inputs and outputs.

Treatment	Input type	Output 1	Output 2	Output 3
fixed hearth incineration	solid	solid	gas	
magnetic separation	solid	solid	solid	
anaerobic digestion	sludge	sludge	gas	
belt filter	sludge	solid	liquid	
evaporation	sludge	solid	gas	
multiple hearth incineration	sludge	solid	gas	
activated sludge	liquid	liquid		
API oil separation	liquid	liquid	liquid	sludge
carbon adsorption	liquid	liquid		
disk filter	liquid	liquid	solid	
dissolved air flotation	liquid	liquid	sludge	
ion exchange	liquid	liquid	liquid	
liquid injection incineration	liquid	gas		
neutralization	liquid	liquid		
reverse osmosis	liquid	liquid	liquid	
precipitation	liquid	sludge	liquid	
sand filtration	liquid	solid	liquid	
screening	liquid	solid	liquid	
settling	liquid	sludge	liquid	
solvent recycling	liquid	solid	liquid	
ultrafiltration	liquid	liquid	liquid	
baghouse filter	gas	solid	gas	
electrostatic precipitation	gas	solid	gas	
packed tower	gas	liquid	gas	
Venturi scrubber	gas	liquid	gas	

4.2 Treatments for Solids

A material is considered to be a solid if it contains less than 50% liquid (Woods, 1994a). Solid waste is a term often used to refer to municipal solid waste, although a significant proportion of the overall waste stream may be waste from industry (Glysson, 1990). Solid industrial wastes can include a variety of 'simple' materials such as metals, paper, cardboard, plastics, agricultural wastes and chemicals, as well as manufactured items combining these materials. Simple materials may include byproducts of processes, contaminated materials, out-of-date chemicals and spent catalysts. Manufactured materials may include damaged or worn equipment, items replaced as part of maintenance, empty containers and items which no longer perform to the required specifications. Solid wastes are often discarded in landfills.

4.2.1 Fixed Hearth Incineration

Incineration of solid wastes is only feasible for wastes which have a significant percent of combustible material or for hazardous materials which require a high temperature to destroy hazardous organic compounds such as PCBs. If the energy value of the material is sufficiently high, energy may be recovered from its use as a fuel. Efficiency of incineration is dependent upon the time, temperature and turbulence in the furnace and even slagging rotary kilns may produce ash with high hydrocarbon content (Stewart, 1990). Glysson (1990) estimates that incineration of hydrocarbons is usually >95% efficient although ash which contains a significant portion of hydrocarbons may be reburned to improve efficiency (Librizzi and Lowery, 1990). Incineration produces a solid ash which contains heavy metals and a gas which may include particulates. Metals may be volatilized at high temperature and, even at lower temperatures, heavy metals may attach to particulates and be emitted. The mass and composition of output gases has been only approximately estimated.

Fixed hearth incinerators are used for incineration of bulky or hazardous solid wastes (Librizzi and Lowery, 1990). They produce low volumes of NOx and particulates since they typically use a reduced atmosphere for combustion and an afterburner (Brunner, 1991). Although substances containing a substantial quantity of organic compounds are the most economical feedstock for incineration, feedstocks containing low levels of organic compounds are also incinerated to destroy toxic organics such as PCBs. Most fixed hearth incinerators can achieve greater than 99.99% reductions in organics and toxic organic compounds under proper working conditions (Oppelt, 1991). Metals, however, are not destroyed, and can pose a significant problem, in both fly and bottom ash. Mercury, in particular, poses a concern since it is volatilized readily and is not captured by pollution control devices. However, the use of mercury in industry is being reduced due to concerns of worker health and safety and it will probably not be common in industrial chemicals or wastes in the future. Residues of specific metals in bottom ash ranges from 0% (mercury) to 58% (iron), with a mean of 36.5% (Brunner, 1993). The remainder is found in fly ash, which must be captured at the stack.

Plastics and rubber contain approximately 3 and 5% chlorine respectively which can pose a problem with acid gases and formation of dioxins and furans (Tillman, Rossi and Vick, 1989). Other industrial wastes which contain high levels of chlorine will also produce acid gas concerns, requiring gas scrubbing.

4.2.2 Magnetic Separation

Differences in magnetic properties are exploited by this treatment, frequently used to separate loose iron-containing material from non-ferrous items. There are a number of designs for magnetic separators depending upon the particulate size of the feed and the percent of ferrous material in the feed stream (Woods, 1994a). The outputs are ferrous and non-ferrous solids with over 95% recovery efficiency (Glysson, 1990). The parameters that are affected by removal of the iron would be both iron and ash content.

4.3 Treatments for Sludges

Although actually two mixed phases, sludges have been classed separately for the purposes of this system as parameters for both the solid and liquid materials are important and many treatments which will treat liquids will not treat sludges. Sludges contain from 50 to 90% liquid (Woods, 1994a) and can be the output from a treatment, from a process or from maintenance procedures. Treatments can be used to separate the solids from the liquid for either further treatment or for recycling.

4.3.1 Anaerobic Digestion

Anaerobic digestion involves the digestion of organic sludge material by bacteria under anaerobic conditions, producing methane gas, carbon dioxide and reducing digestible organics by 72 - 91% (Grady and Lim, 1980). Since this treatment will treat high levels of BOD it has been used for treatment of industrial, particularly food industry, wastes (Librizzi and Lowery, 1990). The process is subject to upsets. Sulphur must be kept below 200 ppm and soluble metals can inhibit anaerobic activity at levels ranging from 10^{-16} - 10 ppm (Grady and Lim, 1980), although other sources indicate that levels up to 100 ppm are acceptable (Stronach, Rudd and Lester, 1986). Maintaining a pH above 6.5 reduces metal solubility. Since oil droplets will reduce the effectiveness of degradation, a limit for oil has been estimated at 100 ppm. Particle size was estimated to be less than 5mm in order to improve digestion efficiency. Solvent levels of greater than 500 ppm will inhibit degradation (Stronach, Rudd and Lester, 1986). Dissolved solids such as sodium (>4500 ppm), potassium (>4000 ppm), magnesium (>1200 ppm) or calcium (>2800 ppm) are also toxic (Librizzi and Lowery, 1990), so an estimated maximum level of 3000 ppm of dissolved solids has been set. Solids should be less than 50% to promote biodegradation (Librizzi and Lowery, 1990). The output gas is generally 65-79% methane, 25-30% carbon dioxide and trace amounts of nitrogen and hydrogen (Metcalf and Eddy, 1979).

4.3.2 Belt Filter

A belt filter removes solids from a liquid or sludge, producing a filter cake and a liquid. The input is dependent solely upon particle size and feed concentration and the outputs are a liquid and a solid. The efficiency of a belt filter ranges from 85 - 95% (Glysson, 1990) and the solid output has a liquid content of 20-40% with oils being more effectively retained by the solids (Woods, 1994a). An assumption is made that the degradable organics are found in both the suspended solids and the dissolved solids, although this may not be correct in reality. The actual composition of the solids and the liquids would be required to provide a more accurate definition of the treatment output. The heavy metal outputs are dependent upon pH so that two inputs are considered. It must also be recognized that the presence of sulphides or hydroxides will also have an effect upon metal solubility. An assumption is made that, to reduce outputs and costs, liquid outputs will be used to wash the belts, then added to the input for re-treatment. Since this treatment is also effective for liquids with a solids content of less than 5%, it was also included as a liquid treatment.

4.3.4 Evaporation

Evaporation or drying is used to reduce liquid content in a sludge or liquid material, producing either a sludge or a solid and gas. When the liquid phase is water, evaporation often takes place in open evaporation ponds; when the liquid phase contains solvents, evaporation should take place in closed containers where the vapors can be contained, liquefied and recycled to reduce employee exposure and to comply with fire safety and air emission guidelines. Evaporation is not highly effective when the liquids are oils or other heavy hydrocarbons.

Evaporation is effective for feed materials with more than 20% solids, particle size >0.01mm (Woods, 1994a) and a water or solvent content less than 80% (Corbitt, 1990). The resulting product can be dried to 30% water (Corbitt, 1990).

4.3.5 Multiple Hearth Incineration

Sludge incineration is feasible if a significant proportion of the sludge is combustible. This treatment reduces both the liquid content and the volume of the waste, producing solid ash and gases. Multiple hearth furnaces are the most common incinerators used for combustion of sludges and these will handle sludges that are 50 - 85% liquid (Brunner, 1991). These incinerators produce a higher level of NOx and particulates than do fixed hearth incinerators, approximately 10-20% airborne particulates. Schroeder, Cresculo, Campbell and Cohen (1981) found that multiple hearth incinerators can destroy over 98% carbons. Oils and greases should be introduced at a lower hearth to ensure their complete combustion (Brunner, 1991). Wastes with a level of chlorine higher than 30% should not be incinerated, as acid emissions would be too difficult to control (Brunner, 1991).

4.4 Treatments for Liquids

Liquid materials contain over 90% liquid (Woods, 1994a) and are a common waste material from industrial facilities. Liquids can include water, aqueous solutions, volatile non-aqueous solutions and oils. Unless standards exist, aqueous liquids are often directly released into rivers or the ocean; solvents are allowed to evaporate and oils are released into rivers or recovered for re-refining if the facilities are available and the cost is minimal.

Treatments used to treat liquids may involve separating particulates from the liquid, removing dissolved material from solution, separating oils, solvent and aqueous solutions, degrading organic material or chemically or biologically changing a compound.

4.4.1 Activated sludge

Conventional activated sludge is commonly used to treat municipal wastewater to remove BOD/COD by 85-95% (Metcalf and Eddy, 1979). It is also used to treat a range of organic industrial wastewaters, such as those from food processing industries, although primarily low-strength wastes. In this treatment, microorganisms are introduced into the waste stream and allowed to consume the soluble organic material in the waste in an aeration tank. The resulting effluent has a solid content which is then removed by settling, yielding an effluent and a liquid with a solids content of approximately 1%. A portion of the liquid with solids, at the rate of 25-50% of the influent flowrate, is returned to the aeration tank. Heavy metals can be inhibitory and must be kept below 100 ppm (Metcalf and Eddy, 1979). In order to improve treatment efficiency and reduce solids production, influent solids should be kept below 1500 ppm and oil below 20 ppm (Metcalf and Eddy, 1979). Both ammonia and sulphur are inhibitory at higher levels and have to be kept to 400 and 200 ppm respectively (Metcalf and Eddy, 1979), while solvents and organic toxics should be less than 200 ppm (Dyer, Vernick and Feiler, 1981). pH must be kept between 6 and 8 for optimum performance.

According to Metcalf and Eddy (1979) activated sludge has no effect on ammonia but removes about 10% nitrate. The effluent mass is based on an average 35% recycle while solid mass is based on a retention time of 10 days. Typical values from Metcalf and Eddy (1979) are used to calculate sludge production although it must be recognized that, with industrial wastes, these values may not apply. Approximately 2.5% of the cellular mass will be phosphorus, removed from the wastewater. Activated sludge treatment will degrade an average of 60% of solvents or organic toxic compounds (Corbitt, 1990).

4.4.2 API Separation

This treatment involves the decanting of a liquid, usually a hydrocarbon, from an immiscible liquid, usually an aqueous solution. The process is frequently used for recovery of oil from waste waters, producing a wastewater with an oil content of 50 ppm or less (Jones, 1971). Solids (80%) and COD (45%) are removed; solvents are reduced by 55% (Jones, 1971), some through stripping. Three outputs result from this treatment - an oily fraction, an aqueous effluent and a sludge. Acid is frequently added to break emulsions and improve oil removal (Librizzi and Lowery, 1990).

The sludge has a solids content of 10% since the separator acts as a settler. The sludge will also contain any heavy oils. Dissolved solids are not removed by this treatment; nor are heavy metals, especially if acids are added to break emulsions.

4.4.3 Carbon Adsorption

Also called activated carbon adsorption, this involves the adsorption of organics and other molecules from aqueous liquids onto activated charcoal. Granular charcoal can be regenerated through heating and the gases either condensed and recycled or incinerated. Oil and grease must be below 10 ppm and solids <50 ppm to prevent clogging of the carbon pores (Freeman, 1989), while dissolved solids should be less than 500 ppm and total organic carbon should be below 10,000 ppm (Lyman, 1978). Both BOD and TOC are 80% removed by carbon adsorption and, in a downflow system, suspended solids are removed by 90% (Lyman, 1978). Toxics such as pesticides can also be removed by 97% (Snoeyink, 1990). Metals are removed by 90 - 99% depending upon the metal, pH and carbon (Metzer and Hughes, 1984; Huang, 1978). Other dissolved solids may only be poorly adsorbed (Huang, 1978).

4.4.4 Disk Filter

This precoat, continuous filter is effective for liquid wastes with between 50 and 5000 ppm particles and removes 95% of the particles to a diameter of .002 mm (Perry and Green, 1984). Oil should be below 50 ppm to prevent clogging. The filter cake which forms on the disks is readily removed and contains about 30% liquid. Acidic and basic solutions must be considered separately, since the concentration of heavy metals in solution depends upon pH (Palmer, et al., 1988).

4.4.5 Dissolved Air Flotation

This treatment is used to remove small drops of oil and fine particles, such as metals, from liquids. The resulting wastewater should have an oil content of 1-20 ppm and about 95-99% solids are removed (Corbitt, 1990). Two outputs are produced - a liquid with 2-10% solids content and a liquid effluent. Some solvents are also lost through stripping and adhering to the particles.

Addition of a precipitate is necessary to remove metal ions. The treatment can achieve from 80 - 99.5% removal, depending upon the metal, pH and the precipitate used (Palmer et al., 1988). Influent concentrations must be less than 100 ppm (Palmer et al., 1988). COD is reduced by 70-90% (Jones, 1971), and solvent removal has been estimated at 55%.

4.4.6 Ion Exchange

Ion exchange involves the exchange of ions in a liquid phase with ions embedded in a resin. Once the resin is spent, it must be regenerated, either by an acid or a base, depending upon the type of resin and, if properly handled, ions can be recovered for recycling. The feed concentration is usually small, less than 2% (20,000 ppm) (Woods, 1994a) although Librizzi and Lowery (1990) suggest a range of 2500 - 4000 ppm to improve resin lifespan. Total dissolved solids removals are in the order of 90 - 99% (Metcalf and Eddy, 1979), while COD removals are between 30 and 60% (Straub, 1989), including toxic organic compounds (Librizzi and Lowery, 1990). Ammonia removals range from 80 to 90% and phosphate removal is 60-90% (Straub, 1989). Weakly polar solvents such as phenols may also be removed by resins, with a removal rate of over 97% and a recovery rate of over 90% (Gao and Su, 1988).

However, organic matter may be released into the effluent fraction. If microorganisms are growing on the resins, the effluent COD concentration may be higher than the influent (Herz and Prunac, 1988). Fines or decomposition products from the resin may also occur. Proper maintenance can prevent these problems; for example, aqueous alcoholic caustic brine solutions may be used to remove organic foulants from anion resins (Ball and Harries, 1988). In addition, selection of resins also has some bearing upon the fouling and removal of organic foulants (Ball and Harries, 1988).

There are a number of different models of ion exchange equipment and most are designed for specific wastewaters and processes (Librizzi and Lowery, 1990). Fixed bed countercurrent systems are the most common. Since systems can be arranged to remove either specific ions or a broad range of ions, it is difficult to define a general effluent or regenerate composition (Palmer et al., 1988). Regenerate quantities are usually less than 2% of the product quantities (Clifford, 1990) but, since they contain the deposited ions, will require either disposal or reuse.

4.4.7 Liquid Incineration

Liquid incineration usually involves the spraying of the liquid into a combustion chamber where, at high temperatures, liquids are thermally oxidized to a gas, with a combustion efficiency of 99.996 - 99.999% (Oppelt, 1991). Sulphur or metallic salt containing wastes will produce acid corrosion and must be controlled. Metals can also adhere to particulates. Particulate emissions from liquid incinerators are generally low, less than 100 mg/m^3 (Oppelt, 1991).

4.4.8 Neutralization

Neutralization involves the addition of either a caustic or an acid to modify the pH to 6-8. Depending upon the chemicals involved, a number of reactions may occur, such as precipitation or release of heat or gases. It is essential that the neutralizing agent be carefully selected. This treatment will increase the dissolved solids in the liquid and produces only one liquid output.

Since the buffering capacities of different acids and bases varies widely, it is difficult to define the volume of caustic or acid required to reach a neutral pH. Moreover, the substance used for neutralization may be gaseous, liquid or solid (Librizzi and Lowery, 1990). To simplify the process, sulphuric acid and sodium hydroxide will be considered as the prime neutralization substances. Estimates of the acid required for neutralizing basic wastewater can be made from the following formulae (Batstone, Smith and Wilson, 1989):

$$\text{acid (mg/L)} = (\text{pH} - 7.0)^2 * 20 \qquad (4.1)$$

and for the base required for acidic wastewaters:

$$\text{base (mg/L)} = (7.0 - \text{pH})^3 * 20 \qquad (4.2).$$

This does not mean that this is an accurate means of estimating the neutralization point; it merely provides an estimation of the final volume and dissolved solids content, suitable for the purposes of this program. Precipitation of metal ions from acidic solutions will occur as the pH rises to 7.0, leaving about 1 ppm in solution (Palmer et al., 1988).

4.4.9 Reverse Osmosis

Removal of smaller ions from liquid solutions requires reverse osmosis. This treatment is used to produce drinking water from saline water but requires a high energy input which reflects in its operating cost. Particles, organics, larger molecules and oils should be removed to reduce fouling - these are better removed by precipitation, ultrafiltration or carbon adsorption. The efficiency of removal is approximately 97% for inorganic ions, 95-97% for dissolved organics, and 98% for biological and colloidal contaminants (Clark, R., 1990). The effluent concentration produced is usually between 10 and 15% of the influent concentration for a range of parameters (Woods, 1994a), although it has been reported to be as high as 20% for metals (LaGrega, Buckingham and Evans, 1994).

4.4.10 Precipitation

Chemical precipitation involves the addition of a chemical precipitant to precipitate dissolved solids which are then settled by gravity sedimentation or removed by filtration. Flocculation involves the addition of a flocculant to promote formation of larger particles which will settle, taking smaller particles with them. Both are included in this treatment. The pH is generally changed to basic and the volume of chemicals added may be as high as 33% of the waste input (Woods, 1994b). Some precipitants add salts to the output and alkaline chemicals must be added to promote precipitation of those salts (Corbitt, 1990). With precipitation, the sludge volume is increased significantly due to the precipitant, flocculant or coagulant added. The sludge usually has a 10% solids content and over 99% of the solids are removed from the supernatant with a sand filter (Palmer et al., 1988). Approximately 99.99% of heavy metals are removed by precipitation (Palmer et al., 1988) while 75-95% of phosphorus is removed (Metcalf and Eddy, 1979). Ammonia and nitrate are not affected (Metcalf and Eddy, 1979)

4.4.11 Sand Filtration

Sand filtration involves passing effluent through sand to remove particulates down to a level of 10 - 30 mg/L, with an efficiency between 95-99% (Corbitt, 1990). Once a significant head loss occurs through clogging of the sand, removal and disposal of the top layer of sand and solids (moisture content ~ 20%) is required. Oil and grease must also be removed to prevent clogging of the sand and unacceptable head loss. At 50 ppm, oil drops are 40 µm in diameter and will pass through the filter - larger oil droplets will cause clogging (Corbitt, 1990). Sand filtration of acidic and basic solutions must be considered separately since the heavy metal concentration in solution would depend upon the pH (Palmer et al., 1988).

4.4.12 Screening

Screening removes low levels of particles with diameters larger than .25 mm (Woods, 1994a) with an efficiency of 90%, producing a solid (30% moisture content) and a liquid output. Since most metal precipitates would not be trapped by screens, acidity is not of concern. Oil or grease must be removed prior to fine screen or the pores will be clogged (Corbitt, 1990). Effluent can be used to rinse the screens, the output being then added to the input.

4.4.13 Settling

Settling removes suspended particles that are heavier than water by allowing them to settle through gravity. This process is also termed clarification and sedimentation. Settling produces a sludge, with approximately 10% solids (Gregory and Zabel, 1988) and removes from 50 - 70% of the solids from the influent (Metcalf and Eddy, 1979). When used with a flocculant, effluent solids can range from 10 - 50 ppm for influents from 1500 - 10,000 ppm, for an efficiency greater than 99% (Librizzi and Lowery, 1990).

4.4.14 Solvent recycling

Solvents are commonly used in many plant operations, including processing and maintenance and include degreasers, paint thinners, metal preparation solvents and cleaners and paint and carbon removers. These solvents can, in general, be easily reclaimed for reuse using simple distillation equipment, with a recovery of 90% with little change in solvent characteristics (Tarrer et al., 1989) and a product purity of over 99% (Woods, 1994a). The input concentration of the volatile solvent should be from 20 - 80% (Woods, 1994a). This treatment produces two outputs - a liquid solvent and a sludge waste which contains contaminant solids and liquids.

Chlorinated solvents contain inhibitors to prevent breakdown, acidity and reactions. Solvent recycling by distillation removes these substances and, therefore, is not recommended for these types of solvents (Tarrer et al., 1989). These should be replaced with non-chlorinated solvents or mechanical processes.

4.4.15 Ultrafiltration

Using a micropore membrane, ultrafiltration removes very fine particulates and large molecules, such as oils, from liquids. New membranes allow both very high and low pH effluents to be treated with this technique. The membranes must be backwashed and replaced when clogged. Grease must be controlled to prevent plugging and high levels of larger particulates should be removed to extend membrane lifespan. Ultrafiltration produces two liquid outputs, with removal efficiencies of 99% of particulates and 95% of COD and a retentate concentration of 2-5% following recycling of the waste water back through the system to improve the efficiency (Palmer, et al., 1988). When heavy metals have been precipitated in a basic solution, they are reduced by 99 - 99.9% (Palmer et al., 1988). Organic toxic compounds are removed by 95% (Woods, 1994a).

4.5 Treatments for Gases

Gases are a common fugitive waste from many plants, released from processes, maintenance operations, heating and cooling systems and treatment systems. They include water and oil vapours, solvents, particulates and gaseous compounds. Treatments for gases include removal of particulates, condensing of liquid vapours and neutralization of acid gases.

4.5.1 Baghouse Filter

This emission treatment removes particulates by filtration through fabric bags with an efficiency of greater than 99% (Brunner, 1991; Iionya and Dennis, 1987). Particle diameters as small as 1 μm are removed (Brunner, 1991; Librizzi and Lowery, 1990). Depending upon the fabric, the filters can withstand a range of corrosive gases but hot gases must be cooled and removal efficiencies are affected by condensation (Brunner, 1991). Baghouse filters do not remove acid or other gases although metals are 99% removed and long-chain hydrocarbons are removed by 67% (Brunner, 1991). These filters produce two outputs - a cleaned gas output and a solid filtrate which is removed from the filter bags and requires recycling or disposal.

4.5.2 Electrostatic Precipitation

Electrostatic precipitation removes particulates through attraction by a static charge. It does not remove acid or other gases and is effective for relatively small particulates, down to 0.1 μm diameter (Woods, 1994a). Particles of 50 μm diameter are 100% collected; over 99% of 5 μm diameter particulates are collected while 98% of particles of 1 μm diameter are removed (Brunner, 1991). Metals are 90% removed while long-chain hydrocarbons are 60% collected. Precipitators can withstand high temperatures and are not affected by humidity, but the capital costs are high (Brunner, 1991).

4.5.3 Packed Tower

A packed bed scrubber removes acid gases and heavy metals from emissions. For most metals, it has a removal of approximately 80%; however, mercury is only reduced by approximately 2% (Brunner, 1991). Since mercury is being used much less due to its toxicity in the environment, a removal efficiency of 80% will be used. Sulphur dioxide, ammonia, chlorine gases and NOx are all removed with an efficiency of 90-99% (Noyes Data Corp., 1972). The outputs are a clean gas and a liquid. Approximately 0.2 L of liquid are produced per kilogram of gas (Noyes Data Corp., 1972).

4.5.4 Venturi Scrubber

A Venturi scrubber removes particles and some gases from a gas stream. These scrubbers are approximately 97% effective in removing 1 μm particles and 100% effective in removing 50 μm particles (Brunner, 1991). This process is most effective for particles in the 0.5-5 μm range (Corbitt, 1990). Water is added to the gases, which are also cooled. Gases such as NOx (25%), HCl (40%) and, to a limited extent, SO_2 (0.1%) are removed, while 98% of oil is removed (Brunner, 1991). A clean gas output and a liquid effluent are produced. The liquid effluent is recycled until the suspended solids reach a concentration of 25% (Noyes Data Corp., 1972).

4.6 Regulation Standards

The program must also consider possibilities for releasing waste materials into the environment - to the air, to water, to landfills and for land treatment. In general, the acceptability for releasing those wastes depends upon the regulations or standards that are in place. At present, there are no standards for releases to the environment in Trinidad. Although environmental impact statements must be completed prior to licensing of new facilities, ministerial order can remove or postpone this requirement and there are no standards for new plants to meet.

Environmental regulation and standards differ, in Canada, from province to province. They may also be specific to a single industry. In order to simplify data input, Ontario standards were incorporated into this knowledge base. However, standards from other provinces or countries could be added to the database and selected for use by the program. The information included in this chapter section is an overview of the standards. Actual regulations and standards are found in Appendix 2.

4.6.1 Air Emissions

Under the Ontario Ambient Air Quality Criteria Regulations (R.R.O. 1990, 337) and the General Air Pollution Regulations (R.R.O. 1990, 346), the limits for emissions are based upon either the concentration of emissions in a 0.5 hour average in $\mu g/m^3$ or an average air contamination over 24 hours, 30 days or 1 year, in ppm, ppb, $\mu g/m^3$, tons/mile^2 and even mg/100cc. In the case of fluoride, emissions are regulated differently, depending upon the season. Consequently, it is difficult to determine how to incorporate these standards into the database. However, by using the weight of dry air as an average mass weight, the standards could be written as ppm and specific parameters incorporated into the program database.

The Air Pollution Regulations include a specific listing of chemicals whose emissions are restricted. This allows regulators to address chemicals of special concern which have been proven to have a known toxicity or detriment to the environment. The developed system does not include all of these chemicals within its parameters and the results should only be considered as suggestions for treatments to meet these standards. It is, therefore, important that the user understand the requirement for bench testing treatments.

Using the listing of chemicals, the level of solvents allowed was based on the phenol level, 100 μ g/m^3. No limit was set on oil fumes under the Ontario guidelines so the U.S. national standard of 160 μ g/m^3 (Godish, 1991) was used. Heavy metals ranged in levels from 2 μg/m^3 for mercury and nickel to 100 μg/m^3 for copper and zinc and a level of 5 μg/m^3 was used. No levels for water vapour, carbon dioxide or particle size were set.

The Refrigerate Regulation (O.Reg. 189/94) specifies that chlorofluorocarbon compounds are not to be released to the atmosphere and that leaks must be repaired within 7 days. Consequently, a limit of zero ppm was set.

4.6.2 Releases to Water Bodies

The Objectives for the Control of Industrial Waste Discharges in Ontario (1988) set the desirable effluent discharge characteristics for industries. A BOD concentration standard was determined to be 15 ppm; BOD was assumed to be 40% of the COD, so the COD standard was set at 37.5 ppm. The heavy metal levels ranged from 1 ppm for chromium, copper, lead, nickel, tin and zinc to 0.001 ppm for cadmium and mercury. When examining the wastes in the case study, none had cadmium or mercury so the level for heavy metals was set at 1 ppm.

Sulphates, chlorides and dissolved solids were not assigned standards but the build-up of these substances is to be minimized with the application of best available, practicable technology, according to the objectives. There are no guidelines or definition of best available, practicable technology and, since reverse osmosis can reduce dissolved solids to less than 1 ppm, this treatment may be considered as such although the economical feasibility of this treatment could be questioned. Since most natural waters contain dissolved solids, especially sulphides, sulphates and chlorides (Hamilton, Klaverkamp, Lockhart and Wageman, 1987), setting a limit this low is certainly uneconomical and, in the case of ocean discharge, unrealistic. In the U.S. the current maximum contaminant level for drinking water is proposed to be 400 mg/L to protect infants and young children (Tate and Arnold, 1990). Although the effluent standards are not necessarily the same as drinking water standards, 400 mg/L of sulphate will be used for this project.

Dissolved solids can include a number of substances, including toxic heavy metals and sulphates which mainly cause diarrhea at levels over 400 mg/L (Tate and Arnold, 1990). Other substances, such as sodium, are found at 2400 mg/L in a typical diet (Tate and Arnold, 1990). Consequently, no standard was set for dissolved solids as the specific contaminant would provide limits.

Under the objectives, toxic substances were to be eliminated or destroyed and were set at a level of 0.001 ppm. Phenols or phenolic equivalents (the parameter was defined as solvents) were set at a limit of 20 ppb.

4.6.3 Deposition to a Landfill

The levels of heavy metals that can be landfilled in municipal landfills are limited to 100 ppm, while PCBs are set to a limit of 50 ppm. However, according to the Guidelines for the Treatment and Disposal of Liquid Industrial Wastes in Ontario (1978), a number of industrial wastes can be landfilled in a secure landfill, including organic sludges and solids, inorganic sludges and solids, cyanide solids, mercury and mercury salts and semi-metals and compounds. Plant or animal-based organic sludges, inert, inorganic sludges and solids and oil/water sludges can be landfilled in municipal landfills, with the approval of the Ministry of the Environment and the landfill owner. Sludges are defined as a mixture of liquids and solids which will flow under normal conditions, as opposed to solids which will not flow.

From those definitions, for a municipal landfill, the pH was considered acceptable within the range of 2 - 12.5 (Corbitt, 1990). Water content was limited to 85% while oil content was limited to 90%. Solvent content was set at 1000 ppm to prevent concerns with volatile emissions or possible combustion.

4.6.4 Land Treatment

The application of industrial substances to land for remediation is both disposal and treatment. According to the Guidelines for the Treatment and Disposal of Liquid Industrial Wastes in Ontario (1978), organic sludge and solids, inert, inorganic sludges and solids and oil/water liquids and sludges can be land treated. Care must be taken to ensure that application levels and toxic substances are sufficiently low to prevent damage to the bacteria and other micro-organisms.

With land treatment, both biological and chemical degradation occurs through interactions with soil particles and microorganisms. Soil bacteria break down organic compounds, nitrification and denitrification occur and the soil matrix removes solids and pathogenic organisms (Corbitt, 1990). Some organic and inorganic substances such as metals, may adsorb to clay materials, particularly in soils containing organic materials (Huilbregtse and Kastman, 1981).

Substances that must be limited for land treatment include:

a) nitrate - nitrogen;
b) cadmium in food chain crops;
c) synthetic organic compounds;
d) salts that inhibit seed germination; and
e) metals that may be phytotoxic to crops (Batstone, Smith and Wilson, 1989).

By assuming an application rate of 1% and considering the parameter levels deemed acceptable for agricultural purposes under the Ontario Decommissioning Guidelines (1990) and the Guidelines for Sewage Sludge Utilization on Agricultural Lands (1986), some indication can be made as to the acceptable levels for land treatment. The pH was set at 5.5-9.5. Since oil and grease will degrade and land treatment has been used extensively for degradation of oily wastes (Boyle, 1992), no level for oil was set.

Heavy metal levels range from 1 ppm for mercury to 1000 ppm for total chromium. However, recognizing the public concerns with heavy metals and the potential for accumulation, a level of 10 ppm in the waste was used. Although iron is a required nutrient, it serves no purpose to add it to soil in large quantities and large particle sizes in metallic form so it was restricted to less than 50,000 ppm for sludge or solid applications. Nitrogen was limited to 0.5% in soil in the Guidelines but, to reduce concerns about nitrate contamination of groundwater, was limited to 10,000 ppm, which is consistent with sewage sludge, according to the Sewage Sludge Utilization Guidelines. By limiting dissolved solids or soluble solids to 1,000 ppm, the possibility of damage to soil by sodium or other ions is reduced. Solvents will volatilize, which can exceed air emission guidelines if too high, and were therefore limited to 100 ppm. Plastic and rubber will not degrade readily but are not phytotoxic so they have been limited to 1,000 ppm; paper and cardboard will biodegrade if mulched into small pieces and were not limited. It must be recognized that, by reducing the rate of application, the level of toxicity can be reduced.

4.7 Summary

A total of 25 treatments have been included in the knowledge, two for solid wastes, four for sludge wastes, 15 for liquid wastes and four for gas wastes. An attempt was made to ensure that a broad range of parameters was covered, particularly for the wastes in the case study. Ontario regulation standards were also included for air and water disposal, disposal to a landfill and land treatment.

Once all the treatment input limits and output formulae and regulation standards were incorporated into the KBDSS as the knowledge base, the case study data were analyzed and incorporated into the data base. Chapter five outlines the case study, the industries used for this system, their inputs and products and the wastes they produce and the results generated by the KBDSS.

5.0 Case Study Application: Point Lisas Industrial Estate, Trinidad

The Caribbean includes a number of small countries in varying degrees of development. These countries have been the focus of a number of attempts to dispose of industrial waste from developed countries (Suite, 1991; White, 1991) and are currently enacting legislation to prevent air and water pollution and the dumping of industrial wastes (CEHI et al., 1989). The Caribbean Environmental Health Institute (CEHI) is promoting sustainable waste management and has funded a study into characterization of industrial wastewaters (Singh, 1992). CEHI proposed that an industrial estate in Trinidad be studied for this research as it is heavily industrialized, particularly along the east-west corridor from Port of Spain and along the Gulf of Paria. The industrial estate at Point Lisas was selected as the case study as it had a variety of both heavy and light industrial plants of varying ages.

This chapter will include the following:

a) a brief description of the island of Trinidad;

b) environmental legislation in Trinidad;

c) a description of the Point Lisas Industrial Estate;

d) a discussion of the selected industrial plants, their management, operation and the plant sites;

e) an outline of the plants' inputs, products and wastes; and

f) results of the KBDS system using these data.

5.1 Overview of Trinidad

The following information was taken from Toppin-Allahar (1992) unless otherwise referenced.

Trinidad is an island of 4,828 km^2, with a population of 1.2 million (1990 census), located 13 km east of Venezuela, on the continental shelf of South America. On the east lies the Atlantic Ocean while the Caribbean Sea is to the north and the Gulf of Paria is located to the west between Trinidad and the mainland (Figure 5.1). Rainfall occurs mainly in the summer monsoon season, with a total average of

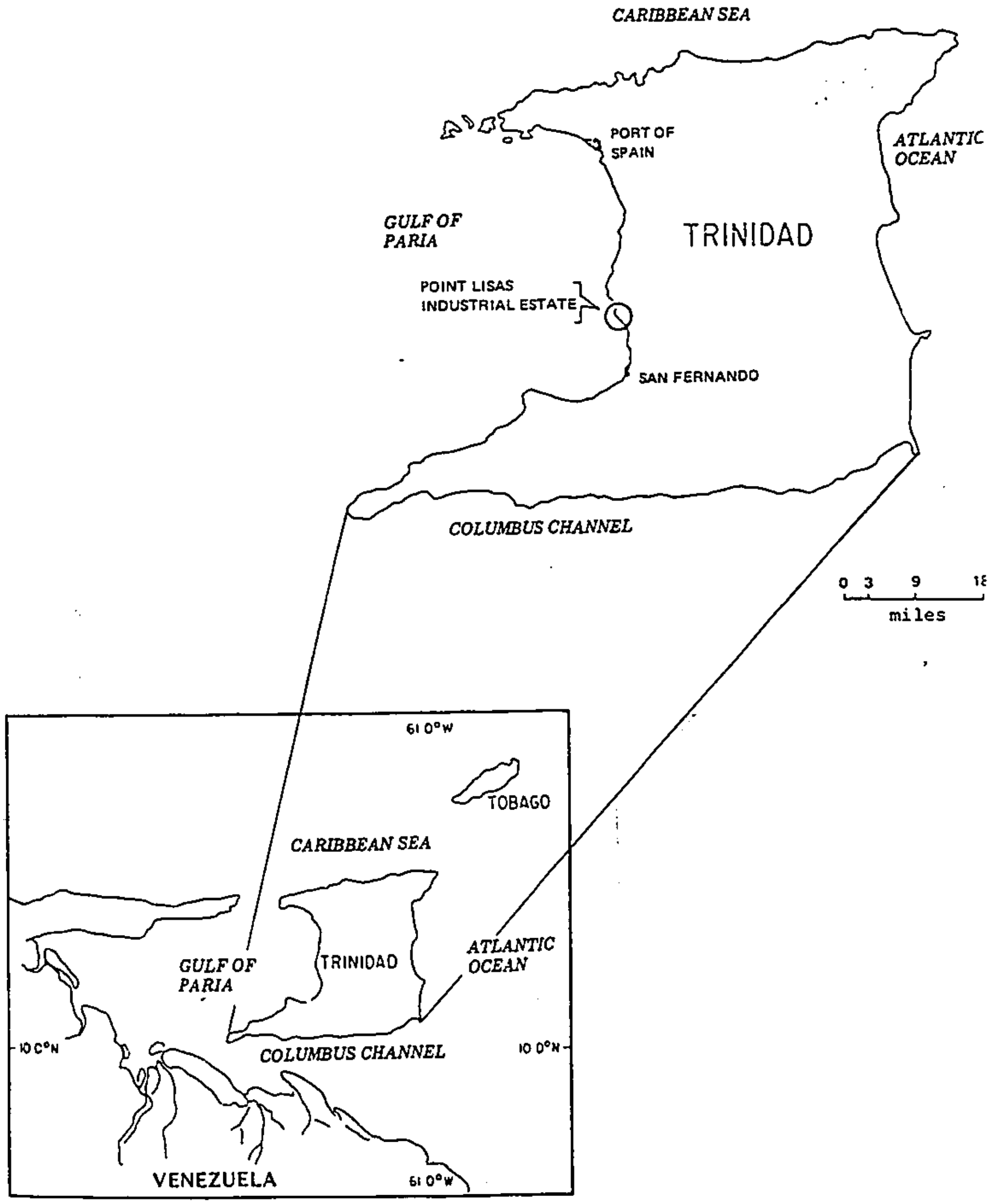


Figure 5.1 The island of Trinidad, located east off the coast of Venezuela. Point Lisas Industrial Estate lies on the west coast halfway down the island.

2200 mm and as high as 3050 mm in the northern mountains. The average temperature in January is 25°C while it is 27.2°C in May and the humidity ranges from 50% in the dry winter season to 100% in the wet summer. There is considerable variation in wind direction.

The majority of the population lives in Port of Spain, with the east-west corridor to Arima and the west coast being the most highly populated and the most heavily industrialized. Agriculture is the prime activity elsewhere, with 34% of the island being under cultivation (Environment Division, 1992).

Among its natural resources, Trinidad has both petroleum and natural gas, and plans to construct a liquid natural gas facility are underway. Trinidad is also home to a number of heavy industries as well as light manufacturing. The cost of capital equipment is estimated to be 2 times the cost in the U.S., due to shipping, exchange rates, shipping duties and taxes (Moore, 1992).

Until the decline in oil prices, Trinidad's petroleum and natural gas provided it with a booming economy and a high standard of living (Environment Division, 1992). However the economy has suffered severely during the recent recession and unemployment is high, particularly in the south. Consequently, environmental conditions have suffered under the concern to industrialize and improve the economy.

The major environmental management issues are considered to be land use, pollution, solid waste management and environmental standards (Environment Division, 1992). There are, at present, no emission or effluent standards set (Moudeen, 1992), nor is there any legislation to control hazardous waste (Goddard, 1992). Consequently, all the rivers in Trinidad are polluted, with industrial effluent being discharged upstream of drinking water treatment plants (Ford, 1992). The west coast of Trinidad has a higher level of pollution from petroleum hydrocarbons than other areas of the world with similar oil-related activities and the oil seepage flow rate into the ocean has been reported to be 100 bbl/day per 1000 sq. miles (Environment Division, 1992). The effect of hydrocarbon contamination from nearby refineries are visible for several kilometres off shore (Siung-Chang, 1992). Methyl mercury contamination is also a concern in fish caught in the gulf (Miller, 1992).

A government-owned company, the Solid Waste Management Company (SWMCO), operates as a private company and manages the country's landfills in addition to consulting and collection services.

Recycling of glass, rags and ferrous and non-ferrous metals is already occurring in Trinidad, paper and cardboard are baled and shipped to Venezuela for recycling and SWMCO is planning to install equipment to shred plastic for recycling in the near future (Goddard, 1992). However, as in many countries, industry has not seriously considered their potential for waste reduction, recycling or reuse.

A small landfill was being operated as a hazardous waste landfill, but SWMCO is discouraging its use (Goddard, 1992). The island's cement producer refuses to accept such wastes until legislation is passed that makes it clear which wastes would be acceptable for burning as fuel. There are no other disposal facilities for hazardous waste on the island, and some companies ship such wastes to England for disposal (Goddard, 1992). However, many such wastes are discarded with general solid waste, including clinical wastes. Hospital wastes are burned at each hospital (Lemaitre, 1992).

For new industries, Town and Country Planning, the main licensing body, is requiring environmental impact statements, including some outline of the methods planned to manage any wastes. However, the legality of such a request is presently being questioned and legislation to cover requirements for an EIS has been drafted (Charles, 1992).

Toppin-Allahar's report on environmental legislation (1992) indicates that Trinidad has little legislation designed to protect its environmental and human health and what little does exist is rarely enforced. At present, the environment comes under the mandate of the Ministry of Planning and Development and consists of three planners and a secretary. An Environmental Management Agency is to be initiated, and a task force is presently involved in determining its structure and function (Salvador-Arthur, 1993). In addition, standards are to be set for emissions and effluents, and mechanisms to enforce regulations are to be instituted.

5.2 The Point Lisas Industrial Port Development

The Point Lisas Industrial Port Development (PLIPD) is located on the west coast of Trinidad, near the town of Couva. Prior to 1956, the area was primarily under sugar cane cultivation and the

Brechin Castle Sugar Factory was the only industry in the area. In 1956, a fertilizer plant was established at Point Lisas and, in the 1960s, a large industrial estate with port facilities was proposed for the area (PLIPDECO, 1982). The Point Lisas Industrial Port Development Company Ltd. was established in 1968 and included 790 hectares. By 1993, over 23 companies, ranging from breakfast cereal manufacturers to steel billet and wire rod production had been constructed. In 1991, a gas processing plant began operating and in 1993, an oil blending plant went into operation and construction of a new methanol plant was initiated. Other developments are being planned for the area (Blaize. 1993).

As part of the initial development, PLIPDECO established an environmental project which was to acquire baseline data and initiate an on-going maintenance program (McShine and Siung-Chang, 1983). However, no environmental standards were set for the industries on the estate and the major limitation that exists for plant operations relates to complaints from affected plants and the surrounding communities when air or water quality deteriorate (Blaize, 1993). There have been no restrictions on disposal of wastes and spills of materials have resulted in a number of fish kills off the coast of Point Lisas (Heileman and Siung-Chang, 1990). Air quality in the surrounding area is poor and both soil and groundwater are contaminated (Farabi, 1992). Reports from one of the plants indicates that toxic chemicals were buried on the plant property in the 1970s and '80s (PLIPDECO, 1981). The estate managers indicated that they were interested in a study to examine the waste production from plants at Point Lisas and requested that plants on the site participate in this project.

5.3 Case Study Methodology

A list of plants and plant mangers was obtained from PLIPDECO. Plant managers were contacted and the project was discussed with them. Once agreement for their participation had been reached, a site visit was arranged. The site visit involved a tour of the facilities and an interview with the appropriate manager to obtain the following information:

1. a detailed description of the plant process;
2. a list of the process inputs and other inputs, the input masses and input components;

3. a list of the process products, product masses and product components;
4. a list of the process wastes and other plant wastes, waste masses, waste components, waste analyses (if available) and treatment and disposal methods;
5. a description of any on-site waste treatment facilities and their capacities;
6. a description of sampling and analytical procedures, if available; and
7. a description of plant maintenance and management procedures.

Once the information had been obtained, it was compiled and, if any data were missing, a further request for the information was made. The data were then analyzed and entered into the computer and a mass balance calculation was done to determine if the data were reasonable.

5.4 Survey Results

A total of 19 plants were visited, out of 24 plants, and some data were obtained for the remaining five plants. Due to the quantity of data, it was decided to use only four of the nineteen plants for the initial analysis and testing of the decision support system prototype. The four plants were selected as they were all fairly large, represented a range of industry types and environmental programs and were able to provide some analyses of their wastes. The selected plants included a recently constructed gas processing plant, a 10 year old methanol plant, a 12 year old fertilizer and urea plant and a 14 year old steel producing plant. Plant descriptions and a discussion of the inputs, products and wastes are discussed below. Input, product and waste composition data from each plant can be found in Appendix 3.

The data provided usually gave waste volumes or masses over varying periods of time, ranging from per day to every 10 years. To provide a better mechanism for accounting for this range of time frames, all wastes were averaged to the quantity generated over one year.

5.4.1. Phoenix Park Gas Processors Limited

Built in 1990-1991, operation was initiated in October, 1991 with a plant designed to process 650 million cubic feet per day of natural gas, remove 98% of propane and heavier components and employ 67 people. A joint venture by National Gas Co., Trinidad and Tobago, (49%), Conoco Inc., Texas (41%) and Pan West Engineers and Constructors, Texas (10%), the plant is designed to produce 6150 barrels per day (b/d) of propane, 3700 b/d of butane and 3650 b/d of natural gasoline.

Site Description

The site was clean and well maintained. A few sample valves showed signs of leakage or release of material onto the ground; in some cases this was a result of poor design. The presence of free oil and black staining under the oily water sump tap indicated the release of oily water onto the ground.

Process Inputs, Products and Wastes

Tables 5.1, 5.2 and 5.3 list the inputs to and products and wastes from various processes at Phoenix Park Gas Processors Limited (Phoenix Park). There is only one input to the refining process, but the maintenance process has nine inputs and there is one input each to the heating and sanitary processes, for a total of 12 inputs. The gas processing plant produces six products, with 330 kg/year going to the flare.

Waste Materials

The refining process yields two wastes. However, the maintenance process produces eight wastes, the storage and heating processes yield one waste each and the sanitary waste process produces two, for a total of 14 different wastes from this plant with a mass of 55,175 tonnes of waste per year (Table 5.4).

Sludge and most solid wastes are landfilled while aqueous liquid wastes (14.0%) are discarded into the drains which flow into the ocean. Emissions arise from the combustion of flare and fuel gases and constitute the majority (84.5%) of the wastes. Oily wastes are collected by the Trinidad and Tobago Oil Company (TRINTOC) to be re-refined, (although the manager was not certain that the oil was actually recycled) while steel barrels are crushed and recycled by ISPAT, unless they are used by employees.

Table 5.1 Inputs to various processes at Phoenix Park.

Process	**Input**	**Mass/year** t/yr	**Input type**
NG refining process	raw natural gas	1497016000	gas
equipment maintenance	methanol	190	liquid
equipment maintenance	canister filters	12 filters	solid
equipment maintenance	dust filter	324 filters	solid
equipment maintenance	paper filters	128 filters	solid
equipment maintenance	compressor oil	3.8	liquid
equipment maintenance	expander lube oil	0.2	liquid
equipment maintenance	oil	0.4	liquid
equipment maintenance	molecular sieve	17	solid
plant maintenance	washwater	18	liquid
heating	heating water	113	liquid
sanitary	sanitary water	5800	liquid

Table 5.2 Products from the refining process at Phoenix Park.

Product	**Mass, t/year**
butane	87700
natural gas	3742900
natural gasoline	104400
propane	122900

Waste Composition

The emissions from the plant refining process are 55.4% carbon dioxide and 44.5% water, resulting from the combustion of natural gas. A small amount of nitrogen dioxide is also present. A compressor presently produces oil fumes but attempts to control the emissions are being made.

The water that is produced by the manufacturing process contains low levels of oil, COD and solvents. The plant washings and sanitary water also contain COD, oil, solvent and dissolved solids, the heating water contains primarily fine particles and the slop oil contains some water. Filters and sewage sludge are landfilled as is molecular sieve, once it cannot be regenerated (approximately a 2 year lifespan).

Table 5.3 Wastes from various processes at Phoenix Park, the mass and type produced and the current disposal method.

Process	**Waste**	**Mass, (t/year)**	**Waste Type**	**Disposal Method**
NG refining process	water	20,507	liquid	drain
NG refining process	carbon dioxide/water	46,600	gas	air
equipment maintenance	slop oil	830	liquid	recycled
equipment maintenance	canister filters (2 kg/filter)*	0.02	solid	landfill
equipment maintenance	dust filters (1 kg/filter)*	0.3	solid	landfill
equipment maintenance	paper filters (1 kg/filter)*	0.1	solid	landfill
equipment maintenance	compressor oil	4	gas	air
equipment maintenance	expand/comp oil	0.2	liquid	recycled
equipment maintenance	molecular sieve	17	solid	landfill
plant maintenance	plant washings	18	liquid	drain
storage	steel barrels (18kg/drum)	0.4	solid	recycled
heating	gas heating water	1100	liquid	drain
sanitary	sanitary water	5900	liquid	drain
sanitary	sewage sludge	7	sludge	landfill

*Filter weights were estimated.

Table 5.4 Quantities of waste materials from Phoenix Park and their means of disposal.

Waste Type	**Mass (T/year)**	**Percent of Waste**	**Disposal**
gas	46,600	84.5	air
liquid	27,525	14.0	to drains
liquid	830	1.5	off-site recycling
sludge	7	≈0	off-site landfill
solid	17	≈0	off-site landfill
solid	0.4	≈0	off-site recycling
Total Mass	**55,174**	**100.0**	

5.4.2 Trinidad and Tobago Methanol Gas Company Limited

The plant was designed and built in 1984 by Toyo Engineering Corporation, Japan and de-bottlenecked in 1990. This facility uses natural gas and CO_2 to produce methanol to a purity of >99.9% and also produces nitrogen for blanketing storage tanks and purging lines. The plant employs 250 workers and produces 1380 thousand tonnes (kt) of methanol per day when CO_2 is available; otherwise, only 1100 kt of methanol are produced.

Site Description

The site was relatively clean, with some old equipment lying around; however, the age of the plant clearly showed in the amount of rusted equipment. Water was leaking from a number of sources but, in general, the plant was well maintained. There was no formal oil recovery mechanism and effluent analyses indicated less than 5 ppm in the wastewater. All large storage tanks were bermed. The warehouse area was clean and well maintained; old equipment had been stored in a yard waiting for disposal.

Process Input, Products and Wastes

Not all of the information requested was available. There was little information provided on oil disposal, sanitary and plant washing water, sewage sludge and emission quantities and characteristics and characteristics of the short-chain hydrocarbon wastes. Tables 5.5, 5.6 and 5.7 list the inputs to and products and wastes from various processes at the Trinidad and Tobago Methanol Plant (TT Methanol Plant).

The manufacturing process requires three inputs while cooling requires nine and equipment maintenance has 12 inputs. Plant and building maintenance would also require some inputs such as water but no information was available on these materials. The cooling process includes the water cooling system as well as the cryogenic cooling system for the nitrogen process. Only methanol is produced by this plant.

Waste Materials

The manufacturing process yields one waste, the heating and cooling processes, two wastes each, and the maintenance process, eleven wastes, for a total of 16 wastes. Of these wastes, 98.6% are liquid and are released into the ocean. The majority of the waste is a product of the methanol production process and has 40 ppm methanol. The gas wastes are a result of fuel combustion (carbon dioxide/water) and fugitive emissions of freon from the cryogenic system. Used oil, which is primarily contaminated with dirt and metals and has lost some of the volatile components, is burned on-site.

Table 5.5 Inputs to various processes at the TT Methanol Plant

Process	Input	Mass, t/year	Input type
methanol production	carbon dioxide	960	gas
methanol production	natural gas	213800	gas
methanol production	water	1138800	liquid
cooling	biocide	2	liquid
cooling	biocide2	3	liquid
cooling	calcium hypochlorite	1	solid
cooling	dispersant	17	liquid
cooling	phosphate	16	liquid
cooling	sulphuric acid	7	liquid
cooling	trichlorostriazinetrione	2	liquid
cooling	hydrazine	0.2	liquid
cooling	water	52600	liquid
cooling/cryogenic	freon	0.3	gas
heating	boiler water	120	liquid
heating	phosphate	0.9	solid
heating	Ferrosperse	1	liquid
equipment maintenance	nickel catalyst	3	solid
equipment maintenance	zinc oxide	0.9	solid
equipment maintenance	copper catalyst	60	solid
equipment maintenance	nickel/molybdenum	1	solid
equipment maintenance	molecular sieve	0.3	solid
equipment maintenance	lubrication oil	0.4	liquid
equipment maintenance	oil filter cartridge	100 filters	solid
equipment maintenance	anion resin	3	solid
equipment maintenance	cation resin	4	solid
equipment maintenance	sodium hydroxide	130	solid
equipment maintenance	sulphuric acid	135	liquid
equipment maintenance	solvent	5	liquid
plant maintenance	water	154	liquid

Table 5.6 Products from the TT Methanol Plant

Product	Mass, t/year
methanol	402600

Table 5.7 Wastes from processes at the TT Methanol Plant.

Process	**Waste**	**Mass,** **t/year**	**Waste** **Type**	**Disposal** **Method**
methanol production	water	1191400	liquid	drains
cooling	cooling water	52600	liquid	drains
heating	carbon dioxide/water	18000	gas	air
heating	boiler blowdown	33	liquid	drains
cooling/cryogenic	freon	0.3	gas	air
equipment maintenance	solvent	5	liquid	drains
equipment maintenance	nickel catalyst	3.	solid	landfill
equipment maintenance	zinc oxide	0.9	solid	landfill
equipment maintenance	copper catalyst	60	solid	off-site recycled
equipment maintenance	nickel/molybdenum	1	solid	off-site recycled
equipment maintenance	molecular sieve	0.3	solid	landfill
equipment maintenance	lubrication oil	0.4	liquid	on-site burning
equipment maintenance	oil filters (2kg/filter)*	0.2	solid	landfill
equipment maintenance	regeneration water	2600	liquid	drains
equipment maintenance	spent anion resin	3	solid	landfill
equipment maintenance	spent cation resin	4	solid	landfill

*weight was estimated

Table 5.8 Mass of wastes per disposal option at the TT Methanol Plant.

Waste Type	**Mass (t/year)**	**Percent** **of Waste**	**Disposal** **Method**
gas	18000	1.4	to air
liquid	1246500	98.6	to drains
liquid	0.4	≈0	on-site burning
solid	12	≈0	off-site landfill
solid	61	≈0	off-site recycling
Total Mass	**1264600**	**100.0**	

5.4.3 Fertilizers of Trinidad and Tobago (Fertrin) / Trinidad and Tobago Urea Company Ltd.

The first plant contains two ammonia processes, one commissioned October, 1981 and the second in August, 1982. The plant utilizes natural gas to form ammonia and carbon dioxide and has 375 employees with 25 on contract. It was run in conjunction but separately from the Trinidad and Tobago Urea Company and some facilities were jointly used. The urea plant, commissioned in Dec. 1983, utilizes ammonia and carbon dioxide from the nearby ammonia plant to produce urea. Basic production is 1620 t/day and the plant employs 55 people. Both plants were purchased by Arcadian, a U.S. company, in June, 1993, and will be operated as a single plant in the future. Consequently, inputs and outputs from both facilities will be reported here as for one plant (Fertrin).

Site Description

The site was relatively clear of debris, although the drains showed signs of oil spills and there were spills of unknown material in and alongside drains. Wastewater from the oil sump, which was jointly shared by Fertrin and the urea company, smelled strongly of ammonia and a layer of oil was apparent on the liquid surface. The equipment disposal yard was heavily overgrown and has not been maintained. Open troughs of white spirit were used for parts washing. However, an actual site inspection of the ammonia plant was not provided, despite requests, so no determination could be made of possible leaking pipes or equipment.

The site of the urea plant was clear of old equipment but old barrels had been left on site, there were urea spills on the ground, ammonia leaks appeared to be common (from personal experience, employees' and other companies' comments) and ammonia carbamate had seriously corroded piping. The urea pelletizing tower was very dusty, to the point of being a health hazard to workers, and safety precautions were lax. The urea storage area was also very dusty and the urea pellets underfoot posed a hazard to workers. There was no mechanism for determining the actual volume of urea produced; it was estimated, using the volume of ammonia purchased and a periodic test run.

On land behind the plant, the vegetation had been severely degraded. Much of the drainage led into a lagoon on ISPAT land which was not tested and the lagoon emptied into the bay.

Process Input, Products and Wastes

Tables 5.9, 5.10 and 5.11 list the inputs to and products and wastes from various processes at the ammonia and urea plants. The ammonia production process requires three inputs and produces two products and no waste materials. The urea production process uses three inputs and produces one product and two waste materials. Twenty-three inputs are needed for equipment maintenance, plant maintenance requires one, the ammonia heating and salt water system need three inputs while the fresh water ammonia cooling system needs two inputs. The urea cooling and heating systems require one input each.

Table 5.9 Inputs to the processes at the Fertrin plant.

Process	**Inputs**	**Mass, t/year**	**Input Type**
ammonia production	air	1465400	gas
ammonia production	natural gas	379800	gas
ammonia production	water	1106220	liquid
urea production	ammonia	163670	liquid
urea production	carbon dioxide	211680	gas
equipment maintenance	antimony potassium tartrate	0.03	liquid
equipment maintenance	monoethanolamine	110	liquid
equipment maintenance	sodium metavanadate	0.5	solid
equipment maintenance	tartaric acid	0.3	liquid
equipment maintenance	triethylene glycol	0.2	sludge
equipment maintenance	solvent	0.7	liquid
equipment maintenance	anion resin	0.2	solid
equipment maintenance	cation resin	0.2	solid
equipment maintenance	activated carbon	0.4	solid
equipment maintenance	canister filters	24 filters	solid
equipment maintenance	molecular sieve	0.4	solid
equipment maintenance	sulphuric acid	1135200	liquid
equipment maintenance	sodium hydroxide	1464000	solid
equipment maintenance	lube oil	8	liquid
equipment maintenance	reformer tubes	20	solid
equipment maintenance	cobalt/molybdenum	4	solid
equipment maintenance	zinc oxide	6	solid
equipment maintenance	nickel oxide	20	solid
equipment maintenance	nickel chromium	8	solid
equipment maintenance	zinc/copper	40	solid
equipment maintenance	iron/chromium	20	solid
equipment maintenance	nickel	3	solid
equipment maintenance	iron oxide	70	solid
plant maintenance	sanitary water	408,800	liquid
heating - ammonia	water	2783000	liquid
heating- ammonia	morpholine	7	liquid
cooling-ammonia	water	1270	liquid
cooling-ammonia	chromate	0.3	solid
cooling - urea	water	1215100	liquid
heating - urea	water	296300	liquid
salt water cooling	biocides	30	liquid
salt water cooling	salt water	17,870,400	liquid
salt water cooling	sulphuric acid	60,000	liquid

Table 5.10 Products of the Fertrin and Urea plants

Products	**Mass, t/year**
ammonia	802,700
carbon dioxide	269,600
urea	272,640

Waste Materials

Twenty-two wastes are produced by the equipment maintenance process while one waste each is produced by plant maintenance, ammonia and urea heating, fresh water ammonia and urea cooling and salt water cooling processes. The ammonia production process produces one waste while the urea production process produces two, for a total of 31 wastes. The fate of two wastes, monoethanolamine and triethylene glycol, is unknown; when discussed with plant engineers, they stated that the wastes had been placed in barrels and were awaiting a decision for disposal. In the past, both wastes had been landfilled.

The majority of the waste produced was from the salt water cooling system (Table 5.11). Initially a cooling tower allowed recycling of the salt water, but the cooling tower has collapsed, resulting in the use of a once-through system. The engineers provided an estimate of 3-4000 t/hr evaporation from the cooling system, but since only 2,000 t/hr are input, this was obviously not correct.

Volumes of waste materials were consistently underestimated by the plant engineers. Estimates of MEA waste were given at 3.85 t/year and at 11.3 t/yr, but records indicated that an average of 108 t/year were being put into the system which is supposed to be closed. The use of antimony, arsenic and vanadium in this system make this a concern. Records also indicated a significant loss of cooling water from the closed fresh water system. This was significant due to the use of chromium as an anti-corrosive in this system. There were no records available to determine the actual amount of solvents and Safe-Sol (a solvent containing chlorinated solvents) that were used.

Table 5.11 Wastes from the processes of the Fertrin plant

Process	**Wastes**	**Mass, t/year**	**Waste Type**	**Disposal**
process - ammonia	ammonia	7	gas	air
process - urea	ammonia	890	gas	air
process - urea	urea processing water	90	liquid	drains
equipment maintenance	regenerate	24000	liquid	drains
equipment maintenance	monoethanolamine	110	sludge	unknown
equipment maintenance	triethylene glycol	3	sludge	unknown
equipment maintenance	solvent	0.7	vapour	air
equipment maintenance	activated carbon	0.3	solid	landfill
equipment maintenance	canister filters (2kg/filter)*	0.05	solid	landfill
equipment maintenance	molecular sieve	0.4	solid	landfill
equipment maintenance	reformer tubes	20	solid	recycled
equipment maintenance	cobalt/molybdenum	4	solid	recycled
equipment maintenance	zinc oxide	6	solid	landfill
equipment maintenance	nickel oxide	20	solid	recycled
equipment maintenance	nickel chromium	8	solid	recycled
equipment maintenance	zinc/copper	40	solid	recycled
equipment maintenance	iron/chromium	20	solid	recycled
equipment maintenance	nickel	3	solid	recycled
equipment maintenance	iron oxide	70	solid	landfill
equipment maintenance	lubricating oil	41	liquid	recycled
equipment maintenance	oily wastes	2	liquid	recycled
equipment maintenance	water	1380	liquid	drains
equipment maintenance	scrap steel	60	solid	recycled
equipment maintenance	spent anion resin	0.2	solid	landfill
equipment maintenance	spent cation resin	0.2	solid	landfill
plant maintenance	sanitary water	408,800	liquid	drains
heating - ammonia	heating water	2,783,000	liquid	drains
cooling - ammonia	NH_3 cooling water	1270	liquid	drains
cooling - urea	urea cooling water	1220	liquid	drains
heating - urea	urea heating water	296.300	liquid	drains
salt water cooling	salt water	17,870,400	liquid	drains

*weight was estimated

Waste Contaminants

Temperature is the main concern with disposal of salt water waste into the ocean. The volume that is being used could have a significant impact on fish, shellfish and algae growth in the vicinity of the outflow (Table 5.12). The outflow from the fresh water cooling system contains 30 ppm Cr^{6+} and, although this does not go directly to the drains, it has been assumed that it will flow to the ocean, 1 km to the west.

The monoethanolamine (MEA) wastes contain antimony, arsenic and vanadium which poses a problem for disposal. The activated carbon filters also would be contaminated with these heavy metals as activated carbon is used to filter MEA. The catalysts and converters gradually lose their effectiveness and require replacing over periods from 2 to 15 years. These materials still contain mainly heavy and other metals. Most are returned to the manufacturer for recycling while some are discarded in landfills.

Table 5.12 Mass and percent of wastes per disposal option from the Fertrin plant

Waste Type	Mass (t/year)	Percent of Waste	Disposal Method
gas	890	0.004	air
liquid	21,386,500	99.994	drains
liquid	40	≈0	off-site recycled
sludge	113	0.001	unknown
solid	70	≈0	landfill
solid	180	0.001	off-site recycled
Total Mass	**21,387,800**	**100**	

5.4.4 Caribbean ISPAT Ltd.

Built in the late 1970s by the Iron and Steel Company of Trinidad and Tobago (ISCOTT), the steel plant first started production in August, 1980, producing steel billets. Production of steel rods was initiated in June, 1981. The plant utilizes the direct reduction process, a Midrex design, two series 400 modules with a production capacity of 420,000 t Direct Reduced Iron (DRI) per year each which is then processed into steel billets. The plant also produces its own lime. The plant has two electric arc furnaces and a ladle furnace for high carbon steel and produces 50,000 t per month of steel billets. The billets are heated in a walking beam reheat furnace and reduced through rolling mills to produce wire rod. About 20% of the DRI and the steel billets are sold. The plant employs 977 people.

Site Description

The site was littered with dust, old equipment, barrels, empty cups, lunch boxes and other garbage. Graffiti had been scrawled on many walls and posts and the building structure had not been maintained, with doors and windows missing. Near the DRI process, DRI pellets had spilled, creating hazardous walking conditions. Dust was heavy from the DRI storage and the lime plant. The meltshop floor was heavily littered with slag, fines, old cables, and other material. The baghouse did not appear to be working at all, with most of the dust being emitted out of the meltshop doors and visibility was affected due to the airborne dust. Heat and noise were also high. Scale was piled around the remelter for the rolling mill and the floor here was also littered with debris. Water leaked heavily from the remelter troughs and the settling tank oil skimmer did not work.

Ditches outside the equipment maintenance shop were coated with oil and a worker stated that all used oil was dumped into the drains. Degreasers used for cleaning equipment were also dumped into the drains, although these were not standard solvents as previous drainage ditch fires resulted in a solvent use ban. Old vehicles stood nearby, in various states of decay. The storage yard was stockpiled with baled wire rod, some quite rusted and some wire had become unbaled.

Water was leaking unchecked from pipes and equipment, oil was leaking from compressors and barrels of unknown material had been left in various locations. Wastewater lagoons were used to settle particulates and a layer of oil lay on top of the upper lagoon, coating the lagoon retaining walls.

Process Input, Products and Wastes

A large number of inputs are required for these processes - a total of 16 inputs, including four to the DRI process, two to the lime process and ten to the steel process (Table 5.13). Nine inputs are needed for equipment maintenance while only one is needed for the cooling process. The plant produces three products (Table 5.14).

The plant produces a considerable quantity of substandard billets and wire which are returned to the furnace for recycling. Discussions with managers indicated that billet production was 96% of the liquid steel, with 0.7-0.8% being trimmed and remelted and 2% being lost as slag and scale. Further losses of up to 20 t/day were incurred in the remelting of the billets, where scale formation is a concern, and in forming of the wire rod. Since most of these materials are returned for remelting they do not appear as waste products although there is a significant energy waste. Total plant efficiency was rated at 84.7% of the liquid steel input.

Table 5.13 Inputs to the processes at the ISPAT plant

Process	Input	Mass, t/year	Input Type
DRI production	iron ore	1,080,000	solid
DRI production	natural gas	255,938	gas
DRI production	oxygen	428,760	gas
DRI production	water	313,200	liquid
lime production	limestone	36,000	solid
lime production	oxygen	18,720	gas
steel production	alloy	1200	solid
steel production	calcium carbide	780	solid
steel production	coal	600	solid
steel production	lime	19,700	solid
steel production	oxygen	1,300	gas
steel production	rice husks	6,800	solid
steel production	scrap steel	336,000	solid
steel production	silicon/manganese	7,620	solid
equipment maintenance	nickel catalyst	56.64	solid
equipment maintenance	solvent	47.97	liquid
equipment maintenance	solvent	64.02	liquid
equipment maintenance	electrodes	2400	solid
equipment maintenance	Draumas oil	59.07	liquid
equipment maintenance	hydraulic oil	94.67	liquid
equipment maintenance	lubricating oil	95.84	liquid
equipment maintenance	oil filters	624	solid
equipment maintenance	transmission fluid	3.9	liquid
cooling	water	2,763,050	liquid

Table 5.14 Products from the ISPAT plant

Products	Mass, t/year
DRI	144,000
wire rod	456,000
steel billets	120,000

Waste Materials

The ISPAT plant produces a high volume of wastes (Table 5.15 and 5.16). The manufacturing process produces six of the wastes, while equipment maintenance produces seven. The cooling process produces two wastes for a total of 15 wastes. A significant portion of these wastes are carbon dioxide/particulates which are released to air, and solids which are sold for recycling. It must be noted that, although scrap steel is purchased for addition to the steel, little scrap that is generated on site appears to be included in that scrap. The reasons given for this exclusion were concerns regarding quality of the steel.

Table 5.15 Wastes from the processes at the ISPAT plant

Process	**Wastes**	**Mass, t/year**	**Waste Type**	**Fate**
DRI production	CO_2/particulates - DRI	985,000	gas	air
DRI production	nitrogen	149	gas	air
lime production	CO_2/particulates - lime	102	gas	air
steel production	CO_2/particulates - steel	814	gas	air
steel production	mill scale	5,400	solid	landfill
steel production	slag	108,000	solid	recycled
equipment maintenance	nickel catalyst	60	solid	recycled
equipment maintenance	lubrication oil	250	liquid	drains
equipment maintenance	oil filters (3 kg/filter)	1,870	solid	landfill
equipment maintenance	cesium source	0.1	solid	on-site landfill
equipment maintenance	metal equipment	12	solid	on-site storage
equipment maintenance	scrap steel	1	solid	on-site storage
equipment maintenance	tires	12	solid	landfill
cooling	cooling tower sludge	22,000	sludge	landfill
cooling	steel cooling water	27,630,500	liquid	drain

The steel plant does have a baghouse but it is capable of handling only half of the plant's production and does not operate effectively. Consequently, the particulate emissions are significant. High levels of heavy metals are found in the particulates emitted from the steel plant. The radioactive cesium, from quality control equipment, is covered with cement and buried on site.

Table 5.16 Mass, percent of wastes and disposal options for the ISPAT plant.

Waste Type	**Mass (t/year)**	**Percent of Waste**	**Disposal Option**
gas	986,000	3.4	air
liquid	27,630,700	96	drains
sludge	22,000	≈0	off-site landfill
solid	13	≈0	on-site storage
solid	108,000	0.4	off-site recycled
solid	0.1	≈0	on-site landfill
solid	7,300	≈0	off-site landfill
Total Mass	**28,753,995**	**100.0**	

5.4.5 Summary of Waste Production

A total of 76 wastes are produced by the four selected plants, with a mass of 49,995,500 t/year. Seventeen wastes are recycled by off-site recyclers and will not be included among the wastes to be reviewed, leaving 59 wastes to be considered. The wastes to be reviewed are summarized in Table 5.17. The majority of the wastes are released into drains to the ocean or emitted to the air. Solid and sludge wastes are landfilled.

It must be recognized that the data obtained may be far from complete. None of the plants had a waste management program and none were keeping records of wastes produced. Some did not keep track of actual input or product amounts. In many cases, changes had been made to the plant manufacturing process and to other processes since construction of the plant and no drawings or records had been kept of the changes. Phoenix Park Gas Processors Limited, the newest plant, had the most complete records and had taken the greatest care in managing their wastes.

A significant number of wastes are produced by the four plants in the case study, particularly as gaseous and particulate emissions. Carbon dioxide is the major component of the gases emitted, a result of combustion of fuels. Water from heating and cooling processes also constitutes a major segment of the wastes. Equipment maintenance produces the greatest variety of wastes and many of these wastes are produced over a number of months or years.

There is little recycling of materials within the four plants but there are wastes which have not been included in this survey since data were not available. Losses of urea were not possible to determine since there was no means of determining actual production. However, spills and dust production indicated that there was definitely some loss of urea. Similarly, a spill of DRI at the ISPAT plant was evident but there was little information to determine how frequently this occurred. Sampling procedures and analyses of wastes were not always available.

Table 5.17 Total mass and disposal of wastes from the four case studies. Recycled wastes have not been included. Discrepancies are due to errors in rounding.

Waste Type	Mass (t/yr)	Percent	Disposal
gas	986,600	2.0	air
liquid	48,864,500	97.7	drains
liquid	0.4	≈0.0	burned
sludge	22,000	≈0.0	landfill
sludge	113	≈0.0	unknown
solid	114,800	0.2	landfill
Total	49,995,500	100.00	

5.5 Potentials for Reusing, Recycling or Disposing of Waste Materials - The Decision Support System

It has been determined that a number of the waste materials have the potential to damage human health or the environment. The decision support system can provide a number of consecutive treatments (a treatment train) which will enable a waste or a component of a waste to be recycled. It will also list those wastes which could be directly reused and would provide treatment trains for a waste for disposal to land (landfills or land treatment), water or air.

The input, process and output data for each plant were loaded into the system, using the system input forms and the system was then run. In this run, wastes for which a recycle market was already being used (such as used oil from Phoenix Park) were not included as a market was deemed to have been found - 15 wastes were being treated and recycled off site. Further information would be needed to ensure that the recycling process was not causing more environmental problems (e.g. wastes sent for recycling were not being landfilled) and to assess the economics of any alternative. A total of 44 different wastes were matched against 73 inputs and 4 regulation standards.

Once all treatment trains are complete, the user then makes a selection as to the treatment trains to be selected. The current selection choices are:

1. minimum number of treatments per train;
2. matching treatment trains for different wastes; and
3. minimum number of treatments for all wastes.

In addition, these selection choices can be used to set priorities. For example, the user may select the shortest treatment trains, then match those wastes to see which train has the greatest number of matches.

5.5.1 System Results

The system currently does an analysis of all possible treatment trains to match a waste material with an input material or a regulation standard. The trains are constrained by the following conditions:

1. only two state changes are allowed per train;
2. a change in material state only (i.e. the treatment changes no other parameter) is allowed once per train; and
3. a specific treatment may be used only once per train.

Even with these constraints, the total number of trains for one waste-input match may be high. With the wastes and inputs in the case study, over 4,600 trains were generated to match all wastes. Approximately 200 records were completed per hour. The matches which took the longest to complete were those matching sanitary waters with water inputs. The large number of treatments which treat liquids probably accounted for the high number of records, together with the number of contaminants in the sanitary water.

As a result, the system took over a week of computation on a 486 33 mHz microcomputer to evaluate the trains for all of the wastes. Of the 44 wastes evaluated, a total of seven wastes were classed as not treatable, meaning no match could be found. Eighteen wastes could be treated and recycled as input materials while 17 wastes could not be recycled to any of the input materials but could be treated for disposal. Two wastes could be directly reused, requiring no treatments. Table 5.18 outlines the results of the possible treatment trains selected by the system.

Table 5.18. A summary of possible treatment trains for all evaluated wastes.

Total Wastes	**Producing Plants**	**No. of Trains**	**Results**	**Comments**
activated carbon	Fertrin	4	Land Treatment	
		4	Ontario Effluent Reg.	
ammonia	Fertrin	0	none	ammonia too high
boiler blowdown	TTMeth	100	water	
		53	Ontario Effluent Reg.	
		21	Land Treatment	
canister filters	PPGP	3	Ontario Air Pollution Reg	
	Fertrin	1	Ontario Landfill Reg.	
carbon dioxide/ particulates - DRI	ISPAT	4	Ontario Effluent Reg.	
		1	Ontario Landfill Reg.	
carbon dioxide/ particulates - lime	ISPAT	11	carbon dioxide	
		3	Land Treatment	
		79	Ontario Effluent Reg.	
		1	Ontario Landfill Reg.	
carbon dioxide/ particulates - steel	ISPAT	1	Land Treatment	
		10	Ontario Effluent Reg.	
carbon dioxide/water	TTMeth	2	Land Treatment	
	PPGP	2	Ontario Landfill Reg.	
cesium source	ISPAT	0	none	heavy metals too high
cooling water	TTMeth	123	water	
		19	Land Treatment	
		2	Ontario Landfill Reg.	
		70	Ontario Effluent Reg.	
cooling tower sludge	ISPAT	3	Ontario Air Pollution Reg	
		2	Ontario Landfill Reg.	
		17	water	
NH_3 cooling water	Fertrin	27	Land Treatment	
dust filters	PPGP	4	Ontario Air Pollution Reg	
		1	Ontario Landfill Reg.	
equipment	ISPAT	1	Ontario Landfill Reg.	
freon	TTMeth	0	none	CFC too high

Table 5.18 (cont)

Total Wastes	**Producing Plants**	**No. of Trains**	**Results**	**Comments**
gas heating water	PPGP	41	water	
		13	Land Treatment	
		2	Ontario Landfill Reg.	
		43	Ontario Effluent Reg.	
heating water	Fertrin	6	water	
		7	Land Treatment	
		16	Ontario Effluent Reg.	
iron oxide	Fertrin	1	iron oxide	no treatments needed
		1	Ontario Landfill Reg.	
lubrication oil	TTMeth	8	Land Treatment	
	ISPAT	105	Ontario Effluent Reg.	
mill scale	ISPAT	1	Ontario Landfill Reg.	
molecular sieve	TTMeth, PPGP	0	none	metal too high
monoethanolamine	Fertrin	26	Land Treatment	
		6	Ontario Air Pollution Reg	
		155	Ontario Effluent Reg.	
nickel catalyst	ISPAT, TTMeth	0	none	metals too high
oil filters	ISPAT	3	Ontario Air Pollution Reg	
	TTMeth	1	Ontario Landfill Reg.	
paper filters	PPGP	8	Ontario Air Pollution Reg	
		1	Ontario Landfill Reg.	
plant washings	PPGP	108	water	
		11	Land Treatment	
		92	Ontario Effluent Reg.	
		2	Ontario Landfill Reg.	
regenerate	Fertrin	10	water	
		2	Land Treatment	
		1	Ontario Effluent Reg.	
regeneration water	TTMeth	2	water	
		6	Land Treatment	
		19	Ontario Effluent Reg.	
salt water	Fertrin	35	salt water	
		31	Land Treatment	
		6	Ontario Effluent Reg.	
sanitary water	PPGP	1084	water	
	Fertrin	159	Land Treatment	
		185	Ontario Effluent Reg.	
scrap steel	ISPAT, Fertrin	1	scrap steel	no treatments needed
		1	Ontario Landfill Reg.	
sewage sludge	PPGP	60	water	
		22	Land Treatment	
		35	Ontario Effluent Reg.	
slag	ISPAT	0	none	metals too high
solvent	TTMeth, Fertrin	1	solvent	

Table 5.18. (cont)

Total Wastes	**Producing Plants**	**No. of Trains**	**Results**	**Comments**
spent anion resin	Fertrin	1	Ontario Air Pollution Reg	
	TTMeth	1	Ontario Landfill Reg.	
spent cation resin	Fertrin	1	Ontario Air Pollution Reg	
	TTMeth	1	Ontario Landfill Reg.	
steel cooling water	ISPAT	78	water	
		2	Land Treatment	
		33	Ontario Effluent Reg.	
tires	ISPAT	1	scrap steel	
		1	Ontario Landfill Reg.	
triethylene glycol	Fertrin	11	Land Treatment	
		7	Ontario Air Pollution Reg	
		110	Ontario Effluent Reg.	
urea cooling water	Fertrin	77	water	
		42	Land Treatment	
		43	Ontario Effluent Reg.	
urea heating water	Fertrin	42	water	
		30	Land Treatment	
urea processing water	Fertrin	33	Ontario Effluent Reg.	
water	TTMeth	1096	water	
	PPGP	49	Land Treatment	
	Fertrin	144	Ontario Effluent Reg.	
		7	Ontario Landfill Reg.	
zinc oxide	TTMeth,Fertrin	0	none	metals too high

5.5.2 Selecting Final Treatment Trains

In order to select options for final treatment trains the system includes mechanisms to screen the total treatments. The user selects the third shortest, second shortest or the shortest treatment trains as the maximum number of treatments per train for each waste or the third lowest, second lowest or the lowest total mass of secondary wastes (wastes produced from the treatments) as the maximum mass of secondary wastes per train from treatments in the train. Table 5.19 lists the number of treatment trains produced from selecting these options. Once one option has been selected (e.g. either number of treatment trains or mass of secondary waste) if the list is still too long, the other option may be selected so that the list of treatment trains is refined even further. The final list of treatment trains can then be matched to determine the treatments that can be used to co-treat more than one waste. When economic data are incorporated, this will become an added selection factor.

Table 5.19 Number of final trains after sorting using specified criteria

Option	**Number of Final Trains**
shortest treatment train	74
2nd shortest treatment train	302
3rd shortest treatment train	963
lowest secondary wastes	51
2nd lowest secondary wastes	100
3rd lowest secondary wastes	135

Treatment trains were matched for the entire list of trains to determine the options available for co-treatment of the wastes. The final option for each waste was selected on the basis of the maximum potential for co-treatment of wastes, considering potentials for reuse or recycling first. Table 5.21 lists the option that was recommended, with Table 5.20 listing the treatment codes used in these tables. Trains with a regulation result means that those wastes are acceptable for release into those environments.

The matching treatments and results indicate the treatments which can be used for co-treatment. In Option A (Table 5.21), all records were assessed to determine the maximum potential for co-treatment by matching treatment trains. It must be noted that in this final option, settling is used twice for sewage sludge although the same treatments are not allowed more than once in one train. Since one treatment was an acid settling and one a basic settling, they were considered to be two different treatments. It must also be reiterated that this option examined the treatment trains for recycling opportunities before any disposal possibilities. In addition, these trains have not been pre-sorted for train length or mass of secondary waste.

A total of fourteen wastes could be recycled to water, with twelve wastes being co-treated using carbon absorption followed by ion exchange. Nine of those wastes would be previously co-treated with ultrafiltration, one with reverse osmosis and one with dissolved air flotation. Prior to those treatments, two of the nine wastes would require neutralization, while three of the others would require a variety of treatments.

Table 5.20 Codes for treatments and disposal options in the treatment trains. An A added to the code denotes an acid waste; a B denotes a basic waste.

Treatment	Code	Treatment	Code
fixed hearth incineration	FHI	neutralization	N
magnetic separation	MS	reverse osmosis	RO
anaerobic digestion	AD	precipitation	P
belt filter	BF	sand filtration	SF
evaporation	EV	screening	SC
multiple hearth incineration	MHI	settling	SE
activated sludge	AS	solvent recycling	SR
API oil separation	API	ultrafiltration	UF
carbon adsorption	CA	baghouse filter	BH
disk filter	DF	electrostatic precipitation	EP
dissolved air flotation	DAF	packed tower	PT
ion exchange	IX	Venturi scrubber	VS
liquid injection incineration	LII		
Ontario Landfill Reg.	Landfill	Ontario Air Pollution Reg.	Air
Ontario Effluent Reg.	Effluent	Ontario Land Treatment Regs	Land treat

By selecting trains generating a maximum mass of secondary waste equal to the third lowest mass, Option B (Table 5.22) was generated. Fewer recycled wastes are included since the primary criterion was to select trains with a secondary waste mass less than or equal to the third lowest secondary waste mass for each waste. Only eight wastes could be treated for recycling to water and only four could be co-treated with carbon adsorption, with three of these being previously co-treated with ultrafiltration and neutralization; three wastes could be co-treated previously with reverse osmosis.

In Option C (Table 5.23), however, trains were first selected for a maximum length of the third shortest train for each waste, then these were matched for treatment trains. Twelve wastes could be recycled to water and eleven of these could be co-treated with ultrafiltration followed by ion exchange. In this scenario, urea cooling water, gas heating water, cooling water and boiler blowdown could be combined for treatment by disk filtration prior to being combined with other pre-treated wastes for co-treatment by ultrafiltration.

Table 5.21. Option A - final options selected for all wastes by matching treatment trains.

Waste	Treatment Train									Result	Secondary
	1	2	3	4	5	6	7	8	9		Waste, t/yr
regeneration water					N-B	DAF	IX	UF-B	RO	water	74
steel cooling water						SE-B	UF-B	CA	IX	water	1673500
water					BF-A	N-A	UF-B	CA	IX	water	43100
sanitary water					API	N-A	UF-B	CA	IX	water	9260
urea cooling water						API	UF-B	CA	IX	water	32
gas heating water							UF-B	CA	IX	water	2.48
urea heating water							UF-B	CA	IX	water	8800
boiler blowdown							UF-B	CA	IX	water	0.7
plant washings					BF-A	SE-A	UF-B	CA	IX	water	1
cooling tower sludge			MHI	BH	VS	PT	UF-B	CA	IX	water	55916
regenerate						UF-B	RO	CA	IX	water	2000
cooling water							DAF	CA	IX	water	1095
sewage sludge	BF-A	SE-A	N-A	SE-B	DF-B	DAF	AS	CA	IX	water	2
heating water									DAF	water	17
solvent									SR	solvent	0.01
tires									MS	scrap steel	10
scrap steel										scrap steel	0
salt water						DF-A	N-A	SE-B	DAF	salt water	213780
iron oxide										iron ore	0
carbon dioxide/ particulates - lime							VS	PT	EP	carbon dioxide	184
mill scale									MS	Landfill	1663
carbon dioxide/water									BH	Landfill	64500
carbon dioxide/ particulates - DRI									BH	Landfill	402
equipment										Landfill	0
spent anion resin										Landfill	0
spent cation resin										Landfill	0
urea process water					DF-B	SE-B	UF-B	RO	IX	Effluent	6
lubrication oil				LII	BH	PT	UF-A	DAF	IX	Effluent	382
activated carbon							FHI	VS	IX	Effluent	0.4
triethylene glycol						MHI	BH	PT	EP	Air	1
monoethanolamine						MHI	BH	PT	EP	Air	36
oil filters						FHI	VS	PT	EP	Air	3450
paper filters							FHI	VS	EP	Air	0.25
canister filters							FHI	VS	EP	Air	0.1
dust filters							FHI	VS	EP	Air	0.5
carbon dioxide/ particulates - steel						BH	PT	N-A	SE-B	Landtreat	817967
NH_3 cooling water					DAF	IX	UF-B	CA	RO	Landtreat	26

Table 5.22. Option B - final options generated for all wastes by first selecting trains which produce a maximum of the third lowest secondary waste mass, then matching treatment trains.

Waste	Treatment Train								Result	Secondary Waste, t/yr
	1	2	3	4	5	6	7	8		
heating water								UF-B	water	550
regenerate					IX	CA	UF-B	RO	water	520
plant washings		SE-A	N-A	SE-B	SF-B	UF-B	IX	RO	water	3
cooling water				AS	CA	UF-B	DAF	RO	water	2560
steel cooling water					BF-B	N-B	UF-B	CA	water	453130
boiler blowdown						N-B	UF-B	CA	water	0.07
cooling tower sludge		MHI	BH	BS	PT	N-A	UF-B	CA	water	55834
sanitary water	SF-A	UF-A	RO	N-A	IX	UF-B	DAF	CA	water	10400
solvent								SR	solvent	0.01
scrap steel									scrap steel	0
salt water					DF-A	SE-A	UF-A	N-A	salt water	243960
iron oxide									iron ore	0
mill scale								MS	Landfill	1663
canister filters								FHI	Landfill	0.03
spent anion resin									Landfill	0
spent cation resin									Landfill	0
equipment									Landfill	0
carbon dioxide/ particulates - DRI					BH	VS	N-A	UF-B	Effluent	412
carbon dioxide/ particulates - steel			BH	PT	N-A	SE-B	DAF	UF-B	Effluent	819
carbon dioxide/ particulates - lime					VS	N-B	BF-B	UF-B	Effluent	104
urea process water			N-B	DF-B	SE-B	UF-B	IX	RO	Effluent	3
regeneration water						UF-B	IX	RO	Effluent	70
tires								FHI	Air	3
paper filters						FHI	PT	EP	Air	0.04
oil filters					FHI	VS	PT	EP	Air	3450
dust filters						FHI	VS	EP	Air	0.5
triethylene glycol	BF-A	SE-A	DF-A	N-A	SE-B	DAF	IX	UF-B	Landtreat	0.7
sewage sludge			BF-A	SE-A	N-A	SE-B	DF-B	UF-B	Landtreat	1
lubrication oil				LII	PT	N-A	DF-B	UF-B	Landtreat	320
water						SE-A	DF-A	UF-A	Landtreat	49200
gas heating water						N-B	UF-B	RO	Landtreat	0.25
NH_3 cooling water				DAF	IX	UF-B	CA	RO	Landtreat	26
urea heating water				N-B	DAF	UF-B	CA	RO	Landtreat	2210
urea cooling water			API	DAF	UF-B	IX	CA	RO	Landtreat	30
monoethanolamine					MHI	VS	DF-A	N-A	Landtreat	137
carbon dioxide/water							VS	N-A	Landtreat	64500
activated carbon						FHI	VS	IX	Landtreat	0.4

Table 5.23. Option C - final options generated by first selecting trains with a maximum length of the third shortest treatment trains, then matching treatment trains.

Waste	Treatment Train							Result	Secondary
	1	2	3	4	5	6	7		Waste, t/yr
water				N-A	SE-B	UF-B	IX	water	63900
sanitary water			API	DAF	N-A	UF-B	IX	water	9300
sewage sludge	BF-A	SE-A	N-A	SE-B	DAF	UF-B	IX	water	1.5
urea cooling water					DF-B	UF-B	IX	water	36
gas heating water					DF-B	UF-B	IX	water	2.5
cooling water					DF-B	UF-B	IX	water	1140
boiler blowdown					DF-B	UF-B	IX	water	0.7
steel cooling water					BF-B	UF-B	IX	water	996690
urea heating water						UF-B	IX	water	8800
plant washings				BF-A	SE-A	UF-B	IX	water	1
regenerate					UF-B	RO	IX	water	2000
heating water							DAF	water	17
solvent							SR	solvent	0.01
tires							MS	scrap steel	10
scrap steel								scrap steel	0
salt water				DF-A	SE-A	UF-A	IX	salt water	596640
iron oxide								iron ore	0
carbon dioxide/ particulates - lime					BS	PT	EP	carbon dioxide	184
mill scale							MS	Landfill	1663
carbon dioxide/water							BH	Landfill	64500
carbon dioxide/ particulates - DRI							BH	Landfill	402
spent cation resin								Landfill	0
spent anion resin								Landfill	0
equipment								Landfill	0
cooling tower sludge								Landfill	0
urea process water			DF-B	SE-B	UF-B	RO	IX	Effluent	6
lubrication oil		LII	BH	PT	UF-A	DAF	IX	Effluent	382
activated carbon					FHI	VS	IX	Effluent	0.4
triethylene glycol				MHI	BH	PT	EP	Air	1
monoethanolamine				MHI	BH	PT	EP	Air	36
oil filters				FHI	VS	PT	EP	Air	3450
paper filters					FHI	VS	EP	Air	0.25
dust filters					FHI	VS	EP	Air	0.5
canister filters					FHI	VS	EP	Air	0.1
carbon dioxide/ particulates - steel				BH	PT	N-A	SE-B	Landtreat	818
regeneration water						UF-B	RO	Landtreat	176
NH_3 cooling water			DAF	IX	UF-B	CA	RO	Landtreat	26

The last example of final options, Option D (Table 5.24), was determined by first selecting trains for a maximum length of the third shortest treatment trains, then finding trains with secondary waste masses less than or equal to the third lowest secondary wastes and, finally, matching the treatment trains. Only six of the wastes could be recycled to water, compared to twelve in previous examples.

None of these scenarios take cost into consideration, which would add a major factor in selection. In addition, the treatment and recycling or disposal of secondary waste still has yet to be considered. However, the system allows the user to make a number of choices to determine final treatment and co-treatment options. Both the short treatment train (Option C) and low secondary waste (Option B) options allow the user to reduce potential costs before these would be explicitly calculated. The system does provide a mechanism to determine the volume of secondary wastes; further additions to the system must be incorporated before the nature of the wastes is also considered and then added to the list of wastes for treatment.

5.5.3 Wastes Classed as Untreatable

Seven of the wastes could not be treated for one or more of the following reasons:

1. Components of the wastes did not match any of the inputs;
2. One or more of the waste parameters could not be reduced to acceptable levels by the treatments in the knowledge base; or
3. The knowledge base was too restrictive to accept the waste.

Further research is necessary to determine if the knowledge base treatment limits and formulae are sufficiently accurate for the purposes of this program. Markets outside the industrial estate need to be identified, the materials defined and included in the data base to broaden the data base scope. In addition, the number of treatments could be increased to cover a broader range of material types.

The actual reason that a waste is rejected for treatment is not specified by the program, since it would require storage of each attempted treatment potential and the parameters that were not met. Even if a material does not match any of the inputs for recycling, it is still tested for potential for treatment for disposal. At least one parameter must cause it to be rejected for disposal, but that parameter may not be the same for each treatment train or for each standard. The reasons listed in Table 5.18 have been generated using the experience and judgment of the author.

It is possible that 'gaps' in the treatability range of the treatments resulted in some of the materials being considered as untreatable. For example, sand filtration treats materials with less than 750 ppm particles while settling treats materials with greater than 1500 ppm particles. Any material with a particle range between 750 and 1500 ppm would not be treatable by either of those two treatments so a third filtering treatment, continuous precoat disk filter, which covers a range from 50 to 5000 ppm particles, was included. Although an attempt was made to include all ranges for each of the treatments, there may be some gaps which would result in some wastes being considered as untreatable.

The list of untreatable wastes includes ammonia. Since ammonia is not an input but a product, it is not considered as an end result for recycling. The system considers that most plants would try to reduce loss of a saleable product to the greatest extent possible as a basic economic necessity and product loss could be also considered as internal plant housekeeping, to be further examined under waste minimization. Fugitive losses of urea, which occur but are not listed here as no data were available, would also have been listed as non-treatable for the same reason.

The system does show some weaknesses when an output is not in the same state as an input. Since only approximately 14 of 29 parameters are included for each material, some of those parameters may not have any value. For example, the CFC content of a solid is not usually measured. Where possible, formulae have been included to provide parameter estimates but, for example, iron is not measured for gases although it may be a component of the particles. Consequently, the dust output may contain sufficient iron for recycling but has not been included, unless it is listed as a main component of the material.

To resolve this problem, the user could be requested to provide data for all 29 parameters. Data on specific heavy metals could also be included, if a total value for heavy metals was entered by the user.

Table 5.24. Option D - final options determined by first selecting for trains with a maximum length of the third shortest trains, followed by selecting trains producing a maximum secondary waste mass equal to or less than the third lowest secondary waste mass, then matching the resulting treatment trains.

Waste	Treatment Train						Result	Secondary Waste, t/yr
	1	2	3	4	5	6		
heating water						UF-B	water	550
urea cooling water				SF-B	UF-B	IX	water	36
gas heating water					UF-B	IX	water	2.5
urea heating water					UF-B	IX	water	8800
boiler blowdown					UF-B	IX	water	0.7
steel cooling water				BF-B	UF-B	CA	water	453140
solvent						SR	solvent	0.01
tires						MS	scrap steel	10
scrap steel							scrap steel	0
iron oxide							iron ore	0
carbon dioxide/particulates - lime				BH	PT	EP	carbon dioxide	21
mill scale						MS	Landfill	166
cooling water					DAF	BF-B	Landfill	52555
carbon dioxide/water						BH	Landfill	64500
carbon dioxide/particulates - DRI						BH	Landfill	402
spent anion resin							Landfill	0
equipment							Landfill	0
cooling tower sludge							Landfill	0
spent cation resin							Landfill	0
sewage sludge	BF-A	SE-A	N-A	SE-B	DAF	UF-B	Effluent	1
regeneration water					UF-B	RO	Effluent	176
urea process water		DF-B	SE-B	UF-B	IX	RO	Effluent	3
paper filters				FHI	PT	EP	Air	0.04
monoethanolamine			MHI	BH	PT	SE-B	Air	36
triethylene glycol			MHI	BH	PT	SE-B	Air	1
oil filters			FHI	PT	VS	SE-B	Air	3450
canister filters				FHI	VS	SE-B	Air	0.1
dust filters				FHI	VS	SE-B	Air	0.5
lubrication oil			N-A	LII	PT	SE-B	Landtreat	322
carbon dioxide/ particulates - steel			BH	PT	N-A	SE-B	Landtreat	818
plant washings				BH-A	N-A	SE-B	Landtreat	0.7
salt water				SE-A	UF-A	RO	Landtreat	2526632
water			N-A	BF-B	UF-B	IX	Landtreat	43100
sanitary water				DF-A	UF-A	IX	Landtreat	9100
NH_3 cooling water		SF-B	UF-B	RO	CA	IX	Landtreat	46
activated carbon				FHI	VS	IX	Landtreat	0.4
regenerate						IX	Landtreat	480

However, it must be recognized that analyses are costly, and the more parameters that are needed, the slower the system will be and the more difficult it is for the user to provide all the data.

5.5.4 Treatment Options

Selection of the shortest treatment trains or the lowest secondary wastes does not consider co-treatment of the wastes but can be used to compare with the final options selected. By selecting the maximum length of the trains or the maximum mass of secondary wastes as equal to the second or third shortest or lowest, the number of trains can be reduced. Since no economic data have been included, the shorter trains or those with lower secondary wastes would conceivably be more economical. Thus, by using those trains to determine co-treatment potentials, the more economical options would be chosen. Table 5.25 lists the characteristics of the developed options which, together with economic data, can be used to decide the option used for treating the wastes. The user may want to consider more than one option in the preliminary stage and use cost analysis and bench testing to determine the most acceptable treatments.

For the case study, the selected options were examined to determine which would be recommended to the Point Lisas Industrial Estate for managing wastes from the four plants. Since waste recycling is a primary goal, a balance must be made between the maximum number of wastes for recycling, the minimum mass of secondary wastes which must be also considered and the number of treatments for each option. Although option D produces the lowest volume of secondary wastes and has the lowest number of treatments, it also recycles the lowest number of wastes. Option A recycles the most wastes but also produces the largest mass of secondary wastes. Option C, however, recycles almost the same number of wastes but has significantly fewer treatments and produces less secondary wastes. Consequently, option C would be the recommended option for the current wastes and masses, pending examination of economic data and examination of potential treatment, recycling and disposal options for the secondary wastes.

Table 5.25 Characteristics of the selected options that may be used for determining the final treatments for treating the wastes.

Option	Wastes Recycled		No. of Treatments		Secondary Wastes, t/yr	
	No.	Mass, t/yr	Recycle	Total	Recycle	Total
A	20	50,392,000	38	73	2,008,000	2,079,000
B	12	48,797,000	36	103	767,000	890,000
C	18	50,266,000	27	59	1,688,000	1,750,000
D	11	30,711,000	11	50	463,000	3,166,000

With regard to co-treatment of the wastes for the Point Lisas Industrial Estate, option C indicates that a centralized facility for treating a number of liquid wastes for recycling as water is feasible (Table 5.26). A significant portion of these wastes could be recycled. Examination of other treatment trains may reveal potentials for treatment of secondary wastes. A recycling facility for solvents should also be established while treatments to recycle tires, equipment and other scrap steel for input into ISPAT should be considered. Some treatments would be required prior to sending the wastes for co-treating.

Table 5.26 Mass potentially recycled by co-treating wastes to water

Waste	Initial Mass tonnes/yr	Recycled Mass tonnes/yr	% Recycled tonnes/yr	% of Recycled Mass (t/yr)
water	1,213,000	1,128,900	94.64	3.61
sanitary water	414,700	405,400	97.75	1.29
sewage sludge	1.5	5.5	78.11	0.00
urea cooling water	1,220	1,180	97.02	0.00
gas heating water	2.48	110	97.80	0.00
cooling water	52,560	51,420	97.83	0.16
boiler blowdown	33	32	97.80	0.00
steel cooling water	27,630,000	26,633,800	96.39	85.06
urea heating water	296,300	287,500	97.03	0.92
plant washings	18	17	93.83	0.00
regenerate	24,000	22,000	91.66	0.07
heating water	2,783,000	2,783,000	100.00	8.89
Total	31,313,400	32,395,300	96.66	100.00

According to option C, a number of wastes must be landfilled, land treated or released to air or water. Markets for those materials should be found outside the four plants, and, if necessary, off the estate site. For example, molecular sieve is primarily aluminum oxide; it could readily be used as an input for an aluminum processing plant or, potentially, for making sandpaper. However, with the results from the above potential options, the following recommendations have been generated for the industrial estate and the four companies.

The Recommended Option

Option C was selected as the recommended option, involving selection of trains shorter or equal to the third shortest treatment trains followed by matching the treatment trains. Implementation of this option would require a central treating facility for the estate, to provide the treatments for co-treating wastes from more than one plant. Some waste would require treatment by the producing plant prior to treatment at the estate facility. Wastes which cannot be co-treated must still be treated on site prior to recycling or disposal. The following outlines the treatments required by each plant and those that should be included at the estate treatment centre.

Point Lisas Industrial Estate Treatment Centre

The main potential for co-treatment lies in treating wastes to recycle water (Table 5.26). Eighteen treatments are needed to treat the 14 water-containing wastes which are produced by all four plants, producing a total of 1,082,000 tonnes of secondary waste per year. This would allow a total of 32,395,300 tonnes of water to be recycled, 96.7% of the initial waste. By introducing waste minimization within each plant, the total volume of wastes and secondary wastes could be reduced, thus requiring a smaller treatment facility.

A central treatment plant should be installed, which provides treatments for wastes from a number of plants to produce materials that can be used as inputs. This treatment centre should provide facilities for co-treating wastes from more than one plant. The recommended trains, waste inputs and final materials are listed in Table 5.27. Through discussions with all plants on and surrounding the estate, potentials for reducing contaminants in the wastes could be explored and the number of treatments required could be reduced.

Table 5.27 Wastes for treatment by a centralized facility, the treatment trains required and the resulting materials.

Waste	Producing Plants	Treatment Train				Result	Secondary Waste, t/yr
		1	2	3	4		
water	PPGP TTMeth Fertrin	N-A	SE-B	UF-B	IX	water	63900
urea cooling water	Fertrin		DF-B	UF-B	IX	water	36
gas heating water	PPGP		DF-B	UF-B	IX	water	2.5
cooling water	TTMeth		DF-B	UF-B	IX	water	1140
boiler blowdown	TTMeth		DF-B	UF-B	IX	water	0.7
urea heating water	Fertrin			UF-B	IX	water	8800
steel cooling water	ISPAT			UF-B	IX	water	996690
sewage sludge	PPGP			UF-B	IX	water	1.5
sanitary water	PPGP, Fertrin			UF-B	IX	water	9300
plant washings	PPGP			UF-B	IX	water	1
regenerate	Fertrin				IX	water	2000
solvent	TTMeth, Fertrin				SR	solvent	0.01
oil filters	ISPAT, TTMeth	FHI	VS	PT	EP	Air	3450
paper filters	PPGP		FHI	VS	EP	Air	0.25
dust filters	PPGP		FHI	VS	EP	Air	0.5
canister filters	PPGP, Fertrin		FHI	VS	EP	Air	0.1
regeneration water	TTMeth				RO	Landtreat	176
NH_3 cooling water	Fertrin				RO	Landtreat	26

Although only the Trinidad and Tobago Methanol plant and Fertrin produce solvent as a waste, other plants also use solvents, as determined by the inputs. These are not listed as a waste as they are allowed to evaporate and the waste quantities could not be determined. By installing a solvent recycler for the entire estate, more plants would be encouraged to save and recycle their solvents instead of pouring them into drains or allowing them to evaporate. This would also discourage the use of Saf-Sol, a chlorinated solvent which cannot be readily recycled.

Most of the plants would produce sewage sludge although this waste was again not listed by those plants. Little seemed to be known about each plant's treatment of sewage. A centralized facility is needed to treat this waste. Further information is required to determine the characteristics of the waste to better determine the treatments needed.

It must be noted that, although a packed tower treatment is not required for paper, dust filters or canister filters, it was recommended. Since all the filters can be treated with fixed hearth incineration, it was considered acceptable to add this pollution control device to remove any heavy metals or acid gases and to reduce the overall cost of the incineration facility by allowing it to treat more wastes. Filters from plants other than the four included in this system could also be incinerated at this facility. By searching the total treatment file, it was determined that the ash from incinerating these wastes could be landfilled.

Some plants recycle lubrication oil off-site at the Trinidad and Tobago Oil Refinery while others treat it as a waste. The estate should encourage recycling by setting standards for the waste oil or oily water and providing a central collection point for all the estate plants. This has been recommended rather than attempting to treat and discard it.

The estate should also assist plants in finding markets for waste materials such as molecular sieve which could possibly be sold to aluminum manufacturers. It should also assist plants in minimizing waste volumes and reducing the hazardous nature of wastes since this will reduce the risk of materials being discarded onto estate property, thus reducing the value of the estate land or potentially creating a situation which will require expensive future remediation. The minimization and recycling of water should be emphasized due to the fresh water shortages in the local community and the deleterious effects of effluents on the aquatic life in Couva Bay.

Due to the presence of oil in the sanitary wastes, an API oil separator is required to initially treat this waste. By encouraging plants to prevent oil from entering the sanitary waste system, this treatment should not be required.

Phoenix Park Gas Processors Limited

The wastes requiring treatment from Phoenix Park Gas Processors are listed in Table 5.28, with their masses, final destinations and train results. The treatments required for treating those wastes on the plant site are illustrated in Figure 5.2. It must be noted that the gaseous compressor oil waste was not included since measures were already being taken to eliminate this waste.

Table 5.28 Wastes from Phoenix Park Gas Processors and their final destinations and results.

Process	**Waste**	**Mass, (T/year)**	**Final Destination**	**Final Result**
NG refining process	water	20,507	recycle	water
NG refining process	carbon dioxide/water	46,600	disposal	landfill
equipment maintenance	canister filters (2 kg/filter)	0.02	disposal	air/landfill
equipment maintenance	dust filters (1 kg/filter)	0.3	disposal	air/landfill
equipment maintenance	paper filters (1 kg/filter)	0.1	disposal	air/landfill
equipment maintenance	molecular sieve	17	potential sale	aluminum
plant maintenance	plant washings	18	recycle	water
heating	gas heating water	1100	recycle	water
sanitary	sanitary water	5900	recycle	water
sanitary	sewage sludge	7	recycle	water
equipment maintenance	slop oil	830	recycle	oil
equipment maintenance	compressor oil (gas)	4	eliminate	none
storage	steel barrels (18kg/drum)	0.4	recycle	steel
equipment maintenance	expand/comp oil	0.2	recycle	oil

Trinidad and Tobago Methanol Gas Company Limited

Table 5.29 lists the wastes from this plant, their masses, final destinations and train results. Figure 5.3 illustrates the treatments required at the plant and the estate treatment facility for these wastes. Measures must be taken to eliminate freon as a waste due to its action as an ozone depleting substance and, if a change of freon is required, it should be captured and recycled. For zinc oxide, nickel catalyst and molecular sieve, other off-site markets should be examined to determine potentials for resale.

Table 5.29 Waste from the Trinidad and Tobago Methanol plant and their final destinations and results.

Process	**Waste**	**Mass, t/year**	**Final Destination**	**Final Result**
methanol production	water	1191400	recycle	water
cooling	cooling water	52600	recycle	water
heating	carbon dioxide/water	18000	disposal	landfill
heating	boiler blowdown	33	recycle	water
cooling/cryogenic	freon	0.3	eliminate	none
equipment maintenance	solvent	5	recycle	solvent
equipment maintenance	nickel catalyst	3.	potential sale	nickel
equipment maintenance	zinc oxide	0.9	potential sale	zinc
equipment maintenance	copper catalyst	60	recycle	copper
equipment maintenance	nickel/molybdenum	1	recycle	nickel/molybdenum
equipment maintenance	molecular sieve	0.3	potential sale	aluminum
equipment maintenance	lubrication oil	0.4	recycle	lubrication oil
equipment maintenance	oil filters (2kg/filter)	0.2	disposal	air/landfill
equipment maintenance	regeneration water	2600	disposal	landfill
equipment maintenance	spent anion resin	3	disposal	landfill
equipment maintenance	spent cation resin	4	disposal	landfill

Fertilizers of Trinidad and Tobago

The wastes from this plant (including the urea plant), their final destination and results are listed in Table 5.30. Figure 5.4 illustrates the treatments and destinations required for these wastes. Although ammonia was listed as being not treatable, it should be recycled back into the manufacturing process - a better alternative would be to minimize loss of this product. Markets for a number of the metal waste products need to be determined, as does a market for the molecular sieve. The salt water system should be examined more carefully and the cooling tower rebuilt to reduce the volume of warm water being discharged into Couva Bay and to reduce the amount of biocides and anticorrosives being used.

The ammonia cooling water requires a number of treatments to enable it to be land treated. Efforts should be made to reduce the contaminants in this waste, especially ammonia, which would then reduce the treatments required. Heavy metals in the triethylene glycol and monoethanolamine should also be reduced to increase the options for disposal for these materials. At present, there is no acceptable disposal method for triethylene glycol while monoethanolamine requires incineration and treatment of emissions.

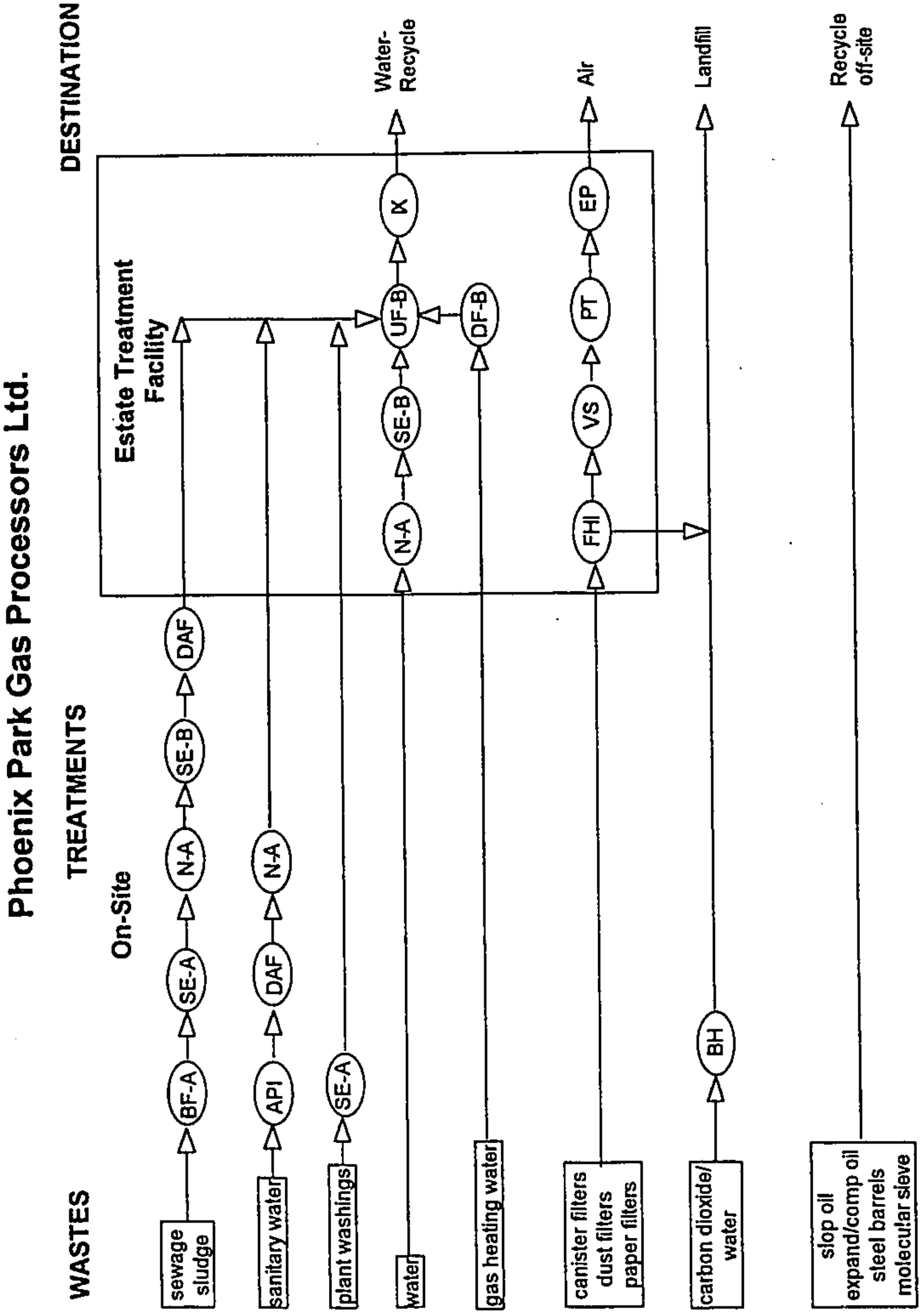


Figure 5.2 The treatments and destinations of the wastes produced by Phoenix Park Gas Processors Ltd., showing the treatments required on-site at the plant and at the estate treatment facility.

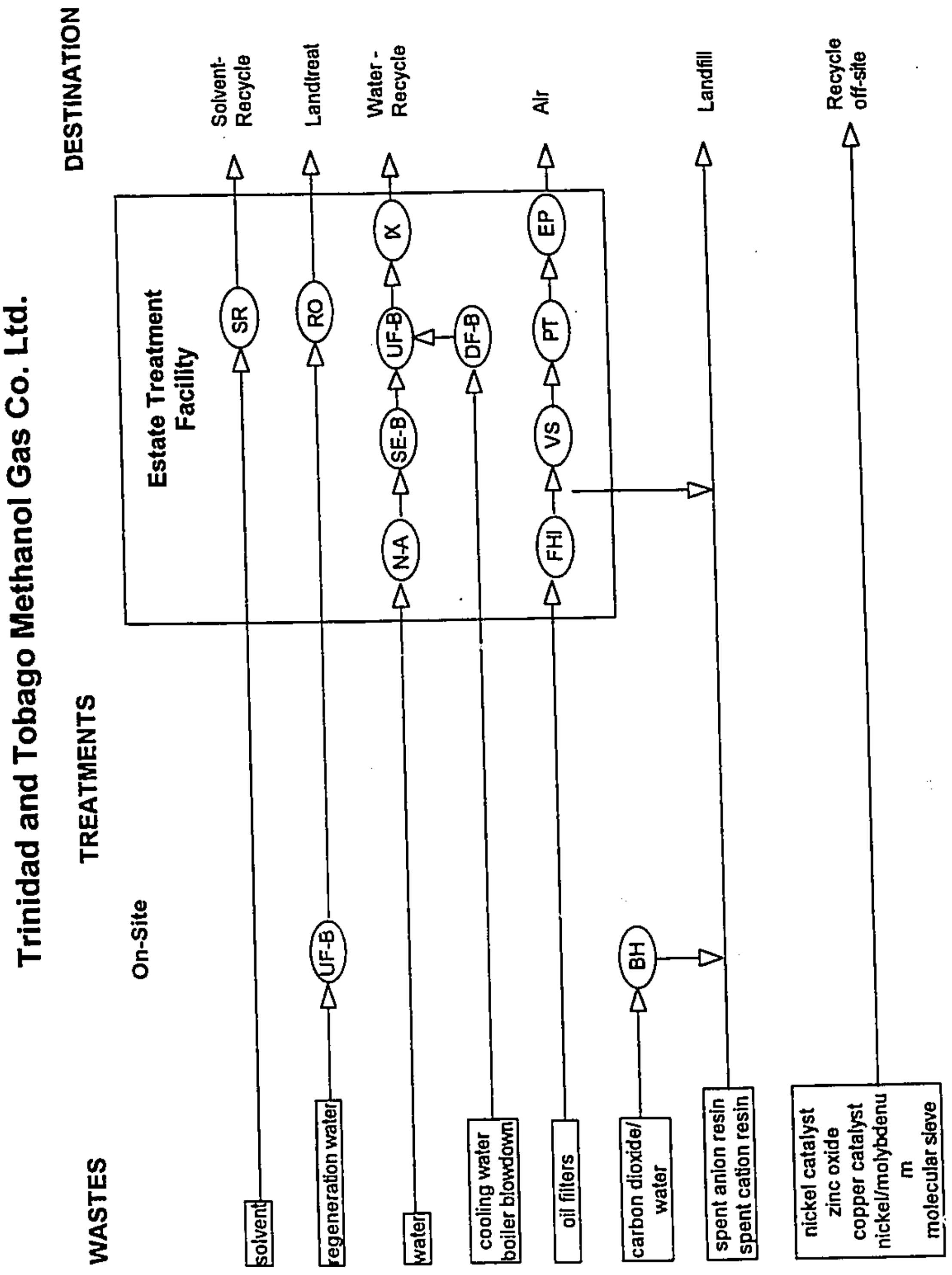


Figure 5.3 The treatments and destinations of the wastes produced by the Trinidad and Tobago Methanol plant, showing the treatments required on-site at the plant and at the estate treatment facility.

Table 5.30 Wastes from the Fertilizers of Trinidad and Tobago plant, their final destinations and results.

Process	**Wastes**	**Mass, t/year**	**Final Destination**	**Final Result**
process - ammonia	ammonia	7	eliminate	none
process - urea	ammonia	890	eliminate	none
process - urea	urea process water	90	disposal	effluent
equipment maintenance	regenerate	24000	recycle	water
equipment maintenance	monoethanolamine	110	disposal	air
equipment maintenance	triethylene glycol	3	disposal	air
equipment maintenance	solvent	0.7	recycle	solvent
equipment maintenance	activated carbon	0.3	disposal	effluent
equipment maintenance	canister filters	0.05	disposal	air/landfill
equipment maintenance	molecular sieve	0.4	recycle	aluminum
equipment maintenance	reformer tubes	20	recycle	iron
equipment maintenance	cobalt/molybdenum	4	recycle	cobalt/molybdenum
equipment maintenance	zinc oxide	6	recycle	zinc
equipment maintenance	nickel oxide	20	recycle	nickel
equipment maintenance	nickel chromium	8	recycle	nickel/chromium
equipment maintenance	zinc/copper	40	recycle	zinc/copper
equipment maintenance	iron/chromium	20	recycle	iron/chromium
equipment maintenance	nickel	3	recycle	nickel
equipment maintenance	iron oxide	70	recycle	iron oxide
equipment maintenance	lubrication oil	41	recycle	oil
equipment maintenance	oily wastes	2	recycle	oil
equipment maintenance	water	1380	recycle	water
equipment maintenance	scrap steel	60	recycle	scrap steel
equipment maintenance	spent anion resin	0.2	disposal	landfill
equipment maintenance	spent cation resin	0.2	disposal	landfill
plant maintenance	sanitary water	408,800	recycle	water
heating - ammonia	heating water	2,783,000	recycle	water
cooling - ammonia	ammonia cooling water	1270	disposal	landtreatment
cooling - urea	urea cooling water	1220	recycle	water
heating - urea	urea heating water	296,300	recycle	water
salt water cooling	salt water	17,870,400	recycle	salt water

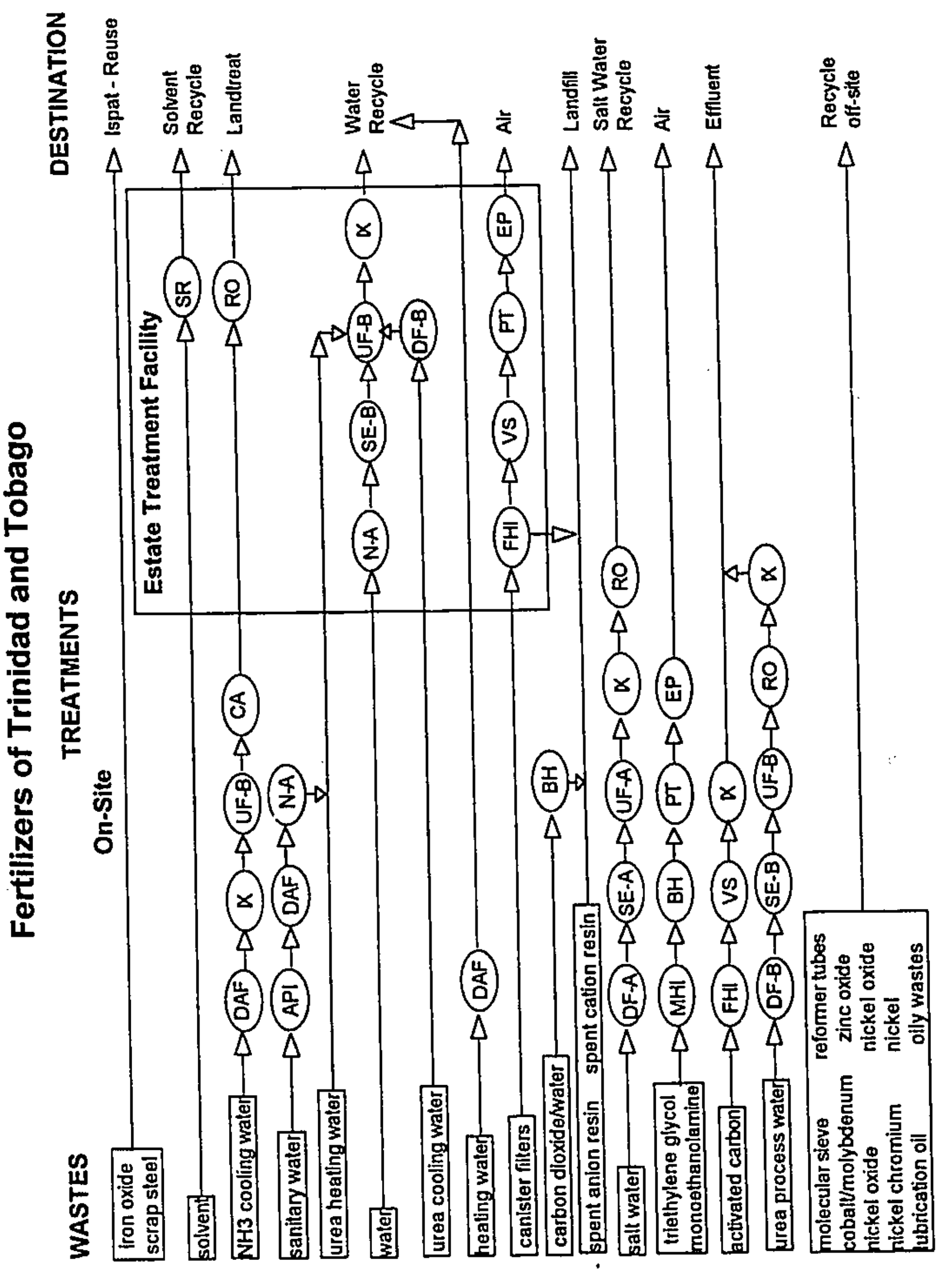


Figure 5.4 The treatments and destinations of the wastes produced by the Fertilizers of Trinidad and Tobago plant (including the urea plant), showing the treatments required on-site at the plant and at the estate treatment facility.

Caribbean ISPAT Ltd.

Table 5.31 lists the wastes from the ISPAT plant, their masses, final destinations and results while the required treatments and destinations for wastes are illustrated in Figure 5.5. There is no recommended disposal method for the cesium as there are no facilities to dispose of this waste in an acceptable manner on the island. Possible alternative mechanisms should be investigated to eliminate this waste.

Table 5.31 Wastes from the ISPAT plant, their final destinations and results.

Process	**Wastes**	**Mass, t/year**	**Final Destination**	**Final Result**
DRI production	CO_2/particulates - DRI	985,116	disposal	landfill
DRI production	nitrogen	149	disposal	air
lime production	CO_2/particulates - lime	102	recycle	carbon dioxide
steel production	CO_2/particulates - steel	814	disposal	landtreat
steel production	mill scale	5,400	disposal	landfill
steel production	slag	108,000	recycle	steel
equipment maintenance	nickel catalyst	60	recycle	nickel
equipment maintenance	lubrication oil	250	recycle	oil
equipment maintenance	oil filters (3 kg/filter)	1,870	disposal	air/landfill
equipment maintenance	cesium source	0.1		
equipment maintenance	metal equipment	12	disposal	landfill
equipment maintenance	scrap steel	1	recycle	steel
equipment maintenance	tires	12	recycle	steel
cooling	cooling tower sludge	22,000	disposal	landfill
cooling	steel cooling water	27,630,500	recycle	water

It was recommended that tires be recycled for their steel. According to plant personnel, the roads at the ISPAT plant cause deterioration of vehicle tires very quickly and road upgrading and maintenance would probably reduce the quantity of waste tires being generated. Tires are recycled on the island and the potential for recycling these tires at those facilities should be investigated since this would probably be a cheaper alternative than the recommended option. Incineration or landfilling of the remaining rubber would be an option, according to the total list of treatment trains.

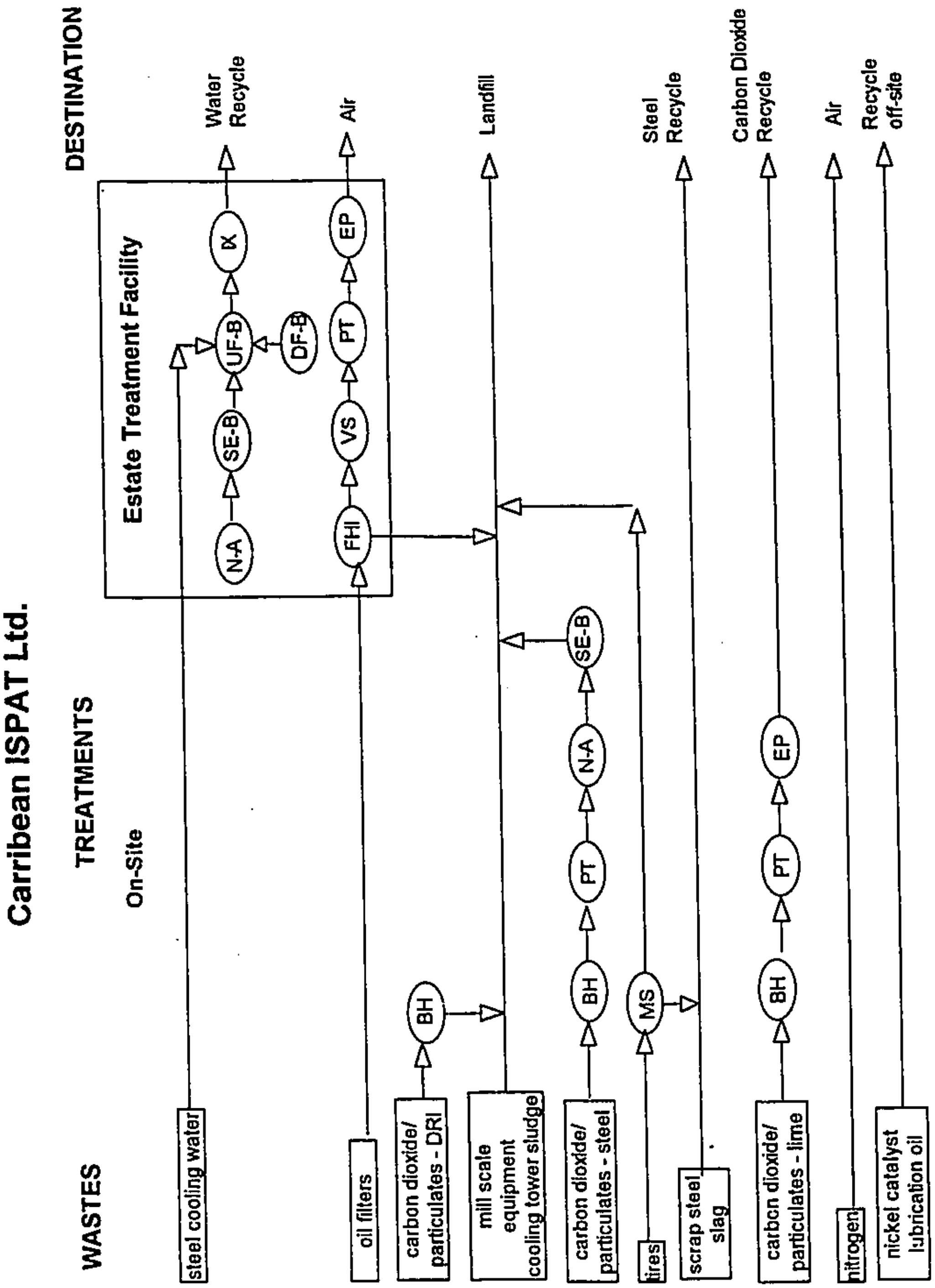


Figure 5.5 The treatments and destinations of the wastes produced by Caribbean ISPAT Ltd., showing the treatments required on-site at the plant and at the estate treatment facility.

Although there are baghouse filters on the meltshop, they are undersized for the facilities and are not maintained. It is important for employee health and safety that these particulate removal systems be upgraded and new control facilities added as suggested.

Secondary Wastes

A significant volume of secondary wastes are produced by the treatments which will require either treatment or disposal. A total of 1,750,000 tonnes per year of secondary waste would be produced by the recommended options. Examination of the total treatment table can provide some answers as to the potential for managing those secondary wastes. For example, a search of the table indicates that oil, canister, paper and dust filters can be incinerated, then the ash landfilled; the emissions are acceptable, once treated, for release. Tires may be recycled for their steel and the rubber landfilled. However, further development of the model is required to incorporate a mechanism to handle secondary wastes more easily.

5.6 Model for Economic Analysis of Treatment Trains

At present the system does not include economic data although a mechanism and model for incorporation of this data have been included in the system. The costs for treatments must take a number of factors into account. Most treatment systems have a minimum equipment size and, consequently, a minimum material volume. Below that volume, the total cost of constructing and operating the facility is constant, so the cost per volume of material increases as the volume decreases.

Once the material volume reaches the minimum, however, the cost per volume tends to decrease as the scale of the facility and equipment increases to a maximum. Beyond this maximum, more than one facility is required so the costs again increase. Consequently, to determine the cost per volume of material for a group of industries, the following information is needed:

the minimum and maximum capacities of treatment equipment or facilities;

special equipment requirements as indicated by material parameters;

minimum construction cost;

minimum operating costs;

cost/volume material treated above the minimums;

cost of input materials; and

value of waste materials sold for recycling.

Rather than determining the cost per individual treatment train, the cost would be assessed per treatment. Once treatment trains are matched and the final options for a treatment system have been selected, the secondary wastes being produced by the treatments can be listed and defined. These wastes are evaluated against the selected treatment trains to determine if they can be successfully treated; if not, then new treatment trains must be included. Once all secondary wastes have been considered, any tertiary wastes from those treatments must be considered, until all wastes have been evaluated.

The total volume of material treated by a treatment can then be determined, as well as the total volume of all outputs. The cost of all treatments can then be calculated to determine the cost per volume of recycled material and this can be compared with the cost per volume of raw material and the disposal costs of the waste materials.

Such a comparison would not include the environmental and social costs of waste disposal, which can be significant but are usually borne by either the government or the individual (Micheal, 1991). In developing countries with no environmental standards, discarding wastes into the environment often results in damage to the environment and human health, and these effects should also be considered (Durning, 1991). Future liabilities are also not included, although these can also be significant (Hirschhorn and Oldenburg, 1991).

5.7 Further Improvements to the KBDSS

In addition to the economic model described above, the system would require further improvements before it could be considered fully utilizable for a specific application. This section outlines some of the improvements required.

1. The results from the system require further validation to both improve the present system and to ensure that the results can be presented as viable solutions. Such validation could include:

   bench testing of the given treatment input limits and output formulae to determine the accuracy of those formulae;

   bench testing of the waste materials to determine the acceptability of the treatment trains and the characteristics of the final results, particularly with regard to the stated requirements of the needed result.

2. The present system does include forms for the user to complete to input data into the data base and the knowledge base. However, assistance is needed by providing "help" dialogue for the user to define the meaning of the parameters and to give a better understanding of the operation of the program.

3. In addition to the economic data, environmental and human health data should be included to provide some indication of the potential threat to the environment and human health. This could be incorporated as a "relative risk" factor, where materials of concern are given a relative rating.

4. The current system does not include materials required for proposed treatments (e.g. acids or bases for neutralization or flocculants for precipitation) as inputs to the plant, but these should be considered once the recycling options for wastes have been selected.

5. At present, Ontario regulation standards are being used to determine the acceptability of a material for disposal to the environment. Further details on the specific site and the actual capacity of the local environment to accept the material should also be included in the system database, as well as a model to calculate acceptable disposal parameters from such information. This would include information such as river or stream flow volumes, ground water table, soil information, prevailing wind speeds and directions, etc. This would allow managers of industrial estates where environmental standards do not exist to better understand the capacities of the environment and to set site-specific standards for the estate.

6. The data and knowledge base would require upgrading to include more of the inputs and treatments available on the specific industrial estate and the local area. The greater the data base, the greater the potential for finding recycling options.

7. The model requires further development to determine options for managing secondary wastes, once an option for a waste has been selected.

5.8 Summary

Four industrial plants, a methanol, fertilizer/ammonia, natural gas and steel plants, located on the Point Lisas Industrial Estate in Trinidad, were selected as the case study for this research. A total of 73 wastes were produced by the four plants, 44 different types of wastes.

The system generated over 4,600 treatment train options for treating the plant wastes. By selecting trains using three selection options (length of treatment train, mass of secondary waste, potential for co-treatment of wastes), the preferred treatment trains for each waste and the potentials for co-treatment were determined. The suggested options were then examined to determine which would entail the fewest treatments yet treat the greatest number of wastes and recommendations were made for reuse and recycle of the wastes on the estate. The treatment train table can be further examined to determine options for managing secondary wastes. Once costs have been introduced into the system, the user will have another criterion to assess the recommended options.

Chapter six will present the conclusions and recommendations for further work arising from this research.

6.0 Conclusions and Recommendations

6.1 Research Summary

Achieving sustainability requires that the concept of the consumer society must be replaced by a conserver society, in the hope that resources will be available for future generations. Production systems must be designed with sustainable and environmental concerns as priorities. Implementation of a waste management program which incorporates waste reduction, material recovery and recycling and disposal with minimal environmental impacts is necessary to meet the goals of sustainability. Such a program should be incorporated at a number of levels to attain the most effective results. At the community level, the concept of industrial ecology, where a group of industries on an industrial estate operate as an ecosystem, can be implemented. By comparing the wastes produced by the plants with the inputs those plants require, the potentials for reusing or recycling those wastes and the treatments required for recycling those wastes can be determined. The requirements for co-treating those wastes for disposal can also be considered. This overall process should be termed integrated resource management, since this requires the managers to consider byproducts as resources rather than wastes.

A mechanism for assisting and promoting integrated resource or waste management is urgently needed in developing countries, where environmental legislation is minimal and sound waste management practices are not practiced. To meet the needs of those countries, any system would have to be inexpensive, include a mechanism for selecting standards and require minimal equipment and expertise to run.

The goals of this research included:

a) Development of a prototype knowledge based decision support system for determining the treatment trains necessary for successfully recycling a waste as an input (recycling or reuse) or treating it for disposal;

b) Determination of the input limits and formulae to define outputs from treatments, including secondary wastes from the treatments, using published data from a variety of sources;

c) Consideration of the concerns of developing countries, regarding cost, equipment, expertise and legislation, for integrated resource management planning; and

d) Collection and analysis of data from industries located on the Point Lisas Industrial Estate, Trinidad to be used as a case study application for the prototype system.

A prototype knowledge-based decision support system was developed to compare the parameters of the inputs and wastes of different industries and determine the treatment required, if any, to recycle those wastes as inputs. The treatments required to meet Ontario standards for disposal of the wastes were also determined. The specific number and order of treatments required was termed a treatment train and was determined through exhaustive searching. A maximum of 10 treatments could be used in a treatment train. The knowledge base included the input limits for each parameter for 25 treatment processes and the formulae that define the output parameters from the treatment. The parameters depend upon the state of the byproduct material and a total of 29 parameters were included. The input limits and formulae could be revised to accommodate specific treatment parameters of an existing system. The system also determined the volume of the secondary wastes produced by the treatment train.

The developed system selects input materials that contain components found in the waste material. The characteristics of that material are then compared with those required by each selected input material. The system then selects treatments that will produce the changes needed to match the waste to the input material. The input limits are compared to those of the byproduct; if they fit, the output characteristics are then calculated and the results compared with the input material to determine if they match. The process continues until the materials match, ten treatments have been selected or no further treatments are available.

Once the material has been compared to all inputs, it is compared with the characteristics required for disposal to the environment, and the treatments needed to match those characteristics are determined. The system allows the user to sort the resulting treatment trains according to length of treatment train, matching of treatment trains and volume of secondary wastes produced.

To test the system, the inputs, products and wastes from four industries on the Point Lisas Industrial Estate, Trinidad were incorporated into the data base. Evaluation of the facilities indicated that a number of fugitive wastes were not included in the data and, with the information available, could not be estimated. Moreover, improved maintenance and operating practices, changes in chemicals and equipment and changes in processes would also significantly reduce the volume of wastes being produced. A total of 73 wastes were incorporated into the data base.

The program produced over 4,600 treatment trains, with 7 waste materials which could not be treated to match an input or a standard for disposal. By selecting trains with the lower masses of secondary wastes, matching treatment trains for co-treatment and selecting the shorter treatment trains, final options for treatment were determined. Economic data has yet to be incorporated into the system, although a mechanism for such an incorporation has been included in the developed prototype.

This research provided the following contributions to academic knowledge:

a) Development of a prototype knowledge based decision support system for determining all possible treatment options for successfully treating a waste to attain the parameters of an input (recycling or reuse) or a specified regulation (disposal);

b) Development of a model for selection of treatment options for each waste using one or more of the following criteria:

   i) number of treatments in an option equal to or less than the third fewest, second fewest or the fewest (as selected by the user) treatments per option;

   ii) a mass equal to or less than the third lowest, second lowest or lowest mass (as selected by the user) of secondary wastes from the treatment option; and

   iii) matching of treatments to permit maximum co-treatment of wastes;

c) Incorporation of different types of wastes (i.e. gases, liquids, sludges and solids) and wastes from different producers into the developed prototype system;

d) Determination of the input limits and formulae to define outputs from treating a material with a specified treatment, including secondary wastes from the treatments, using published data from a variety of sources;

e) Development of an approach that considers the concerns of developing countries, regarding cost, equipment, expertise and legislation, for integrated resource management planning.

The remainder of this chapter contains the conclusions and recommendations from this research.

6.2 Conclusions

6.2.1 Developing countries often have little environmental legislation to control disposal or discharge of industrial wastes and have few facilities to treat such wastes. Consequently there is often little knowledge regarding the costs and consequences of discharging industrial waste by an industry and the damage to human health and the environment is often undocumented. Moreover, the lack of environmental standards and awareness of costs for waste disposal has resulted in a lack of interest and knowledge in waste minimization in developing countries and potentials for waste reduction, recycling or reuse that could reduce costs have not been fully explored by industries in developing counties.

6.2.2 By matching the major components and parameters of a waste material with the requirements needed for an input, the potentials for reuse or recycle can be determined. Changes which are needed to match the input requirements can be effected by a series of treatments, each of which change the parameters of the waste material. The series of required treatments is termed a treatment train. Once all treatment trains have been defined for a group of wastes, the final selection of treatment options can be made to provide an optimal waste management system. Selection of treatment trains with few treatments or which produce low volumes of secondary wastes assists in reducing the final train costs, as does co-treating wastes.

6.2.3 To determine if a treatment will effectively treat a specific material, bench tests are necessary for most treatments. However, an indication of the potential for treating a specific material by a treatment can be defined by the parameters of a material. Bench tests are also necessary to more accurately characterize the outputs from a treatment. Sufficient data were available to derive formulae that approximated or estimated the output characteristics for the treatments included in this research.

6.2.4 There is a paucity of literature defining input parameters and the characteristics of the output stream for-waste treatments. There was sufficient information to define or estimate the range of input parameters that can be treated by a treatment and the range of the output characteristics that are produced. However, it must be recognized that the operating conditions of a specific treatment would further define those ranges.

6.2.5 Outputs from treatments may be defined by a formulae, e.g. sludge production from anaerobic digestion (Metcalf and Eddy, 1978). Other treatments may remove a percentage of the input component, e.g. 97% of particles are removed by sand filtration. Finally, the resulting component may be a set amount, dependent upon the properties of that component in the overall material; for example, neutralization will produce a specific pH of 7. In some cases, the final result is a maximum; e.g. dissolved oil flotation will leave no more than 20 ppm and if the input oil level is less than that, then the input amount will remain. Any decision support system which assesses treatment potentials must allow for either a formulae or a set amount to be used.

6.2.6 Much of the wastewater from the plants in the case study should be treated and reused. Since much of Trinidad suffers from water shortages, this would alleviate some water shortages in the area. Moreover, other potentials for reusing and recycling wastes should be further examined by the producing companies and the industrial estate managers to both improve economic return and to reduce the disposal of those wastes into the environment.

6.2.7 The prototype system was able to perform the following tasks:

identify wastes from the case studies which could be reused as inputs without treatment and those which could be recycled as inputs;

determine all treatment options which could be used for recycling the case study wastes or treating them for disposal;

calculate the total quantity of secondary wastes generated by a treatment train and the quantity of the waste material remaining after each treatment;

select trains equal or shorter than the 3rd, 2nd or shortest treatment trains or those trains which produced equal or lower secondary wastes than the 3rd, 2nd or lowest total secondary wastes to assist the user in making a selection of treatment options;

match treatment trains for selection of options for co-treatment of wastes produced by more than one plant and

identify wastes which could not be treated for either recycling or disposal using the treatments incorporated into the data base.

6.3 Recommendations

6.3.1 The results from the system require further validation to both improve the present system and to ensure that the results can be presented as viable solutions. Such validation could include:

bench testing of the given treatment input limits and output formulae to determine the accuracy of those formulae;

bench testing of the waste materials to determine the acceptability of the treatment trains, the characteristics of the final results and the acceptability of the final product.

6.3.2 Further work is required to adequately define the input limits and output formulae of most of the treatments with regard to the general parameters selected and to determine if a broader range of parameters is necessary.

6.3.2 The following economic/capacity data are needed to incorporate costs into the system:

the minimum and maximum capacities of treatment equipment or facility;
special equipment requirements as indicated by material parameters;
minimum construction costs;
minimum operating costs; and
construction and operating cost per volume of material treated above the minimum capacity.

6.3.3 The system requires a mechanism to consider input limits for treatments that are dependent upon either other limits or material volumes. For example, Woods (1994a) indicates that the input limit on particles for filtration may be dependent upon particle size.

6.3.4 The present system does include forms for the user to complete to input data into the data base and the knowledge base. However, assistance is needed by providing "help" dialogue for the user to define the meaning of the parameters and a better understanding of the operation of the program.

6.3.5 In addition to the economic data, environmental and human health data should be included to provide some indication of the potential threat to the environment and human health. This could be incorporated as a "relative risk" factor, where materials of concern are given a relative rating.

6.3.6 The current system does not consider inputs to treatments as inputs to the system, but these also have to be examined when evaluating wastes for recycling. These inputs include materials such as acids or bases for neutralization or flocculants for precipitation. However, the costs of input materials are usually included in the operating costs of the treatment.

6.3.7 Ontario regulation standards were used to determine the acceptability of a material for disposal to the environment. However, further details on the specific site and the actual capacity of the local environment to accept the material should also be included in the system database, as well as a model to calculate acceptable disposal parameters from such information. This would include information such as river or stream flow volumes, ground water table, soil information, prevailing wind speeds and directions, etc. This would allow managers of industrial estates where environmental standards do not exist to better understand the capacities of the environment and to set site-specific standards for the estate.

6.3.8 The data and knowledge base require upgrading to include more of the inputs and treatments available on the industrial estate and the local area. The larger the data base, the greater the potential for finding recycling options.

7.0 References

Abbou, R., 1988. Hazardous Waste Detection, Control, Treatment. Elsevier Science Publishers, Amsterdam, Netherlands.

Allessie, M.M.J., 1989. An approach to the prevention and recycling of waste. UNEP Industry and Environment, January/February/March 1989, pg. 25 - 29.

Angehrn, A.A., 1993. Computers that Criticize You: Stimulus-Based Decision Support Systems. Interfaces 23(3): 17-28.

Angehrn, A.A. and H.J. Lüthi, 1990. Intelligent Decision Support Systems: A Visual Interactive Approach. Interfaces 20(6): 17-28.

Armstrong, J.H., 1989. Environmental impact of managing engineering projects in developing countries - engineer's responsibility. Proceedings of the Institution of Civil Engineers, Part 1, 86:1040-1042.

Ball, M. and R.R. Harries, 1988. Ion exchange resin assessment. *in* Streat, M. (ed.). Ion Exchange for Industry. Ellis Horwood Publishers, Chichester.

Barnard, R. and G. Olivetti, 1990. Limiting environmental impact by waste management. Resources, Conservation and Recycling 4:51-62.

Batstone, R., J.E. Smith and D. Wilson (eds), 1989. The Safe Disposal of Hazardous Wastes. World Bank Technical Paper No. 43. World Bank, Washington, D.C., U.S.

Bingham, E., 1991. Global Pollution. Toxicology and Industrial Health 7(5/6):31-33.

Biswas, A.K., 1988. Environmental Aspects of Hazardous Waste Management for Developing Countries: Problems and Prospects. *in* Abbou, R. (ed.). Hazardous Waste Detection, Control, Treatment. Elsevier Science Publishers, Amsterdam, Netherlands, pg. 517 - 535.

Blaize, H., 1993. personal communication. Estate Manager, PLIPDECO, Point Lisas, Trinidad.

Botes, W.A.M. and K.S. Russell, 1992. The Option to Discharge Industrial or Sewage Effluent to the Marine Environment. Water Science and Technology 25(1):75-82.

Bowonder, B., 1987. Environmental problems in developing countries. Progress in Physical Geography, 11(2): 246-259.

Boyle, C.A., 1992. Petroleum Waste Management: Amine Process Sludges. Environment Canada and the Canadian Petroleum Association, Calgary, Alberta.

Bradshaw, 1991. Ecological Applications Using a Novel Expert System Shell. Computer Applications in the Biosciences 7(1):79-83.

Braithwaite, A. 1992. personal communication. Waste Management, Ministry of the Environment, Hamilton, Ontario.

Brown, G.I., 1972. Introduction to Physical Chemistry. Longman Group Ltd., London.

Brunner, C.R., 1991. Hazardous Waste Incineration. McGraw Hill, Inc., U.S.A.

Brunner, C.R., 1993. Hazardous Waste Incineration 2nd ed. McGraw Hill, Inc., U.S.A.

Brunner, P.H. and P. Baccini, 1992. Regional material management and environmental protection. Waste Management and Research 10:203-212.

CEHI et al., 1989. Workshop Recommendations. *in* Regional and National Management of Industrial Chemicals. Report of a Workshop. CEHI, Castries, St. Lucia, pg 2-10.

Charles, V., personal communication. Director, Town and Country Planning, Port of Spain, Trinidad.

Chemical Manufacturers Association, 1989. CMA Waste Minimization Resource Manual. Chemical Manufacturers Association, Washington, D.C., U.S.

Chen, S., 1991. Water Pollution Simulation Over a River Basin Using a Computer Graphic Model. Water Science and Technology 24(6):101-108.

Chenu, M.T. and J.A. Crenca, 1990. The Cost of Remedial Action Model. *in* J.M. Hushon, (ed.), Expert Systems for Environmental Applications. ACS Symposium Series 431, American Chemical Society, Washington, D.C., pg. 162-175.

Choudhari, S.R. and P.M. Modak, 1989. The low- and non-waste technology database at the Centre for Environmental Science and Engineering, Bombay. UNEP Industry and Environment, January/February/March 1989, pg. 48.

Clark, P., 1990. Representing knowledge as arguments: applying expert system technology to judgmental problem-solving. *in* T.R. Addis and R.M. Muir (eds), Research and Development in Expert Systems VII. Cambridge University Press, Cambridge, U.K.

Clark, R., 1990. Water Supply. *in* Corbitt, R., Standard Handbook of Engineering. McGraw-Hill, USA.

Clifford, D.A., 1990. Ion Exchange and Inorganic Adsorption. *in* Pontius, F.W. (ed.) Water Quality and Treatment. McGraw-Hill, Inc., New York.

Collins, A.G. and L.E. Bristol, 1992. Structure of an Expert System to Aid Small Waste Treatment Plants. Department of Civil and Environmental Engineering, Clarkson University, Potsdam, N.Y.

Contant, C.K. and L.L. Wiggins, 1991. Defining and Analyzing Cumulative Environmental Impacts. Environmental Impact Assessment Review 11:297-309.

Corbitt, R., 1990. Wastewater Disposal. *in* Corbitt, R., Standard Handbook of Engineering. McGraw-Hill, USA.

Coté, P., 1992. Membrane Systems. seminar, February, 1992, McMaster University, Hamilton, Ontario.

Côté, R. and T. Plunkett, 1994. Industrial Ecology: Efficient and Excellent Production. School for Resource and Environmental Studies, Dalhousie University, Nova Scotia.

Côté, R. et al., 1994. Designing and Operating Industrial Parks as Ecosystems. School for Resource and Environmental Studies, Dalhousie University, Nova Scotia.

Crittenden, G., 1992. Treasure Hunt. Hazardous Materials Management, August, 1992, pg. 54.

Cross, G.R., C. Flores-Pineda and E. Hindin, 1990. Expert Systems for Hazardous Waste Remedial Action Decisions. Hazardous Waste and Hazardous Materials 7(2):185-200.

Davis, G.A., 1988. Waste Reduction Strategies: European and American Policy and Practice. *in* Abbou, R. (ed.). Hazardous Waste Detection, Control, Treatment. Elsevier Science Publishers, Amsterdam, Netherlands, pg. 195-213.

Dharmavaram, S., J.B. Mount and B.A. Donahue, 1990. Automated Economical Analysis Model for Hazardous Waste Minimization. Journal of Air and Waste Management Association 40:1004-1011.

Dold, P., 1989. Current Practice for Treatment of Petroleum Refinery Wastewater and Toxics Removal. Water Pollution Research Journal of Canada 24(3):363-390.

Dreyfus, H. and S. Dreyfus, 1986. Why Expert Systems Do Not Exhibit Expertise. IEEE Expert, 1(2):86-90.

Duchin, F., 1992. Industrial input-output analysis: Implications for industrial ecology. Proc. Natl. Acad. Sci. 89: 851-855.

Durning, A., 1990. Ending Poverty. *in* Brown, L.R. et al. State of the World, 1990. Worldwatch Institute Report. W.W. Norton and Co., N.Y., pg. 135-153.

Dyer, J.C., A.S. Vernick and H.D. Feiler, 1981. Handbook of Industrial Wastes Pretreatment. Garland STPM Press, New York.

Ehreth, D.J., 1991. An Overview of Hazardous Waste Management. Toxicology and Industrial Health, 7(5/6):15 - 30.

Ekins, P., 1991. The Sustainable Consumer Society: A Contradiction in Terms. International Environmental Affairs 3(4):243-258.

El-Ashry, M.T., 1993. Balancing Economic Development with Environmental Protection in Developing and Lesser Developed Countries. Air and Waste 43:18-24.

Ellis, J.H., E.A. McBean and G.J. Farquhar, 1985. Stochastic Optimization/Simulation of Centralized Liquid Industrial Waste Treatment. Journal of Environmental Engineering 111(6):804-821.

Ellis, K.V. and S.L. Tang, 1991. Wastewater treatment optimization model for developing world. I: Model development. Journal of Environmental Engineering 117(4):501-518.

Ellis, K.V. and S.L. Tang, 1994. Wastewater Treatment Optimization Model for Developing World. II: Model Testing. Journal of Environmental Engineering 120(3):610-624.

Environment Division, 1992. National Report on Environment and Development. Trinidad and Tobago Ministry of Planning and Development, Port of Spain, Trinidad.

Environmental Information, Ltd., 1992. Waste Minimization. Waste Business West 3(1):24.

Erhle, C., 1991. We're off to see the wizard. Resources July, 1991, pg. 11-12.

Evenson, E.J. and B.W. Baetz, 1994. Selection and sequencing of hazardous waste treatment processes: A knowledge-based systems approach. Waste Management 14(2):161-165.

Farabi, H., 1992. Perspectives in Industrial Waste Management in the Caribbean: Part II - Industrial. Faculty of Engineering, The University of the West Indies, St. Augustine, Trinidad.

Fang, H.Y., G.M. Mkroudis and S. Panukcu, 1990. Multidomain Expert Systems for Hazardous Waste Site Investigations. *in* J.M. Hushon, (ed.). Expert Systems for Environmental Applications. ACS Symposium Series 431, American Chemical Society, Washington, D.C., pg. 146-161.

Ford, L., 1992. personal communication. Water and Sewage Authority, Curepe, Trinidad.

Foster, S., 1992. Environmental Software. Waste Business West 3(2): supplement.

Freeman, H.M., 1989. Standard Handbook of Hazardous Waste Treatment and Disposal. McGraw-Hill Publishing, New York, U.S.A.

Freeman, H. M., 1990. Hazardous Waste Minimization. McGraw-Hill Publishing, U.S.A.

French, H.F., 1991. Restoring the East European and Soviet Environments. *in* Brown, L.R. et al. State of the World, 1991. Worldwatch Institute Report. W.W. Norton and Co., N.Y., pg. 93-112.

Frosch, R.A., 1992. Industrial ecology: A philosophical introduction. Proc. Natl. Acad. Sci. 89: 800-803.

Frosch, R.A. and N.E. Gallopoulos, 1989. Strategies for Manufacturing. *in* Managing Planet Earth, special edition, Scientific American, Sept. 1989, p.144-152.

Fujita, K. and S.P. Maltezou, 1991. UNIDO's Approach to Industrial Pollution Prevention. Toxicology and Industrial Health 7(5/6):3-4.

Fuwa, K., 1991. Environmental Problems: Past and Present. Toxicology and Industrial Health 7(5/6):5-7.

Galil, N. and Y. Levinsky, 1991. Expert Support System for Cost Modeling and Evaluation of Wastewater Treatment. Water Science and Technology 24(6):291-298.

Galil, N. and M. Rebhun, 1992. Waste management solutions at an integrated oil refinery based on recycling of water, oil and sludge. Water Science and Technology 25(3):101-106.

Gao, H and Y. Su, 1988. Removal and recovery of phenols from industrial effluent by extracting resin. *in* Streat, M. (ed.). Ion Exchange for Industry. Ellis Horwood Publishers, Chichester.

Geiger, W., G. Osterkamp and R. Weidemann, 1991. Assessment and evaluation of former industrial sites with the aid of the XUMA expert system. UNEP Industry and Environment July/August/September 1991, pg. 7-12.

Gevarter, W.B., 1987. The Nature and Evaluation of Commercial Expert System Building Tools. Computer 20(5):24-41.

Glysson, E.A., 1990. Solid Waste. *in* Corbitt, R., Standard Handbook of Engineering. McGraw-Hill, USA.

Goddard, G., 1992. personal communication. Civil Engineer, Solid Waste Management Company, Port of Spain, Trinidad.

Godish, T., 1991. Air Quality. 2nd ed.. Lewis Publishers, Michigan.

Goldblum, D.K., J.M. Clegg and J.D. Erving, 1992. Use of Risk Assessment Groundwater Model in Installation Restoration Program (IRP) Site Decisions. Environmental Progress 11(2):91-97.

Grady, C.P.L. and H.C. Lim, 1980. Biological Wastewater Treatment. Marcel Dekker Inc., New York.

Gregory, R. and T.F. Zabel, 1990. Sedimentation and Flotation *in* Pontius, F.W. (ed.) Water Quality and Treatment. McGraw-Hill, Inc., New York.

Guida, M., P. Marchesi and G. Basaglia, 1992. Knowledge-based decision support systems for manufacturing decision-making. Information and Decision Technologies 18(347-361).

Gujer, U., 1991. Waste minimization: a major concern of the chemical industry. Water Science and Technology 24(12):43-56.

Hamilton, R.D., J.F. Klaverkamp, W.L. Lockhart and R. Wageman, 1987. Major Aquatic Contaminants, Their Sources, Distribution, and Effects. *in* M.C. Healey and R.R. Wallace (eds), Canadian Aquatic Resource. Rawsom Academy of Aquatic Science, Fisheries and Ocean, Ottawa, Ontario.

Hasan, M., 1991. Status of Management of Hazardous Wastes in Commonwealth Countries. *presented at* the Commonwealth Science Council Workshop on Management of Hazardous Wastes, Trinidad, June 10-12, 1991.

Hazardous Waste Engineering Research Laboratory, 1988. Waste Minimization Opportunity Assessment Manual. U.S. EPA, Cincinnati, Ohio.

Henrichs, R., 1992. Environmental Issues and the Law. Proc. Natl. Acad. Sci., 89:856-859.

Herz, G.P. and A.D. Prunac, 1988. A new mixed bed ion exchange resin for ultra-pure water systems. *in* Streat, M. (ed.). Ion Exchange for Industry. Ellis Horwood Publishers, Chichester.

Hickey, J.P. et al, 1990. An Expert System for Prediction of Aquatic Toxicity of Contaminants. *in* Hushon, J.M. (ed.), Expert Systems for Environmental Applications. ACS Symposium Series 431, American Chemical Society, Washington, D.C., pg. 90-107.

Hirschhorn, J.S., 1985. Toxic Waste and the Environmental Deficit: Whose Future are We Discounting? Futures Research Quarterly, Winter, 1985, pg. 7-14.

Hirschhorn, J.S. and K.U Oldenburg, 1991. Prosperity Without Pollution. Van Nostrand Reinhold, New York.

Huang, C.P., 1978. Chemical Interactions Between Inorganic and Activated Carbon. *in* Cheremisinoff, P.N. and F. Ellerbusch, Carbon Adsorption Handbook. Ann Arbor Science Publishers Inc., Michigan.

Huibregtse, K.R. and K.H. Kastman, 1981. Soil/Chemical Concerns in Hazardous Waste Siting. *in* J.P. Collins and W.P. Saukin (eds). The Hazardous Waste Dilemma: Issues and Solutions. American Society of Civil Engineers, New York.

Huisingh, D., 1989. Cleaner technologies through process modifications, material substitutions and ecologically based ethical values. UNEP Industry and Environment January/February/March 1989, pg. 4 - 8.

Huisingh, D., L. Siljebratt and M. Backman, 1989. Preventive Environmental Protection Strategy: Preliminary Results of an Experiment in Lndskrona, Sweden. UNEP Industry and Environment January/February/March 1989, pg. 9-10.

Hunt, R.G., J.D. Sellers and W.E. Franklin, 1992. Resource and Environmental Profile Analysis: A Life Cycle Environmental Assessment for Products and Procedures. Environmental Impact Assessment Review 12:245-269.

Hushon, J. (ed.), 1990. Overview of Environmental Expert Systems. *in* Hushon, J.M. (ed.), Expert Systems for Environmental Applications. ACS Symposium Series 431, American Chemical Society, Washington, D.C., pg. 1-24

Hushon, J., 1987. Expert systems for environmental problems. Environmental Science and Technology 21(9):838 - 841.

Iinoya, K. and R. Dennis, 1987. Industrial Gas Filtration in Matheson, M.J.(ed). Filtration Principles and Practices, 2nd ed. Marcel Dekker Inc., New York.

Jacobs, R.A., 1991. Design Your Process for Waste Minimization. Chemical Engineering Progress 87(6): 55-59.

Jain, R.K., 1988. Overview of Hazardous/Toxic Waste Management. *in* Gronow, J.R., A.N. Schofield and R.K. Jain (eds). Land Disposal of Hazardous Waste. Ellis Horwood Ltd., Chichester, U.K.

Jeffery, M., 1992. Environmental Liability for Directors and Officers in the Aftermath of the Bata Industries Decision. Enviroflash, March, 1992.

Jelinski, L.W., T.E. Graedel, R.A. Laudise, D.W. McCall and C.K.N. Patel, 1992. Industrial ecology: Concepts and approaches. Proc. Natl. Acad. Sci. 89:793-797.

Jensen, L., 1990. Turning Trash into Cash. Source, June, 1990, pg. 14-17.

Jones, H.R., 1971. Environment Control in the Organic and Petrochemical Industries. Noyes Data Corp., New York.

Karam, J.G., C. St. Cin and J. Tilly, 1988. Economic evaluation of waste minimization options. Environmental Progress 7(3):192-197.

Katin, R.A., 1991. Minimize Waste at Operating Plants. Chemical Engineering Progress 87(7):39-41.

Keoleian, G.A. and D. Menerey, 1994. Sustainable Development by Design: Review of Life Cycle Design and Relate Approaches. Air and Waste 44:645-668.

Kreith, F., 1991. Solid Waste Management in the U.S. and 1989-1991 State Legislation. Energy 17(5):427-476.

LaGrega, M.D., P.L. Buckingham and J.C. Evans, 1994. Hazardous Waste Management. McGraw-Hill Inc., New York.

Landry, M., J.L. Malouin and M. Oral, 1987. Model validation in operations research. European Journal of Operational Research 14:207-220.

Laukkanen, R. and J. Pursianen, 1991. Rule-Based Expert System in the Control of Wastewater Treatment Systems. Water Science and Technology 24(6):299-306.

Lemaitre, A., 1992. personal communication. Principle Medical Officer (Environmental Health), Ministry of Health, Barataria, Trinidad.

Librizzi, W.J. and C.N. Lowery, 1990. Hazardous Waste Treatment Processes. Water Pollution Control Federation, Virginia.

Linnerooth, J. and Wynne, B., 1988. Hazardous Waste Control: Closing the Implementation Gap. *in* Abbou, R. (ed.). Hazardous Waste Detection, Control, Treatment. Elsevier Science Publishers, Amsterdam, Netherlands, pg. 311-321.

Lynch, D. and C.E. Hutchinson, 1989. Environmental education. Proc. Natl. Acad. Sci. 89: 864-867.

Lyman, W.J., 1978. Applicability of Carbon Adsorption to the Treatment of Hazardous Industrial Wastes. *in* Cherenisinoff, P.N. and F. Ellerbusch, (ed). Carbon Adsorption Handbook. Ann Arbor Science Publishers, Inc., Michigan.

Mackerle, J, 1989. A review of expert systems development tools. Engineering Computer 6:2-17.

MacLaren Engineers Inc., 1989. Waste Management Master Plan for the Municipalities of Dufferin County: Stage 1 Draft Report. Corporation of the Town of Orangeville, Orangeville, Ontario.

MacNeill, J., 1989. Strategies for Sustainable Economic Development. Scientific American Sept. 1989, pg. 155-165.

Marcus, S. and J. McDermott, 1989. Salt: A Knowledge-Acquisition Language for Propose and Revise Systems. Artificial Intelligence 39(1):1-37.

Matilla, E.M., 1989. Clean technologies policy of the European Economic Community. UNEP Industry and Environment January/February/March 1989, pg. 11-13.

McShine, H. and A. Siung-Chang, 1983. Point Lisas Environmental Protection Project. Trinidad and Tobago Naturalist, 1983, pg 13-26..

Merry, M., 1985. Expert Systems - Some Problems and Opportunities. *in* Merry, M. (ed.). Proceedings of the 5th Technical Conference of the British Computer Society. Cambridge University Press, Cambridge, U.K., pg. 1-8.

Metcalf and Eddy, Inc., 1979. Wastewater Engineering Treatment, Disposal, Reuse. McGraw-Hill Book Company, New York.

Mettrey, W., 1992. Expert Systems and Tools: Myths and Realities. IEEE Expert 7(1):4-12.

Metzer, A. and D.E. Hughes, 1984. Adsorption of Copper, Lead and Cobalt, by Activated Carbon. Water Resources 18:927.

Michael, D.N., 1991. Leadership's shadow: the dilemma of denial. Futures 23(1):69-79.

Michie, 1990. Machine executable skills from 'silent' brains. *in* Addis, T.R. and R.M. Muir (eds.), 1990. Research and Development in Expert Systems VII. British Computer Society Conference Series, Cambridge University Press, Cambridge, U.K., pg. 1-24.

Miller, G., 1992. personal communication. Program consultant, FAO, Washington, U.S.A.

Mollenkamp, R.A., 1989. Applying Process AI Expert Systems. ISA Transactions 28(1):1-8.

Moore, R., 1992. personal communication. Operations Manager, Phoenix Park Gas Processing Company, Point Lisas Industrial Estate, Point Lisas, Trinidad.

Morse, M.E., 1989. U.S. EPA shifts its priorities to pollution prevention. UNEP Industry and Environment January/February/March 1989, pg. 30 - 33.

Morita, M., 1991. The Distribution, Cycling, and Potential Hazards of Industrial Chemicals in Marine Environments. Toxicology and Industrial Health, 7(5/6):35 - 42.

Moudeen, H., 1992. personal communication. Standards Officer, Trinidad and Tobago Bureau of Standards, Macoya, Trinidad.

Munshi, U., 1990. An Integrated Approach to Pollution Control. Gerland Publishers, New York.

Murphy, K., 1994. personal communication. Professor, Civil Engineering, McMaster University, Hamilton, Ontario.

Nash, J. and M.D. Stoughton, 1994. Learning to Live With Life Cycle Assessment. Environment, Science and Technology 28(5):236A - 237A.

Nazareth, D.L., 1989. Issues in the verification of knowledge in rule-based systems. International Journal of Man-Machine Studies 30:255-271.

Noyes Data Corporation, 1972. Air and Gas Cleaning Equipment, 2nd ed. Noyes Data Corp., New York.

O'Brian, J.A., 1990. Management Information Systems. Irwin Inc., Boston.

O'Gallagher, B., 1990. Waste Management Technologies. Department of Industry, Technology and Commerce, Australia.

O'Keefe, R.M., O. Balci and E.P. Smith, 1987. Validating Expert System Performance. IEEE Expert 2(4):81-89.

O'Leary, T.J., M. Goul, K.E. Moffitt and A.E. Radwan, 1990. Validating Expert Systems. IEEE Expert 5(3):51-58.

Olivero, R.A. and D.W. Bottrell, 1990. Expert Systems to Support Environmental Sampling, Analysis and Data Validation. *in* Hushon, J.M. (ed.), Expert Systems for Environmental Applications. ACS Symposium Series 431, American Chemical Society, Washington, D.C., pg. 69-81.

Ontario Waste Management Corporation, 1987. Industrial Waste Audit and Reduction Manual: A practical guide to conducting an in-plant survey for waste education. Ontario Waste Management Corporation, Toronto, Ontario.

Oppelt, E.T., 1991. Overview *in* Rickman, W.S. (ed), Handbook of Incineration of Hazardous Wastes. CRC Press, Boston.

Ostrowsky, M.F. and R.C. Swezey, 1989. An Expert System Shell: Expert System Environment/VM. ISA Transactions 28(1):9-14.

PAHO, 1991. Comments on Draft "Requirements for Liquid Effluent from Wastewater Treatment Plants into the Environment". Pan American Health Organization, Port of Spain, Trinidad.

Palmer, P., 1982. Chemical Recycling: Making it Work, Making it Pay. *in* D. Huisingh and V. Bailey. Making Pollution Pay: Ecology with Economy as Policy. Pergammon Press, New York, pg. 73-85.

Palmer, S.A.K., et al., 1988. Metal/Cyanide Containing Wastes. Noyes Data Corp., New York.

Pareek, N.K., 1992. Industrial Wastewater Management in Developing Countries. Water Science and Technology 25(1):69-74.

Pariza, M., 1992. An approach to evaluating carcinogenic risk. Proc. Natl. Acad. Sci. 89:860-861.

Parker, C. and T. Case, 1993. Management Information Systems 2nd ed.. McGraw-Hill, California.

Peer Consultants, P.C. and University of Dayton Research Institute, 1992. User's Guide: Strategic Waste Minimization Initiative, Version 2.0. U.S. Environmental Protection Agency, Cincinnati, Ohio.

Penner, S.S. and M.B. Richards, 1989. Estimates of Growth-Rates for Municipal-Waste Incineration and Environmental Control Costs for Coal Utilization in the United States. Energy - The International Journal 14(12):961-963.

Perry, R.H. and D.W. Green, 1984. Perry's Chemical Engineer's Handbook, 6th ed. McGraw Hill Book Company, New York.

Piazza, J.R. et al., 1992. A Systems Engineering Methodology for Manufacturing Waste Minimization. AT&T Technical Journal, Mar/Apr. 1992, pg. 11-18.

Pictet, J., J. Giovannoni and L.Y. Maystre, 1992. Impact Assessment of Urban Waste Processing Systems Using a Multibox Model. Water, Air and Soil Pollution 63:155-178.

Pintér, J., 1993. Environmentally Sensitive Investment System (ESIS) Project. School for Resource and Environmental studies and School of business Administration, Dalhousie University, Halifax, Nova Scotia.

PLIPDECO, 1981. Point Lisas Environmental Protection Project Vol VIII. Report on Factory Visits. PLIPDECO and Institute of Marine Affairs, Trinidad.

PLIPDECO, 1982. Point Lisas Environmental Protection Project Vol 1. Executive Summary. PLIPDECO and Institute of Marine Affairs, Trinidad.

Rabe, B.G., 1991. Exporting Hazardous Waste in North America. International Environmental Affairs 3(2):108-125.

Reimann, D.O., 1989. Heavy metals in domestic refuse and their distribution in incinerator residues. Waste Management and Research 7:57-62.

Renard, F.X., L. Sterling and C. Brosilow, 1993. Knowledge Verifcation in Expert Systems Combining Declarative and Procedural Representations. Computers in Chemical Engineering 17(11):1067-1090.

Rhee, C.H., P.C. Martyn and J.G. Kramer, 1987. Removal of Oil and Grease in the Hydrocarbon Processing Industry. Proceedings of the 42 Industrial Waste Conference, May 12-14, 1987. Purdue University, Lewis Publishers Inc., Indiana.

Risk, M., 1992. personal communication. Professor, Department of Geology, McMaster University, Hamilton, Ontario.

Rittmeyer, R.W., 1991 Prepare and Effective Pollution Prevention Program. Chemical Engineering Progress, 87(5)56-62.

Robinson, B. and J. Bazelmans, 1991. Appropriate Management Systems for Hazardous Wastes. *presented at* the Workshop on Management of Hazardous Wastes, Trinidad, June 10-1, 1991.

Ruckelshaus, W.D., 1989. Toward a Sustainable World. Scientific American 261(3):166-174.

Russell, M., 1992. The U.S. Hazardous Waste Dilemma. Environment 34(6):12-39.

Salvador-Arthur, M., 1992. personal communication. Senior Planning Officer, Environment Division, Trinidad and Tobago Ministry of Planning and Development, Port of Spain, Trinidad.

Sammy, G., 1992. personal communication. Consultant, CEHI, Trinidad.

Saraswat, N. and P. Khanna, 1989. Waste minimization in industry: issues and prospects. UNEP Industry and Environment January/February/March 1989, pg. 45-47.

Schaum, J.L., et al. 1990. Computerized System for Performing Risk Assessments for Chemical Constituents of Hazardous Waste. *in* Hushon, J.M. (ed.), Expert Systems for Environmental Applications. ACS Symposium Series 431, American Chemical Society, Washington, D.C., pg. 176-192.

Schneider, T., 1991. Management of Industrial Waste - A European Perspective. Toxicology and Industrial Health 7(5/6):262-266.

Schroeder, W.H., P.J. Cresculo, H.W. Campbell, D.B. Cohen, 1981. Sludge Incineration and Precipitant Recovery Vol. IV Research Report No. 107. Ontario Ministry of the Environment and Environment Canada, Oshawa, Ontario.

Shaw, R.W. and S. Öberg, 1993. Sustainable development: applications of systems analysis. The Science of the Total Environment 149:193-214.

Shieh, Y.S. and W.J. Sheehan, 1992. Integrated refinery waste management. Water Science and Technology 25(3):273-275.

Shubert, M.S., 1990. Respect for the Planet. IBM Canada Ltd, North York, Ont. Canada.

Singh, N., 1991. Environmental Problems and Opportunities in Small Open Economies. *presented at* The Symposium of Small States: Problems and Opportunities in a World of Rapid Change. March 25-27, 1991, St. Kitts.

Singh, N., 1990. Waste Management and Sustainable Development in the Caribbean. *presented at* Conference on Public Policy Implications of Sustainable Development in the Caribbean Region. May 28-30, 1990, Kingston, Jamaica.

Singh, N., 1992. personal communication. Director, Caribbean Environmental Health Institute (CEHI), Castries, St. Lucia.

Sirkin, T. and M. ten Houten, 1994. The Cascade Chain: A Theory and Tool for Achieving Resource Sustainability with Application for Product Design. Resource Conservation and Recycling 10:213-277.

Siung-Chang, A., 1992. personal communication. Principal Research Officer, Institute of Marine Affairs, Chaguaramus, Trinidad.

Smart, B.(ed.), 1992. Beyond Compliance. World Resources Institute, U.S.

Smee, R., 1992. Pacific Materials Exchange. Waste Business West 3(1):14.

Snoeyink, V.L., 1990. Adsorption of Organic Compounds. *in* Pontius, F.W. (ed.) Water Quality and Treatment. McGraw-Hill, Inc., New York.

Somlyody, L., 1991. Application of Systems Analysis in Water Pollution Control: Perspectives for Central and Eastern Europe. Water Science and Technology 24(6): 73-87.

Spearman, M.K. and S.J. Zagula, 1992. The development of a waste minimization program at Amoco Oil Company. Water Science and Technology 25(3):107-116.

Straub, C.P., 1989. Practical Handbook of Environmental Control. CRC Press Inc., Florida.

Stewart, G.G., 1990. Slagging Rotary Kilms for Hazardous Waste Incineration. *in* Freeman, H. (ed.), Innovative Hazardous Waste Treatment Technology Series Vol. 1. Thermal Processes. Technomic Publishing Co. Ltd., Lancaster, Penn.

Stronach, S.M., T. Rudd and J.N. Lester, 1986. Anaerobic Digestion Processes in Industrial Wastewater Treatment. Springer Verlag, New York

Stunder, M., 1990. Verification and Validation of Environmental Expert Systems. *in* Hushon, J.M. (ed.), Expert Systems for Environmental Applications. ACS Symposium Series 431, American Chemical Society, Washington, D.C., pg. 39-51.

Suite, W.H.E., 1991. The Expert of Hazardous Waste to the Caribbean Basin Region. Toxicology and Industrial Health 7(5/6): 221-227.

Sutter, H., 1989. The new International Association for Clean Technology: its role in fostering communication and developments in cleaner technology and effective waste minimization. UNEP Industry and Environment January/February/March 1989, pg. 50.

Tarrer, A.R. et al., 1989. Reclamation and Reprocessing of Spent Solvents. Noyes Data Corporation, New Jersey.

Tate, C.H. and K.F. Arnold, 1990. Health and Aesthetic Aspects of Water Quality. *in* Pontius, F.W. (ed.), Water Quality and Treatment. McGraw-Hill, Inc., New York.

Thompson, T., 1992. personal communication. Environmental Engineer, Pan American Health Organization, Port of Spain, Trinidad.

Tillman, D.A., A.J. Rossi and K.M. Vick, 1989. Incineration of Municipal and Hazardous Solid Waste. Academic Press, Inc., California.

Toppin-Allahar, C., 1992. Institutional Strengthening and Legal Infrastructure. Government of Trinidad and Tobago, Port of Spain.

Ugelow, J., 1994. Short-Term/LongTerm Solutions in Waste Management: Economics and the Transition Process. Waste Management and Research 12:243-256.

UN ECE, 1978. Non-Waste Technology and Production. Pergammon Press, Oxford, U.K.

U.S. EPA, 1988. Waste Minimization Opportunity Assessment Manual. U.S. Environmental Protection Agency, Cincinnati, Ohio, U.S.A.

Uriarte Jr, F.A., 1991. Waste Management in ASEAN Countries. Toxicology and Industrial Health., Vol. 7(5/6): 229-248.

Vaananen, P., P. Pouttu and T. Kulmala, 1992. Joint Treatment of Industrial and Municipal Wastewater - Case Project: City of Kotka, Finland. Water Science and Technology 25(1):83-92.

van Weelderen, J.A. and H.G. Sol, 1993. MEDESS: A Methodology for Designing Expert Support Systems. Interfaces 23(3): 51-67.

Vlugman, A., 1991. Operational Status of Waste Water Treatment and Disposal of Effluents and Sludges in Caricom Member States. Caribbean Environmental Health Institute, Castries, St. Lucia.

von Weizsäcker, E.U., 1994. Sustainable economy. The Science of the Total Environment 143:149-156.

Vos, J.B., 1992. The scope for economic instruments of environmental policy in the EC. The Science of the Total Environment 129:29-38.

Wassersug, S.R., 1992. Risk assessment and international policy on chemical and waste management activities. Water Science and Technology 25(3):1-11.

Weast, R.C. (ed.), 1972. Handbook of Chemistry and Physics, 53rd edition. Chemical Rubber Company, Ohio.

Williamson, Jr., R.L., 1992. U.S. regulatory approaches: A critical appraisal. Water Science and Technology 25(3):13-21.

Wilson, D. and F. Balkau. 1990. Adapting hazardous waste management to the needs of developing countries - an overview and guide to actions. Waste Management and Research 8:87-97.

Winter, G., 1991. Modern materials management: more environmental, more comprehensive, more influential. UNEP Industry and Environment July/August/September 1991, pg. 28-32.

Whelan, G., et al., 1992. Overview of the Multimedia Environmental Pollutant Assessment System (MEPAS). Hazardous Waste and Hazardous Materials 9(2):191-208.

White, A.L., 1991. Venezuela's Organic Law: Regulating pollution in an industrializing country. Environment 33(7):16-20, 37-42.

White, A.L., and Shapiro, K., 1993. Life Cycle Analysis: A Second Opinion. Environment, Science and Technology 27(6):1016-1017.

Woods, D.R., 1994a. Process Design and Engineering Practice. Prentice Hall, New Jersey.

Woods, D.R., 1994b. personal communication. Professor, Chemical Engineering, McMaster University, Hamilton, Ontario.

Woolard, E.S., 1990. A Sustainable World. Chemistry and Industry, Nov. 19, pg. 738-740.

World Environment Report, 1992. Consumers Remain Concerned About Environment: Survey. World Environment Report, August 4, pg. 140.

Yong, R., 1991. Land Disposal of Hazardous Wastes: Issues, Policies and Implementation. *presented at* the Workshop on Management of Hazardous Wastes, Commonwealth Science Council, Trinidad, June 10-12, 1991.

Young, J.E., 1991. Reducing Waste, Saving Materials. *in* Brown, L.R. et al. State of the World, 1991. Worldwatch Institute Report. W.W. Norton and Co., N.Y., pg. 35-55.

Yurman, D., 1990. Success Factors for Expert Systems. *in* Hushon, J.M. (ed.), Expert Systems for Environmental Applications. ACS Symposium Series 431, American Chemical Society, Washington, D.C., pg. 25-38.

Appendix 1 Treatment Input Limits and Output Formulae

This appendix includes tables of the criteria used to define the acceptable inputs for each treatment and the formulae to define the parameters of the outputs from those treatments. The formulae are derived from published information as presented in Chapter 4. "No reference" indicates that the criteria or formulae were estimated using other information .

It must be recognized that the input and output parameters for a treatment are highly dependant upon equipment design and operating procedures. The values used for these treatments were averaged, if sufficient information was available. In some cases, values had to be estimated as no information was available or requirements were vague (e.g., metallic salts have to be kept low to prevent corrosive depositions from forming during incineration according to Brunner (1991)).

Acceptable input parameters may be expressed in a range. According to Woods (1994a) the range of a parameter that is acceptable may be dependant upon another variable; for example, the acceptable concentration may be dependant upon the particle size when considering magnetic separation. At present, the developed system is not able to make that determination; it considers all input parameters to be independant.

Depending upon the process and the authority consulted, some treatment outputs may be determined by either a formula or a specific number. This system allows the user to use one or the other or to define the output according to the operating parameters of an existing treatment system. Where a range of efficiency for a treatment was indicated, an average of the range was used. It must be recognized that the parameters, with the exception of pH and particle size, were in ppm and, when calculating mass, this must be taken into consideration.

The formulae use shortened forms for each parameter (Tables A1.1 and A1.2) while the input masses are referred to as M_1 and the output masses are M_2. Formulae were derived, where possible, from available literature and are based on mass-balance principles.

Table A1.2. The parameters used for each state and the shortened version used in the formulae.

Gas Parameters	Acronym	Liquid Parameters	Acronym
corrosivity	pH	pH	pH
volatiles	Vol	COD	COD
oil	Oil	solvent	Vol
water	Wat	oil	Oil
heavy metals	HM	water	Wat
particulates	Part	heavy metals	HM
particulate size	PS	particulates	Part
CFC	CFC	particulate size	PS
CO_2	CO2	dissolved solids	DS
SO_2	SO2	NO_3	NO3
NO_x	NOX	NH_3	NH3
Cl	Cl	sulphur	S
NH_3	NH3	PO_4	PO4
		toxics	Tox

Sludge Parameters	Acronym	Solid Parameters	Acronym
pH	pH	leachate pH	pH
COD	COD	COD	COD
solvent	Vol	solvent	Vol
oil	Oil	oil	Oil
water	Wat	water	Wat
heavy metals	HM	heavy metals	HM
particulates	Part	iron	Fe
particulate size	PS	other metals	OM
dissolved solids	DS	soluble solids	SS
TN	TN	toxics	Tox
sulphur	S	particle size	PS
iron	Fe	paper/cardboard	Pap
toxics	Tox	plastic/rubber	Plas
ash	Ash	ash	Ash

The formulae were derived using basic mass balance principles from available data. Where a removal efficiency was available, e.g. 97% removal of oil, the resulting formulae would be:

for output 1:

$$0.03*Oil*mass_1/mass_2$$

and for output 2:

$$0.97*Oil*mass_1/mass_2$$

where

mass_1 = original mass and

mass_2 = mass of output.

When a specific amount of a material is left in the output, e.g. 20 ppm of oil, the resulting formulae would be for output 1:

20 ppm

and for output 2:

$(\text{Oil}*\text{mass}_1-20*(\text{mass1}-\text{mass2}))/\text{mass}_2$

where:

mass_1 = original mass

mass_2 = mass of output

Oil = quantity of oil in wastes, ppm.

For treatments for liquid materials where a sludge or solid output results, some allowances must be made for the liquid fraction of the sludge or solid. If the original liquid fraction contained oil, solvent or water, then the sludge or solid will contain some amount of these liquids.

In calculating changes from liquid to gas, some approximations have been made. COD is assumed to be approximately 97% of the theoretical oxygen demand (Murphy, 1994). In considering solvents and oils, they are assumed to have a hydrocarbon formulae of C_nH_{2n+2}. Solvents are assumed to be non-chlorinated; however, it must be recognized that this may not be the case. Oils are assumed to be generally non-soluble, with 20 ppm in emulsion (Rhee et. al, 1987). Incineration of 1g of oil or solvent (0.857g C and 0.143g H) therefore produces 3.14g CO_2 and 1.29g H_2O.

Gas parameters are often measured as $\mu g/m^3$. However, for the purposes of mass balances, this is not practical, so 1 m^3 of air is assumed to have a weight of 1.25 kg (Weast, 1972). For incineration, paper/cardboard and plastic/rubber are assumed to have the components listed in Table A1.3. Combustion products are listed in Table A2.4.

Table A1.3. Components of paper/cardboard and plastic/rubber (estimated from Tillman, Rossi and Vick, 1989).

Component	**Paper/Cardboard**	**Plastic/Rubber**
C	34.7%	49.8%
H	4.70	6.58
N	0.16	1.09
Cl	0.24	3.98
S	0.20	0.73
H_2O	21.0	12.5
Ash	6.5	15.5

Table A1.4 Combustion products from 1 kg of paper/cardboard and plastic/rubber, with 100% combustion (estimated from Tillman, Rossi and Vick, 1989).

Combustion Products	**Amount Produced per kg of Material** **Paper/Cardboard**	**Plastic/Rubber**
CO_2	1270 g	1830 g
H_2O	633	717
NO_2	5.3	35.8
Cl	240	398
SO_2	40	146
Ash	65	155

1. Fixed Hearth Incineration

Table A1.5 Fixed hearth incineration input criteria - organic carbon destruction

Fixed Hearth Incineration	**Input - solid**	**Reference**
ash	<900,000 ppm	estimated

Table A1.6 Fixed hearth incineration input criteria - toxic organic destruction

Fixed Hearth Incineration	**Input - solid**	**Reference**
non-metal toxics	>1ppm	Librizzi and Lowery, 1990
ash	<999,999ppm	Librizzi and Lowery, 1990

Table A1.7 Fixed hearth incineration - solid output formulae

Solid Output	**Formulae**	**References**
mass (M_2)	((Ash/1000000)*M_1) + 1.55	est. Oppelt, 1991
leachate pH		
COD	(.00005*COD*M_1)/M_2	Oppelt, 1991
solvent	(.00005*Vol*M_1)/M_2	Oppelt, 1991
oil	(.00005*Oil*M_1)/M_2	Oppelt, 1991
water	(.00005*Wat*M_1)/M_2	Oppelt, 1991
heavy metals	(.3*HM*M_1)/M_2	Brunner, 1993
iron	(.5*FE*M_1)/M_2	Brunner, 1993
other metals	(.4*OM*M_1)/M_2	Brunner, 1993
soluble solids	(.5*SS*M_1)/M_2	
non-metal toxics	(.00005*Tox*M_1)/M_2	Oppelt, 1991
particle size	PS	
paper/cardboard	(.00005*Pap*M_1)/M_2	Oppelt, 1991
plastic/rubber	(.00005*Plas M_1)/M_2	Oppelt, 1991
ash	9999950	Oppelt, 1991

Table A1.8. Fixed hearth incineration - gas output formulae

Gas Output	**Formulae**	**Reference**
mass	(M_1-(Ash*M_1/1000000))+.27* COD*M_1/1000000	
corrosivity		
volatiles	0	
oil	0	
water	(0.48*COD*M_1)/M_2	est. from Tillman, Rossi and Vick, 1989
heavy metals	(.44*HM*M_1)/M_2	Brunner, 1993
particulates	.067 ppm	est. from Brunner, 1991
particulate size	<.3mm	Brunner, 1991
CFC	0	
CO_2	(1.03*COD*M_1)/M_2	Brunner, 1991
SO_2	((.15*Plas+.04*Pap)*M_1)/M_2	Tillman, Rossi and Vick, 1989
NO_x	<13 ppm	Brunner, 1991
Cl	((.2*Pap+.4*Plas)*M_1)/M_2	Brunner, 1993
NH_3	0	

2. Magnetic Separation

Table A1.9. Magnetic separation - input criteria

Magnetic Separation	**Input - solid**	**Reference**
iron	>100 ppm	Woods, 1994a
particle size	>.45mm	Woods, 1994a

Table A1.10. Magnetic separation - ferrous solid output formulae

Solid Output	**Formulae**	**Reference**
mass (M_2)	(.95*Fe/1000000)*M_1	Woods, 1994a
leachate pH	pH	
COD	(.03*Oil*M_1)/M_2	
solvent	0	
oil	(.01*Oil*M_1)/M_2	
water	(.01*Wat*M_1)/M_2	
heavy metals	(.05*HM*M_1)/M_2	Woods, 1994a
iron	990,000 ppm	Woods, 1994a
other metals	50,000 ppm	Woods, 1994a
soluble solids	0	
toxics	0	
particle size	PS	
pap/cardboard	0	
plastic	0	
ash	990,000 ppm	Woods, 1994a

Table A1.11. Magnetic separation - non-ferrous solid formulae

Solid Output	**Formulae**	**References**
mass	M_1-(.95*Fe/1000000*M_1)	Woods, 1994a
leachate pH	pH	
COD	(COD *M_1)/M_2	
solvent	(Vol*M_1)/M_2	
oil	(.99*Oil*M_1)/M_2	
water	(.99*Wat*M_1)/M_2	
heavy metals	(.99*HM*M_1)/M_2	Woods, 1994a
iron	(.05*Fe*M_1)/M_2	Woods, 1994a
other metals	(.95*OM*M_1)/M_2	Woods, 1994a
soluble solids	(SS*M_1)/M_2	
toxics	(Tox*M_1)/M_2	
particle size	PS	
pap/cardboard	(Pap*M_1)/M_2	
plastic	(Plas*M_1)/M_2	
ash	((Ash - .95*Fe)*M_1)/M_2	Woods, 1994a

3. Anaerobic Digestion

Table A1.12 Anaerobic digestion - input criteria

Anaerobic Digestion	**Input - sludge**	**Reference**
pH	6.5-7.7	Grady and Lim, 1980
COD	20,000 - 2,700,000 ppm	Grady and Lim, 1980
solvent	<500 ppm	Stronach, Rudd and Lester, 1986
oil	<100 ppm	
heavy metals	<100 ppm	Grady and Lim, 1980
particulates	<500,000	Librizzi and Lowery, 1990
particulate size	<5 mm	
dissolved solids	<3000 ppm	est. from Librizzi and Lowery, 1990
TN	<3000 ppm	Metcalf and Eddy, 1979
sulphur	<200 ppm	Grady and Lim, 1980
iron	<200 ppm	Librizzi and Lowery, 1990
toxics	<.05 ppm	Stronach, Rudd and Lester, 1986

Table A1.13 Anaerobic digestion - sludge output formulae

Sludge Output	**Formulae**	**References**
mass.	$(.45*M_1*COD)/(1.9)+Wat/1000000)/M_1$	Metcalf and Eddy, 1979
pH	pH	Metcalf and Eddy, 1979
COD	$(.1*COD*M_1)/M_2$	Metcalf and Eddy, 1979
solvent	$(.1*Vol*M_1)/M_2$	Metcalf and Eddy, 1979
oil	$(.3*Oil*M_1)/M_2$	Metcalf and Eddy, 1979
water	$(Wat*M_1)/M_2$	Metcalf and Eddy, 1979
heavy metals	$(HM*M_1)/M_2$	Metcalf and Eddy, 1979
particulates	$((Part+(0.19*COD/1.9))*M_1)/M_2$	Metcalf and Eddy, 1979
particulate size	PS	Metcalf and Eddy, 1979
dissolved solids	$(DS*M_1)/M_2$	Metcalf and Eddy, 1979
TN	$(TN*M_1)/M_2$	Metcalf and Eddy, 1979
sulphur	$(S*M_1)/M_2$	Metcalf and Eddy, 1979
iron	$(Fe*M_1)/M_2$	Metcalf and Eddy, 1979
toxics	$(Tox*M_1)/M_2$	Metcalf and Eddy, 1979
ash	$(Ash*M_1)/M_2$	Metcalf and Eddy, 1979

Table A1.14 Anaerobic digestion - gas output formulae

Gas Output	Formulae	Reference
mass	0.225*M1*COD/1000000	Metcalf and Eddy, 1979
corrosivity	pH	
volatiles	0	
oil	0	
water	0	
heavy metals	0	
particulates	0	
particulate size	0	
CFC	0	
CO_2	(.3*M_2)	Metcalf and Eddy, 1979
SO_2	0	Metcalf and Eddy, 1979
NO_x	0	Metcalf and Eddy, 1979
Cl	0	
NH_3	0	Metcalf and Eddy, 1979

4. Belt Filter

Table A1.15 Belt filter - acid input criteria

Belt Filter - acid	Input - sludge	Reference
pH	<7.0	
particulates	5,000-60,000 ppm	Woods, 1994a
particulate size	.2 - 75mm	Woods, 1994a

Table A1.16 Belt filter (acid inputs) - solid output formulae

Solid Output		References
mass	((1.3*Part)/1000000)*M_1	Glysson, 1990
leachate pH	<7	
COD	(.85*COD*M_1)/M_2	Glysson, 1990
solvent	(.40*Part*(Vol/(Vol+Wat+Oil))*M_1)/M_2	Glysson, 1990
oil	(.40*Part*(Oil/(Vol+Wat+Oil))*M_1)/M_2	Glysson, 1990
water	(.40*Part*(Wat/(Vol+Wat+Oil))*M_1)/M_2	Glysson, 1990
heavy metals	(.01*HM*M_1)/M_2	Corbitt, 1990
iron		
other metals		
soluble solids	(.7*DS*M_1)/M_2	Glysson, 1990
toxics	(.01*Tox*M_1)/M_2	
particle size	PS	
paper/cardboard	0	
plastic	0	
ash	(Ash*M_1)/M_2	

Table A1.17 Belt filter (acid inputs) - liquid output formulae

Liquid Output		**Reference**
mass	(M_1-(1.3*Part/1000000)*M_1)	Glysson, 1990
pH	< 7	
COD	(.15*COD*M_1)/M_2	Glysson, 1990
solvent	((Vol*M_1)-(.4*Part*Vol/(Vol+Wat+Oil)*(M_1-M_2)))/M_2	Glysson, 1990
oil	((Oil*M_1)-(.4*Part*Oil/(Vol+Wat+Oil)*(M_1-M_2)))/M_2	Glysson, 1990
water	((Wat*M_1)-(.4*Part*Wat/(Vol+Wat+Oil)*(M_1-M_2)))/M_2	Glysson, 1990
heavy metals	(.99*HM*M_1)/M_2	Corbitt, 1990
particulates	(.1*Part*M_1)/M_2	
particulate size	<0.2 mm	
dissolved solids	((DS*M_1)-(DS*.4*Part*(M_1-M_2)))/M_2	Glysson, 1990
NO_3	((NO3*M_1)-(.4*Part*NO3*(M_1-M_2)))/M_2	
NH_3	((NH3*M_1)-(.4*Part*NH3*(M_1-M_2)))/M_2	
sulphur	(.01*S*M_1)/M_2	
PO_4	((PO4*M_1)-(.4*Part*PO4*(M_1-M_2)))/M_2	
toxics	(.99*Tox*M_1)/M_2	

Table A1.18 Belt Filter - basic input criteria

Belt Filter - basic	**Input - sludge**	**Reference**
pH	>7.0	
particulates	5,000-60,000 ppm	Woods, 1994a
particulate size	.2 - 75mm	Woods, 1994a

Table A1.19 Belt filter (basic inputs) - solid output formulae

Solid Output		**Reference**
mass	((1.3*Part)/1000000)*M_1	Glysson, 1990
leachate pH	>7	
COD	(.85*COD*M_1)/M_2	Glysson, 1990
solvent	(.4*Part*Vol/(Vol+Wat+Oil)*M_1)/M_2	Glysson, 1990
oil	(.4*Part*Oil/(Vol+Wat+Oil)*M_1)/M_2	Glysson, 1990
water	(.4*Part*Wat/(Vol+Wat+Oil)*M_1)/M_2	Glysson, 1990
heavy metals	(.999*HM*M_1)/M_2	Corbitt, 1990
iron		
other metals		
soluble solids	(DS*.4*Part*M_1)/M_2	Glysson, 1990
toxics	(.01*Tox*M_1)/M_2	
particle size	PS	
paper/cardboard	0	
plastic/rubber	0	
ash	(Ash*M_1)/M_2	

Table A1.20 Belt filter (basic inputs) - liquid output formulae

Liquid Output		**Reference**
mass	$M_1-(((1.3*Part)/1000000)*M_1)$	Glysson, 1990
pH	> 7	
COD	$(.15*COD*M_1)/M_2$	Glysson, 1990
solvent	$((Vol*M_1)-(.4*Part*Vol/(Vol+Wat+Oil)*(M_1-M_2))/M_2$	Glysson, 1990
oil	$((Oil*M_1)-(.4*Part*Oil/(Vol+Wat+Oil)*(M_1-M_2))/M_2$	Glysson, 1990
water	$((Wat*M_1)-(.4*Part*Wat/(Vol+Wat+Oil)*(M_1-M_2)))/M_2$	Glysson, 1990
heavy metals	$(.001*HM*M_1)/M_2$	Corbitt, 1990
particulates	$(.01*Part*M_1)/M_2$	
particulate size	<0.2mm	
dissolved solids	$((DS*M_1)-(DS*.4*Part*(M_1-M_2)))/M_2$	Glysson, 1990
NO_3	$((NO3*M_1)-(.4*Part*NO3*(M_1-M_2)))/M_2$	
NH_3	$((NH3*M_1)-(.4*Part*NH3*(M_1-M_2)))/M_2$	
sulphur	$(.001*S*M_1)/M_2$	
PO_4	$((PO4*M_1)-(.4*Part*PO4*(M_1-M_2)))/M_2$	
toxics	$(.99*Tox*M_1)/M_2$	

Note: This treatment is also designated for liquid wastes

5. Evaporation

Table A1.21 Evaporation - input criteria

Evaporation	**Input**	**Reference**
solvent	<800,000 ppm	Corbitt, 1994
water	300,000 -800,000 ppm	Corbitt, 1994
particulates	>200,000 ppm	Woods, 1994a
particulate size	>0.01 mm	Woods, 1994a

Table A1.22 Evaporation - solid output formuale

Solid Output	**Formulae**	**Reference**
mass	$M_1-(((Vol+Wat-300000)/1000000)*M_1)$	
leachate pH	pH	
COD	$(COD-(3.29*Vol))*M_1/M_2$	
solvent	0	
oil	$Oil*M_1/M_2$	
water	300,000 ppm	Corbitt, 1990
heavy metals	$HM*M_1/M_2$	
iron		
other metals		
soluble solids	$DS*M_1/M_2$	
toxics	$Tox*M_1/M_2$	
particle size	PS	
pap/cardboard	0	
plastic	0	
ash	$Ash*M_1/M_2$	

Table A1.23 Evaporation - gas output formuale

Gas Output	Formulae	Reference
mass	$((Vol+Wat-300000)/1000000)*M_1$	
corrosivity	0	
volatiles	$(Vol*M_1)/M_2$	
oil	0	
water	$((Wat*M_1)-(300000*(M_1-M_2)))/M_2$	Corbitt, 1990
heavy metals	0	
particulates	0	
particulate size	0	
CFC	0	
CO_2	0	
SO_2	0	
NO_x	0	
Cl	0	
NH_3	0	

6. Multiple Hearth Incineration

Table A1.24 Multiple hearth incineration - input criteria

Multiple Hearth Incineration	Input - sludge	Reference
water	500,000 - 850,000 ppm	Brunner, 1991
ash	<900,000 ppm	est. from Brunner, 1991

Table A1.25 Multiple hearth incineration - solid output formulae

Solid Output	Formulae	Reference
mass	$(Ash/1000000*.87*M_1)$	Schroeder, Cresculo, Campbell, and Cohen, 1981
leachate pH		
COD	$(.015*COD*M_1)/M_2$	Schroeder, Cresculo, Campbell, and Cohen, 1981
solvent	0	
oil	0	
water	0	
heavy metals	$(.85*HM*M_1)/M_2$	Brunner, 1991
iron	$(.85*Fe*M_1)/M_2$	Brunner, 1991
other metals	$(.85*OM*M_1)/M_2$	Brunner, 1991
soluble solids	$(.85*DS*M_1)/M_2$	
toxics	$(.01*Tox*M_1)/M_2$	Schroeder, Cresculo, Campbell, and Cohen, 1981
particle size	PS	
paper/cardboard	0	
plastic/rubber	0	
ash	$(0.85*Ash*M_1)/M_2$	Brunner, 1991

Table A1.26 Multiple hearth incineration - gas output formulae

Gas Output	Formulae	Reference
mass	M_1-(Ash/1000000*.87*M_1)+ .27*COD*M1/1000000	Schroeder, Cresculo, Campbell, and Cohen, 1981
corrosivity	4	est. from Brunner, 1991
volatiles	0.02*Vol*M_1/M_2	Brunner, 1991
oil	0.02*Oil*M_1/M_2	Brunner, 1991
water	0.48*COD*M_1/M_2	
heavy metals	0.15*HM*M_1/M_2	Brunner, 1991
particulates	0.15*Part*M_1/M_2	Brunner, 1991
particulate size	<.3mm	Brunner, 1991
CFC	0	
CO_2	0.79*COD*M_1/M_2	Schroeder, Cresculo, Campbell, and Cohen, 1981
SO_2	0.15*S*M_1/M_2	Brunner, 1991
NO_x	0.15*TN*M_1/M_2	Brunner, 1991
Cl		
NH_3	0	

7. Activated Sludge

Table A1.27 Activated sludge - input criteria

Activated sludge	Input - liquid	Reference
pH	6-8	Metcalf and Eddy, 1979
COD	50 - 15,000 ppm	Grady and Lim, 1980
solvent	<200 ppm	Dyer, Vernick and Feiler, 1981
oil	<20 ppm	Metcalf and Eddy, 1979
heavy metals	<100 ppm	Metcalf and Eddy, 1979
particulates	<1500 ppm	Metcalf and Eddy, 1979
particulate size	<.05mm	Metcalf and Eddy, 1979
NH_3	<400 ppm	Metcalf and Eddy, 1979
sulphur	<200 ppm	Metcalf and Eddy, 1979
toxics	<100 ppm	Dyer, Vernick and Feiler, 1981

Table A1.28 Activated sludge - liquid output formulae

Liquid Output	Formulae	References
mass	$M_1-((225*COD)/1000000*M_1)$	Metcalf and Eddy, 1979
pH	pH	Metcalf and Eddy, 1979
COD	.10*COD	Metcalf and Eddy, 1979
solvent	$(.5*Vol*M_1)/M_2$	Dyer, Vernick and Feiler, 1981
oil	$(.9*Oil*M_1)/M_2$	Dold, 1989
water	$(Wat*M_1)/M_2$	Metcalf and Eddy, 1979
heavy metals	$(.4*HM*M_1)/M_2$	Dyer, Vernick and Feiler, 1981
particulates	5 ppm	Metcalf and Eddy, 1979
particulate size	PS	
dissolved solids	$(DS*M_1)/M_2$	Metcalf and Eddy, 1979
NO_3	$(.9*NO3*M_1)/M_2$	Metcalf and Eddy, 1979
NH_3	$(.6*NH3*M_1)/M_2$	Dold, 1989
sulphur	$(S*M_1)/M_2$	
PO_4	$((PO4*M_1)-(.022*COD*PO4))*(M_1-M_2)))/M_2$	Metcalf and Eddy, 1979
toxics	$(.5*Tox*M_1)/M_2$	Dyer, Vernick and Feiler, 1981

Table A1.29 Activated sludge - wasted liquid output formulae

Liquid Output	Formulae	References
mass	$(125*COD)/1000000*M_1$	Metcalf and Eddy, 1979
pH	pH	Metcalf and Eddy, 1979
COD	.10*COD	Metcalf and Eddy, 1979
solvent	0	Dyer, Vernick and Feiler, 1981
oil	0	Dold, 1989
water	$.9*Wat*M_1/M_2$	Metcalf and Eddy, 1979
heavy metals	$(.6*HM*M_1)/M_2$	Dyer, Vernick and Feiler, 1981
particulates	$((.225*COD+Part)*M_1)/M_2$	Metcalf and Eddy, 1979
particulate size	PS	
dissolved solids	$(DS*M_1)/M_2$	Metcalf and Eddy, 1979
NO_3	$(.9*NO3*M_1)/M_2$	Metcalf and Eddy, 1979
NH_3	$(.6*NH3*M_1)/M_2$	Dold, 1989
sulphur	$(S*M_1)/M_2$	
PO_4	$((PO4*M_1)-(.022*COD*PO4))*(M_1-M_2)))/M_2$	Metcalf and Eddy, 1979
toxics	$(.5*Tox*M_1)/M_2$	Dyer, Vernick and Feiler, 1981

8. API Oil Separation

Table A1.30 API oil separation - input criteria

API Separation	Input - liquid	Reference
oil	<1000 ppm	Woods, 1994a
particulates	<2500 ppm	Woods, 1994a
particulate size	.025 - 2mm	Woods, 1994a

Table A1.31 API oil separation - oily liquid output formula

Oily liquid	**Formulae**	**References**
mass	10*(.55*Vol+(Oil-50)/1000000)*M1	est. from Jones, 1971
pH	pH	
COD	$(1.5*COD*M_1)/M_2$	Jones, 1971
solvents	$(.55*Vol*M_1)/M_2+$ $(.45*Vol/(Wat+.45*Vol))*900,000$	Jones, 1971
oil	$((Oil*M_1)-(50*(M_1-M_2))/M_2$	Jones, 1971
water	(Wat/(Wat + .45*Vol))*900,000	
heavy metals	.9*HM	
particulates	$(.1*Part*M_1)/M_2$	
particulate size	<.02mm	Woods, 1994a
dissolved solids	.9*DS	
NO_3	.9*NO3	Metcalf and Eddy, 1979
NH_3	.9*NH3	Metcalf and Eddy, 1979
sulphur	.9*S	
PO_4	.9*PO4	
toxics	$(.5*Tox*M_1)/M_2$	

Table A1.32 API oil separation - aqueous output formulae

Aqueous Output	**Formulae**	**References**
mass	$M_1-10*(\frac{(.55*Vol+(Oil-50)+.8*Part)}{1000000}*M_1)$	estimated from Jones, 1971
pH	pH	
COD	$((COD-(1.8*Vol))*M_1)/M_2$	Jones, 1971
solvents	$(Vol*M_1)-((.55*Vol*M_1)+$ $(.45*Vol/(Wat+.45*Vol)*900,000*(M_1-M_2)))/M_2$	Jones, 1971
oil	50 ppm	Jones, 1971
water	$((Wat*M_1)-(Wat/(Wat+45*Vol)*900,000*(M_1-M_2)))/M_2$	
heavy metals	$((HM*M_1)-(.9*HM*(M_1-M_2)))/M_2$	
particulates	$(.2*Part*M_1)/M_2$	Jones, 1971
particulate size	<.25 mm	Woods, 1994a
dissolved solids	$((DS*M_1)-(.9*DS*(M_1-M_2)))/M_2$	
NO_3	$((NO3*M_1)-(.9*NO3*(M_1-M_2)))/M_2$	Metcalf and Eddy, 1979
NH_3	$((NH3*M_1)-(.9*NH3*(M_1-M_2)))/M_2$	Metcalf and Eddy, 1979
sulphur	$((S*M_1)-(.9*S*(M_1-M_2)))/M_2$	
PO_4	$((PO4*M_1)-(.9*PO4*(M_1-M_2)))/M_2$	
toxics	$((Tox*M_1)-(.9*Tox*(M_1-M_2)))/M_2$	

Table A1.33 API oil separation - sludge output formulae

Sludge output	**Formulae**	**Reference**
mass	10*(.8*Part*M1)/1000000	estimated from Jones, 1971
pH	pH	
COD	$(1.8*COD*M_1)/M_2+.45*COD$	Metcalf and Eddy, 1979
solvents	(.45*Vol/(Wat+.45*Vol))*900,000	Gregory and Zabel, 1990
oil		Metcalf and Eddy, 1979
water	(Wat/(Wat+.45*Vol))*900,000	Gregory and Zabel, 1990
heavy metals	.9*HM	Palmer et.al, 1988
particulates	100,000 ppm	Woods, 1994b
particulate size	>.25 mm	
dissolved solids	.9*DS	Corbitt, 1990
TN	$(.03*COD*M_1)/M_2+9*(.23*NO3+.82*NH3)$	Metcalf and Eddy, 1979
sulphur	.9*S	Palmer et. al, 1988
iron		
toxics	.9*Tox	
ash	$(100000-((.55*COD*M_1)/M_2)$	est. from Metcalf and Eddy, 1979

9. Carbon Adsorption

Table A1.34 Carbon adsorption - input criteria

Carbon Adsorption	**Input - liquid**	**Reference**
COD	<10,000 ppm	Lyman, 1978
oil	<10 ppm	Freeman, 1989
heavy metals	<100 ppm	Lyman, 1978
particulates	<50 ppm	Freeman, 1989
dissolved solids	<1000 ppm	Lyman, 1978
NO_3	<1000 ppm	Lyman, 1978
NH_3	<1000 ppm	Lyman, 1978
sulphur	<1000 ppm	Lyman, 1978
PO_4	<1000 ppm	Lyman, 1978
toxics	<10,000 ppm	Lyman, 1978

Table A1.35 Carbon adsorption - liquid output formuale

Liquid Output	**Formulae**	**Reference**
mass	M_1-((.8*(Vol+Oil)+0.9*Part+ 0.5*DS)*M_1/1000000)	
pH	pH	
COD	(.2*COD*M_1)/M_2	Lyman, 1978
solvent	(.2*Vol*M_1)/M_2	Lyman, 1978
oil	(.2*Oil*M_1)/M_2	Lyman, 1978
water	(Wat*M_1)/M_2	
heavy metals	(.05*HM*M_1)/M_2	Huang, 1978
particulates	(.1*Part*M_1)/M_2	Lyman, 1978
particulate size	PS	
dissolved solids	(.5*DS*M_1)/M_2	est. from Huang, 1978
NO_3	(NO3*M_1)/M_2	Metcalf and Eddy, 1979
NH_3	(NH3*M_1)/M_2	Metcalf and Eddy, 1979
sulphur	(S*M_1)/M_2	
PO_4	(PO4*M_1)/M_2	
toxics	(.03*Tox*M_1)/M_2	Snoeyink, 1990

10. Disk Filter

Table A1.36 Disk filter - base input criteria

Disk Filter - base	**Input - liquid**	Reference
pH	>7.0	
oil	<50 ppm	
particulates	50 - 5000 ppm	Perry and Green, 1984
particulate size	>.01mm	Woods, 1994a

Table A1.37 Disk filter - solid output formulae

Solid Output	**Formulae**	**Reference**
mass	1.3((.95*Part)/1000000)*M_1	est. from Corbitt, 1990
leachate pH	pH	
COD	(.60*COD*M_1)/M_2	est. from Corbitt, 1990
solvent	(.29*Part*(Vol/(Vol+Wat))*M_1)/M_2	est. from Woods, 1994a
oil	(.5*Oil*M_1)/M_2	
water	(.29*Part*(Wat/(Vol+Wat))*M_1)/M_2	
heavy metals	(.99*HM*M_1)/M_2	Palmer et.al, 1988
iron	.99*Fe*M_1/M_2	
other metals	.99*OM*M_1/M_2	
soluble solids	(.29*Part*DS*M_1)/M_2	est. from Woods, 1994a
toxics	(.29*Part*Tox*M_1)/M_2	
particle size	PS	est. from Woods, 1994a
pap/cardboard	0	
plastic	0	
ash	((.29*Part)*M_1)/M_2	

Table A1.38 Disk filter - liquid output formulae

Liquid Output	**Formulae**	**Reference**
mass	$(M_1-((.95*Part)/1000000*M_1)$	est. from Corbitt, 1990
pH	pH	
COD	$(.40*COD*M_1)/M_2$	
solvent	$(Vol*M_1-(.29*Part*Vol/(Vol+Wat))*(M_1-M2))/M_2$	est. from Woods, 1994a
oil	$(.5*Oil*M_1)/M_2$	
water	$(Wat*M_1-.29*Part*Wat/(Vol+Wat)*(M_1-M_2))/M_2$	est. from Woods, 1994a
heavy metals	$(.01*HM*M_1)/M_2$	Palmer et.al. 1988
particulates	$((.95*Part)*M_1)/M_2$	
particulate size	<0.01 mm	Woods, 1994a
dissolved solids	$((DS*M_1)-(.29*Part*DS*(M_1-M_2))/M_2$	est. from Woods, 1994a
NO_3	$((NO3*M_1)-(.29*Part*NO3*(M_1-M_2))/M_2$	est. from Woods, 1994a
NH_3	$((NH3*M_1)-(.29*Part*NH3*(M_1-M_2))/M_2$	est. from Woods, 1994a
sulphur	$((S*M_1)-(.29*Part*S*(M_1-M_2))/M_2$	est. from Woods, 1994a
PO_4	$((PO4*M_1)-(.29*Part*PO4*(M_1-M_2))/M_2$	est. from Woods, 1994a
toxics	$((Tox*M_1)-(.29*Part*Tox*(M_1-M_2))/M_2$	est. from Woods, 1994a

Table A1.39 Disk filter - acid input criteria

Sand Filtration - acid	**Input - liquid**	**Reference**
pH	<7.0	
oil	<50 ppm	
particulates	50 - 5000 ppm	Perry and Green, 1984
particulate size	>.01mm	Woods, 1994a

Table A1.40 Disk filter - solid output formulae

Solid Output	**Formulae**	**References**
mass	$1.3((.97*Part)/1000000)*M_1$	est. from Corbitt, 1990
leachate pH	pH	
COD	$(.60*COD*M_1)/M_2$	est. from Corbitt, 1990
solvent	$(.29*Part*(Vol/(Vol+Wat))*M_1)/M_2$	est. from Woods, 1994a
oil	$(.5*Oil*M_1)/M_2$	
water	$(.29*Part*(Wat/(Vol+Wat))*M_1)/M_2$	
heavy metals	$(.29*Part)*HM*M_1)/M_2$	Palmer et.al. 1988
iron	$(.29*Part*Fe*M_1)/M_2$	
other metals	$(.29*Part*OM*M_1)/M_2$	
soluble solids	$(.29*Part*DS*M_1)/M_2$	est. from Woods, 1994a
toxics	$(.29*Part*Tox*M_1)/M_2$	
particle size	PS	est. from Woods, 1994a
pap/cardboard	0	
plastic	0	
ash	$(.29*Part*M_1)/M_2$	

Table A1.41 Disk filter - liquid output formulae

Liquid Output	**Formulae**	**Reference**
mass	$(M_1-((.95*Part)/1000000*M_1)$	est. from Corbitt, 1990
pH	pH	
COD	$(.40*COD*M_1)/M_2$	
solvent	$((Vol*M_1)-(.29*Part*Vol/(Vol+Wat)*(M_1-M2)))/M_2$	est. from Woods, 1994a
oil	$(.5*Oil*M_1)/M_2$	
water	$((Wat*M_1)-(.29*Part*Wat/(Vol+Wat)*(M_1-M_2)))/M_2$	est. from Woods, 1994a
heavy metals	$(HM*M_1)-(.29*Part*(M_1-M_2)))/M_2$	Palmer et.al, 1988
particulates	$(.95*Part*M_1)/M_2$	
particulate size	<0.01 mm	Woods, 1994a
dissolved solids	$((DS*M_1)-(.29*Part*DS*(M_1-M_2))/M_2$	est. from Woods, 1994a
NO_3	$((NO3*M_1)-(.29*Part*NO3*(M_1-M_2))/M_2$	est. from Woods, 1994a
NH_3	$((NH3*M_1)-(.29*Part*NH3*(M_1-M_2))/M_2$	est. from Woods, 1994a
sulphur	$((S*M_1)-(.29*Part*S*(M_1-M_2))/M_2$	est. from Woods, 1994a
PO_4	$((PO4*M_1)-(.29*Part*PO4*(M_1-M_2))/M_2$	est. from Woods, 1994a
toxics	$((Tox*M_1)-(.29*Part*Tox*(M_1-M_2))/M_2$	est. from Woods, 1994a

11. Dissolved Air Flotation

Table A1.42 Dissolved air flotation - input criteria

Dissolved Air Flotation	**Input - liquid**	**Reference**
pH	6-8	Palmer et. al, 1988
oil	<1000 ppm	Woods, 1994a
heavy metals	<100 ppm	Palmer et. al, 1988
particulates	<750 ppm	Woods, 1994a
particulate size	<.1 mm	Woods, 1994a

Table A1.43 Dissolved air flotation - liquid output formulae

Liquid Output	**Formulae**	**References**
mass	$M_1-10*(\frac{.55*Vol+(Oil-15)+.90*Part}{1000000}*M_1)$	
pH	pH	
COD	$(.2*COD*M_1)/M_2$	Jones, 1971
solvents	$((Vol*M_1)-.55*Vol/(Wat+.55*Vol)*900000*(M_1-M_2)))/M_2$	
oil	20 ppm	Rhee et. al, 1987
water	$((Wat*M_1)-(Wat/(Wat+.55*Vol)*900000*(M_1-M_2)))/M_2$	
heavy metals	$((HM*M1)-(.9*HM*(M_1-M_2)))/M_2$	Palmer et. al, 1988
particulates	$(.1*Part*M_1)/M_2$	Rhee et. al, 1987
particulate size	<.02 mm	
dissolved solids	$((DS*M_1)-(.9*DS*(M_1-M_2)))/M_2$	
NO_3	$((NO3*M_1)-(.9*NO3*(M_1-M_2)))/M_2$	Metcalf and Eddy, 1979
NH_3	$((NH3*M_1)-(.9*NH3*(M_1-M_2)))/M_2$	Metcalf and Eddy, 1979
sulphur	$((S*M_1)-(.9*S*(M_1-M_2)))/M_2$	
PO_4	$((PO4*M_1)-(.9*PO4*(M_1-M_2)))/M_2$	
toxics	$((Tox*M_1)-(.9*Tox*(M_1-M_2)))/M_2$	

Table A1.44 Dissolved air flotation - waste liquid output formulae

Liquid Output	**Formulae**	**Reference**
mass	$10*(\frac{(.55*Vol+.9*Part+(Oil-15))*M_1}{1000000})$	
pH	pH	
COD	$(.8*COD*M_1)/M_2$	Jones, 1971
solvents	$(.55*Vol/(Wat+.55*Vol))*900{,}000$	Gregory and Zabel, 1990
oil	$((Oil*M_1)-(20*(M_1-M_2)))/M_2$	Metcalf and Eddy, 1979
water	$(Wat/(Wat+.55*Vol))*900{,}000$	Gregory and Zabel, 1990
heavy metals	.9*HM	Palmer et. al. 1988
particulates	$(.9*Part*M_1)/M_2$	Woods, 1994a
particulate size	0.1-.02 mm	Woods, 1994a
dissolved solids	.9*DS	Corbitt, 1990
NO_3	.9*NO3	Metcalf and Eddy, 1979
NH_3	.9*NH3	Metcalf and Eddy, 1979
sulphur	.9*S	
PO_4	$.9*PO_4$	
toxics	.9*Tox	est. from Metcalf and Eddy, 1979

12. Ion Exchange

Table A1.45 Ion exchange - input criteria

Ion Exchange	Input - liquid	Reference
COD	<20,000 ppm	Woods, 1994a
oil	<20,000 ppm	Woods, 1994a
heavy metals	<20,000 ppm	Woods, 1994a
particulates	<50 ppm	Librizzi and Lowery, 1990
particulate size	<.01mm	
dissolved solids	<20,000 ppm	Woods, 1994a
NO_3	<20,000 ppm	Woods, 1994a
NH_3	<20,000 ppm	Woods, 1994a
sulphur	<20,000 ppm	Woods, 1994a
PO_4	<20,000 ppm	Woods, 1994a
toxics	<20,000 ppm	Woods, 1994a

Table A1.46 Ion exchange - eluent formulae

Eluent	Formulae	Reference
mass	M_1	
pH	7	
COD	$(.55*COD*M_1)/M_2$	Straub, 1989
solvent	$(.1*Vol*M_1)/M_2$	Gao and Yu, 1988
oil	$(Oil*M_1)/M_2$	
water	$(Wat+.95*DS+.05Part+.9*Vol)*M_1/M_2$	
heavy metals	$(.05*HM*M_1)/M_2$	Palmer et. al, 1988
particulates	$0.95*Part*M_1/M_2$	Librizzi and Lowery, 1990
particulate size	PS	
dissolved solids	$(.05*DS*M_1)/M_2$	Metcalf and Eddy, 1979
NO_3	$(.15*NO3*M_1)/M_2$	Metcalf and Eddy, 1979
NH_3	$(.15*NH3*M_1)/M_2$	Metcalf and Eddy, 1979
sulphur	$(.05*S*M_1)/M_2$	Metcalf and Eddy, 1979
PO_4	$(.25*PO4*M_1)/M_2$	Straub, 1989
toxics	$(.55*Tox*M_1)/M_2$	est. from Straub, 1989

Table A1.47 Ion exchange - regenerate formulae

Regenerate	**Formulae**	**Reference**
mass	$.02*M_1$	Clifford, 1990
pH	pH	
COD	$(.45*COD*M_1)/M_2$	Straub, 1989
solvent	$(0.9*Vol*M_1)/M_2$	Gao and Yu, 1988
oil	0	
water	$(1000000-.95*DS+Part+Vol*.9)*M_1)/M_2$	
heavy metals	$(.95*HM*M_1)/M_2$	Palmer et. al, 1988
particulates	$(.05*Part*M_1)/M_2$	Librizzi and Lowery, 1990
particulate size	PS	
dissolved solids	$(.95*DS*M_1)/M_2$	Metcalf and Eddy, 1979
NO_3	$(.85*NO3*M_1)/M_2$	Metcalf and Eddy, 1979
NH_3	$(.85*NH3*M_1)/M_2$	Metcalf and Eddy, 1979
sulphur	$(.95*S*M_1)/M_2$	Metcalf and Eddy, 1979
PO_4	$(.75*PO4*M_1)/M_2$	Straub, 1989
toxics	$(.45*Tox*M_1)/M_2$	est. from Straub, 1989

13. Liquid Injection Incineration

Table A1.48 Liquid injection incineration - input criteria

Liquid Injection Incineration	**Input - liquid**	**Reference**
COD	>2,000 ppm	Woods, 1994a
solvents	>2,000 ppm	Woods, 1994a
oil	>2,000 ppm	Woods, 1994a
water	<750,000	LaGrega, Buckingham and Evens, 1994
heavy metals	<1,000 ppm	
particulates	<20,000 ppm	Woods, 1994a
particulate size	<.04 mm	Brunner, 1991
sulphur	<1,000 ppm	

Table A1.49 Liquid injection incineration - gas output criteria

Gas Output	**Formulae**	**References**
mass	M1+(.27*COD*M1/1000000)	
corrosivity		
volatiles	$(.001*Vol*M_1)/M_2$	Oppelt, 1991
oil	$(.0001*Oil*M_1)/M_2$	Oppelt, 1991
water	$.48*COD*M_1/M_2$	Oppelt, 1991
heavy metals	$(HM*M_1)/M_2$	Oppelt, 1991
particulates	$((Part+HM+DS)*M_1)/M_2$	Oppelt, 1991
particulate size	PS	
CFC	0	
CO_2	$.79*COD*M_1/M_2$	Oppelt, 1991
SO_2	$(2*S*M_1)/M_2$	Librizzi and Lowery, 1990
NO_x	$((.28*NO3+.82*NH3)*M_1)/M_2$	Oppelt, 1991
Cl		
NH_3	0	

14. Neutralization

Table A1.50 Neutralization - acid input criteria

Neutralization - acid	Input - liquid	Reference
pH	2-6.5	Batstone, Smith and Wilson, 1989

Table A1.51 Neutralization - liquid output formulae

Liquid Output	Formulae	References
mass	$M_1+((7-pH)*90)$	Batstone. Smith and Wilson. 1989
pH	7.0	
COD	$(COD*M_1)/M_2$	
solvents	$(Vol*M_1)/M_2$	
oil	$(Oil*M_1)/M_2$	
water	$(1.1*Wat*M_1)/M_2$	
heavy metals	$(HM*M_1)/M_2$	
particulates	$((Part+.9*HM)*M_1)/M_2$	Palmer et.al. 1988
particulate size	PS	
dissolved solids	$(2*DS*M_1)/M_2$	
NO_3	$(NO3*M_1)/M_2$	
NH_3	$(NH3*M_1)/M_2$	
sulphur	$(S*M_1)/M_2$	
PO_4	$(PO4*M_1)/M_2$	
toxics	$(Tox*M_1)/M_2$	

Table A1.52 Neutralization - basic input criteria

Neutralization - base	Input - liquid	Reference
pH	7.5-12	Batstone, Smith and Wilson, 1989

Table A1.53 Neutralization - liquid output formulae

Liquid Output	Formulae	References
mass	$M_1+((pH-7)*60)$	Batstone, Smith and Wilson, 1989
pH	7.0	
COD	$(COD*M_1)/M_2$	
solvents	$(Vol*M_1)/M_2$	
oil	$(Oil*M_1)/M_2$	
water	$(Wat*M_1)/M_2$	
heavy metals	$(HM*M_1)/M_2$	
particulates	$(Part*M_1)/M_2$	
particulate size	PS	
dissolved solids	$(2*DS*M_1)/M_2$	
NO_3	$(NO3*M_1)/M_2$	
NH_3	$(NH3*M_1)/M_2$	
sulphur	$(1.2*S*M_1)/M_2$	
PO_4	$(PO4*M_1)/M_2$	
toxics	$(Tox*M_1)/M_2$	

15. Precipitation

Table A1.54 Precipitation - input criteria

Precipitation	Input - liquid	Reference
pH	2.9 - 8.5	Corbitt, 1990
particulates	<750 ppm	Woods, 1994a
dissolved solids	100,000 - 600,000	Woods, 1994a

Table A1.55 Precipitation - sludge output formulae

Sludge output	Formulae	Reference
mass	$13*(\frac{(.99*Part+HM+.6*DS)*M_1}{1000000})$	
pH	pH	
COD	$(.35*COD*M_1)/M_2+.6*COD$	Metcalf and Eddy, 1979
solvents	(Vol/(Wat+Vol))*900,000	Gregory and Zabel, 1990
oil	$(.3*Oil*M_1)/M_2$	Metcalf and Eddy, 1979
water	(Wat/(Wat+Vol))*900,000	Gregory and Zabel, 1990
heavy metals	$((HM*M_1)-(.1*HM*(M_1-M_2)))/M_2$	Palmer et.al, 1988
particulates	$(1.3*(.99*Part+HM+.6*DS)*M_1)/M_2$	Woods, 1994b
particulate size	>.25 mm	
dissolved solids	$(.5*DS*M_1)/M_2$	Corbitt, 1990
TN	$(.03*COD*M_1)/M_2+$ 0.9*(.23*NO3+.82*NH3)	Metcalf and Eddy, 1979
sulphur	$(.99*S*M_1)/M_2$	Palmer et. al, 1988
iron		
toxics	.9*Tox	
ash	$(100000-((.35*COD*M_1)/M_2)$	est. from Metcalf and Eddy, 1979

Table A1.56 Precipitation - liquid output formulae

Liquid Output	**Formulae**	**References**
mass	$M_1\text{-}9*(\frac{(.99*Part+HM+.6*DS)*M_1}{1000000})$	
pH	< 7	
COD	$(.65*COD*M_1)/M_2$	Metcalf and Eddy, 1979
solvents	$\frac{Vol}{(Wat+Vol+.7*Oil)}*(1000000\text{-}\frac{.01*Part*M_1}{M_2})$	Gregory and Zabel, 1990
oil	$\frac{.7*Oil}{(Wat+Vol+.7*Oil)}*(1000000\text{-}\frac{.01*Part*M_1}{M_2})$	Metcalf and Eddy, 1979
water	$\frac{Wat}{(Wat+Vol+.7*Oil)}*(1000000\text{-}\frac{.01*Part*M_1}{M_2})$	Gregory and Zabel, 1990
heavy metals	.1 ppm	Palmer et. al, 1988
particulates	$(.35*Part*M_1)/M_2$	
particulate size	<.05	est. from Woods, 1994a
dissolved solids	$(.1*DS*M_1)/M_2$	
NO_3	$(NO3*M_1)/M_2$	Metcalf and Eddy, 1979
NH_3	$(NH3*M_1)/M_2$	Metcalf and Eddy, 1979
sulphur	$(.01*S*M_1)/M_2$	Palmer et. al, 1988
PO_4	$(.15*PO4*M_1)/M_2$	Metcalf and Eddy, 1979
toxics	$(Tox*M_1)/M_2$	

16. Reverse Osmosis

Table A1.57 Reverse osmosis - input criteria

Reverse Osmosis	**Input - liquid**	**Reference**
pH	2-12	Coté, 1992
COD	2 - 100,000 ppm	Woods, 1994a
oil	<100 ppm	Coté, 1992
heavy metals	2 - 100,000 ppm	Woods, 1994a
particulates	<100 ppm	Coté, 1992
particulate size	<.0001mm	Woods, 1994a
dissolved solids	2 - 100,000 ppm	Woods, 1994a
NO_3	2 - 100,000 ppm	Woods, 1994a
NH_3	2 - 100,000 ppm	Woods, 1994a
sulphur	2 - 100,000 ppm	Woods, 1994a
PO_4	2 - 100,000 ppm	Woods, 1994a
toxics	2 - 100,000 ppm	Woods, 1994a

Table A1.58 Reverse osmosis - retentate formulae

Retentate	**Formulae**	**Reference**
mass	$0.97*DS*M_1/150000+$ $(.99*Part+.85*Oil)*M_1/1000000$	Woods, 1994a
pH	pH	
COD	$(.96*COD*M_1)/M_2$	Clark, 1990
solvent	$850000*(Vol/(Vol+Wat)*M_1)/M_2$	Woods, 1994a
oil	$(.96*Oil*M_1)/M_2$	Clark, 1990
water	$850000*(Wat/(Vol+Wat))*M_1)/M_2$	Woods, 1990
heavy metals	$(.93*HM*M_1)/M_2$	Clark, 1990
particulates	$(.99*Part*M_1)/M_2$	Woods, 1994a
particulate size	>.0001mm	Woods, 1994a
dissolved solids	$(.97*DS*M_1)/M_2$	Clark, 1990
NO_3	$(.97*NO3*M_1)/M_2$	Metcalf and Eddy, 1979
NH_3	$(.97*NH3*M_1)/M_2$	Metcalf and Eddy, 1979
sulphur	$(.97*S*M_1)/M_2$	Clark, 1990
PO_4	$(.97*PO4*M_1)/M_2$	Clark, 1990
toxics	$(.96*Tox*M_1)/M_2$	Clark, 1990

Table A1.59 Reverse osmosis - permeate formulae

Permeate	**Formulae**	**Reference**
mass	$M_1-(0.97*DS*M_1/150000+$ $(.99*Part+.85*Oil)*M_1/1000000)$	Woods, 1994a
pH	7	
COD	$(.04*COD*M_1)/M_2$	Clark, 1990
solvent	$(Vol*M_1)-(850000*Vol/(Vol+Wat))*(M_1-M_2)))/M_2$	
oil	$(.15*Oil*M_1)/M_2$	Clark, 1990
water	$((Wat*M_1)-(850000*(Wat/(Vol+Wat))*(M_1-M_2)))/M_2$	
heavy metals	$(.07*HM*M_1)/M_2$	Clark, 1990
particulates	$(.01*Part*M_1)/M_2$	Woods, 1994a
particulate size	<.0001 mm	Woods, 1994a
dissolved solids	$(.03*DS*M_1)/M_2$	Clark, 1990
NO_3	$(.03*NO3*M_1)/M_2$	Metcalf and Eddy, 1979
NH_3	$(.03*NH3*M_1)/M_2$	Metcalf and Eddy, 1979
sulphur	$(.03*S*M_1)/M_2$	Clark, 1990
PO_4	$(.03*PO4*M_1)/M_2$	Clark, 1990
toxics	$(.04*Tox*M_1)/M_2$	Clark, 1990

17. Sand Filter

Table A1.60 Sand filter - base input criteria

Sand Filter - base	**Input - liquid**	Reference
pH	>7.0	
oil	<50 ppm	
particulates	50-750 ppm	Woods, 1994a
particulate size	>.01mm	Woods, 1994a

Table A1.61 Sand filter - solid output formulae

Solid Output	**Formulae**	**Reference**
mass	$1.3*.97*Part/1000000*M_1$	est. from Corbitt, 1990
leachate pH	pH	
COD	$(.60*COD*M_1)/M_2$	est. from Corbitt, 1990
solvent	$(.29*Part*(Vol/(Vol+Wat))*M_1)/M_2$	est. from Woods, 1994a
oil	$(.5*Oil*M_1)/M_2$	
water	$(.29*Part*(Wat/(Vol+Wat))*M_1)/M_2$	
heavy metals	$(.99*HM*M_1)/M_2$	Palmer et.al, 1988
iron		
other metals		
soluble solids	$(.29*Part*DS*M_1)/M_2$	est. from Woods, 1994a
toxics	$(.29*Part*Tox*M_1)/M_2$	
particle size	>.01 mm	est. from Woods, 1994a
pap/cardboard	0	
plastic	0	
ash	$((.29*Part)*M_1)/M_2$	

Table A1.62 Sand filter - liquid output formulae

Liquid Output	**Formulae**	**Reference**
mass	$(M_1-((.97*Part)/1000000*M_1)$	est. from Corbitt, 1990
pH	pH	
COD	$(.40*COD*M_1)/M_2$	
solvent	$((Vol*M_1)-(.29*Part*Vol/(Vol+Wat)*(M_1-M_2)))/M_2$	est. from Woods, 1994a
oil	$(.5*Oil*M_1)/M_2$	
water	$((Wat*M_1)-(.29*Part*Wat/(Vol+Wat)*(M_1-M_2)))/M_2$	est. from Woods, 1994a
heavy metals	$(.01*HM*M_1)/M_2$	Palmer et.al. 1988
particulates	$(.97*Part*M_1)/M_2$	
particulate size	<0.01 mm	Woods. 1994a
dissolved solids	$((DS*M_1)-(.29*Part*DS*(M_1-M_2)))/M_2$	est. from Woods, 1994a
NO_3	$((NO3*M_1)-(.29*Part*NO3*(M_1-M_2)))/M_2$	est. from Woods, 1994a
NH_3	$((NH3*M_1)-(.29*Part*NH3*(M_1-M_2)))/M_2$	est. from Woods, 1994a
sulphur	$((S*M_1)-(.29*Part*S*(M_1-M_2))/M_2$	est. from Woods, 1994a
PO_4	$((PO4*M_1)-(.29*Part*PO4*(M_1-M_2)))/M_2$	est. from Woods, 1994a
toxics	$((Tox*M_1)-(.29*Part*Tox*(M_1-M_2))/M_2$	est. from Woods, 1994a

Table A1.63 Sand filter - acid input criteria

Sand Filtration - acid	**Input - liquid**	**Reference**
pH	<7.0	
oil	<50 ppm	
particulates	50-750 ppm	Woods, 1994a
particulate size	>.01mm	Woods, 1994a

Table A1.64 Sand filter - sludge output formulae

Solid Output	**Formulae**	**References**
mass	$1.3((.97*Part)/1000000)*M_1$	est. from Corbitt, 1990
leachate pH	pH	
COD	$(.60*COD*M_1)/M_2$	est. from Corbitt, 1990
solvent	$(.29*Part*(Vol/(Vol+Wat))*M_1)/M_2$	est. from Woods, 1994a
oil	$(.5*Oil*M_1)/M_2$	
water	$(.29*Part*(Wat/(Vol+Wat))*M_1)/M_2$	
heavy metals	$(.3*(.97*Part)*HM*M_1)/M_2$	Palmer et.al, 1988
iron		
other metals		
soluble solids	$(.3*(.97*Part)*DS*M_1)/M_2$	est. from Woods, 1994a
toxics	$.3*(.97*Part)*Tox*M_1)/M_2$	
particle size	>.01 mm	est. from Woods, 1994a
pap/cardboard	0	
plastic	0	
ash	$(.3*(.97*Part)*M_1)/M_2$	

Table A1.65 Sand filter - liquid output formulae

Liquid Output	**Formulae**	**Reference**
mass	$(M_1-((.97*Part)/1000000*M_1)$	est. from Corbitt, 1990
pH	pH	
COD	$(.40*COD*M_1)/M_2$	
solvent	$(Vol*M_1)- .29*Part*Vol/(Vol+Wat)*(M_1M_2))/M_2$	est. from Woods, 1994a
oil	$(.5*Oil*M_1)/M_2$	
water	$(Wat*M_1)- .29*Part*Wat/(Vol+Wat)*(M_1M_2))/M_2$	est. from Woods, 1994a
heavy metals	$(HM-.3*(.97*Part)*M_1)/M_2$	Palmer et.al, 1988
particulates	$((.97*Part)*M_1)/M_2$	
particulate size	<0.01 mm	Woods, 1994a
dissolved solids	$((DS*M_1)-(.29*Part*DS*(M_1-M_2)))/M_2$	est. from Woods, 1994a
NO_3	$((NO3*M_1)-(.29*Part*NO3*(M_1-M_2)))/M_2$	est. from Woods, 1994a
NH_3	$((NH3*M_1)-(.29*Part*NH3*(M_1-M_2)))/M_2$	est. from Woods, 1994a
sulphur	$((S*M_1)-(.29*Part*S*(M_1-M_2)))/M_2$	est. from Woods, 1994a
PO_4	$((PO4*M_1)-(.29*Part*PO4*(M_1-M_2)))/M_2$	est. from Woods, 1994a
toxics	$((Tox*M_1)-(.29*Part*Tox*(M_1-M_2)))/M_2$	est. from Woods, 1994a

17. Screening

Table A1.66 Screening - input criteria

Screening	**Input - liquid**	**Reference**
oil	<100ppm	est. from Corbitt, 1990
particulates	50,000-220,000 ppm	Woods, 1994a
particulate size	.25 - 6 mm	Woods, 1994a

Table A1.67 Screening - solid output formulae

Solid Output	**Formulae**	
mass	$((1.2*Part/1000000)*M_1$	Woods, 1994a
leachate pH	pH	
COD	$(.85*COD*M_1)/M_2$	
solvent	$(.3*Part*(Vol/(Vol+Wat))*M_1)/M_2$	Woods, 1994a
oil	$(.3*Part*Oil*M_1)/M_2$	
water	$(.3*Part*(Wat/(Vol+Wat))*M_1)/M_2$	Woods, 1994a
heavy metals	$(.01*HM*M_1)/M_2$	
iron		
other metals		
soluble solids	$(.3*DS*M_1)/M_2$	Woods, 1994a
toxics	$(.01*Tox*M_1)/M_2$	
particle size	>.25	
paper/cardboard	0	
plastic/rubber	0	
ash	$((.9*DS)+(.3*Part*DS)*M_1)/M_2$	

Table A1.68 Screening - liquid output formulae

Liquid Output	**Formulae**	**Reference**
mass	$M_1-(((.1.2*Part)/1000000)*M_1)$	
pH	pH	
COD	$(.15*COD*M_1)/M_2$	
solvent	$((Vol*M_1)-(.2*Part*Vol/(Vol+Wat)*(M_1-M_2)))/M_2$	Woods, 1994a
oil	$((Oil*M_1)-(.3*Part*Oil*(M_1-M_2)))/M_2$	Woods, 1994a
water	$((Wat*M_1)-(.2*Part*(Wat/(Vol+Wat)*(M_1-M_2)))/M_2$	Woods, 1994a
heavy metals	$(.99*HM*M_1)/M_2$	
particulates	$(.1*Part*M_1)/M_2$	
particulate size	<.25	Woods, 1994a
dissolved solids	$(DS*M_1)-.2*Part*DS*(M_1-M_2)))/M_2$	Woods, 1994a
NO_3	$(NO3*M_1)-.2*Part*NO3*(M_1-M_2)))/M_2$	Woods, 1994a
NH_3	$(NH3*M_1)-.2*Part*NH3*(M_1-M_2)))/M_2$	Woods, 1994a
sulphur	$(.01*S*M_1)/M_2$	
PO_4	$(PO4*M_1)-.2*Part*PO4*(M_1-M_2)))/M_2$	Woods, 1994a
toxics	$(.99*Tox*M_1)/M_2$	

18. Settling

Table A1.69 Settling - acid input criteria

Settling - acid	**Input - liquid**	**Reference**
pH	<7.0	
particulates	1,500-10,000 ppm	Metcalf and Eddy, 1979
particulate size	.025 - 2mm	Woods, 1994a

Table A1.70 Settling - sludge output formulae

Sludge output	**Formulae**	**Reference**
mass	(6.3*Part*M_1)/1000000	est. from Gregory and Zabel, 1990
pH	pH	
COD	(1.25*COD*M_1)/M_2	Metcalf and Eddy, 1979
solvent	(Vol/(Wat+Vol))*900,000	Gregory and Zabel, 1990
oil	(.3*Oil*M_1)/M_2	Metcalf and Eddy, 1979
water	(Wat/(Wat+Vol))*900,000	Gregory and Zabel, 1990
heavy metals	.9*HM	Palmer et. al, 1988
particulates	100,000 ppm	Gregory and Zabel, 1990
particulate size	>.25 mm	Woods, 1994a
dissolved solids	.9*DS	
TN	.9*TN	
sulphur	.9*S	
iron	.9*Fe	Palmer et.al, 1988
toxics	.9*Tox	
ash	(100000-((.35*COD*M_1)/M_2)	Metcalf and Eddy, 1979

Table A1.71 Settling - liquid output formulae

Liquid Output	**Formulae**	**References**
mass	M_1-(6.3*Part*M_1)/1000000	est. from Gregory and Zabel, 1990
pH	pH	
COD	(.65*COD*M_1)/M_2	Metcalf and Eddy, 1979
solvent	$\frac{Vol}{(Wat+Vol+.7*Oil)}*(1-\frac{.1*Part*M_1}{M_2})$	Gregory and Zabel, 1990
oil	$\frac{.7*Oil}{(Wat+Vol+.7*Oil)}*(1-\frac{.1*Part*M_1}{M_2})$	Metcalf and Eddy, 1979
water	$\frac{Wat}{(Wat+Vol+.7*Oil)}*(1-\frac{.1*Part*M_1}{M_2})$	Gregory and Zabel, 1990
heavy metals	(HM*M_1-(.9*HM*(M_1-M2)))/M_2	Palmer et.al, 1988
particulates	(.1*Part*M_1)/M_2	Gregory and Zabel, 1990
particulate size	<.05	Woods, 1994a
dissolved solids	(DS*M_1)/M_2	Metcalf and Eddy, 1979
NO_3	(NO3*M_1)/M_2	Metcalf and Eddy, 1979
NH_3	(NH3*M_1)/M_2	Metcalf and Eddy, 1979
sulphur	(S*M_1)/M_2	Metcalf and Eddy, 1979
PO_4	(PO4*M_1)/M_2	Metcalf and Eddy, 1979
toxics	(Tox*M_1)/M_2	Metcalf and Eddy, 1979

Table A1.72 Settling - base input formulae

Settling - base	**Input - liquid**	Reference
pH	>7.0	
particulates	1,100-2,500 ppm	Woods, 1994a
particulate size	.025 - 2mm	Woods, 1994a

Table A1.73 Settling - sludge output formulae

Sludge output	**Formulae**	**Reference**
mass	$(6.3*Part*M_1)/1000000$	est., Gregory and Zabel, 1990
pH	pH	
COD	$(.35*COD*M_1)/M_2+.6*COD$	Metcalf and Eddy, 1979
solvents	$(Vol/(Wat+Vol))*900,000$	Gregory and Zabel, 1990
oil	$(.3*Oil*M_1)/M_2$	Metcalf and Eddy, 1979
water	$(Wat/(Wat+Vol))*900,000$	Gregory and Zabel, 1990
heavy metals	$((HM*M_1)-(.1*(M_1-M_2)))/M_2$	Palmer et. al, 1988
particulates	100,000 ppm	Gregory and Zabel, 1990
particulate size	>.25 mm	Woods, 1994a
dissolved solids	$.9*DS$	
TN	$.9*TN$	
sulphur	$.9*S$	
iron	$(.9999*Fe*M_1)/M_2$	Palmer et.al, 1988
toxics	$.9*Tox$	
ash	$(100000-((.35*COD*M_1)/M_2)$	Metcalf and Eddy, 1979

Table A1.74 Settling - liquid output formulae

Liquid Output	**Formulae**	**References**
mass	$M_1-(6.3*Part*M_1)/1000000$	est., Gregory and Zabel, 1990
pH	pH	
COD	$(.65*COD*M_1)/M_2$	Metcalf and Eddy, 1979
solvents	$\frac{Vol}{(Wat+Vol+.7*Oil)}*(1-\frac{.1*Part*M_1}{M_2})$	Gregory and Zabel, 1990
oil	$\frac{.7*Oil}{(Wat+Vol+.7*Oil)}*(1-\frac{.1*Part*M_1}{M_2})$	Metcalf and Eddy, 1979
water	$\frac{Wat}{(Wat+Vol+.7*Oil)}*(1-\frac{.1*Part*M_1}{M_2})$	Gregory and Zabel, 1990
heavy metals	0.1ppm	Palmer et.al, 1988
particulates	$(.1*Part*M_1)/M_2$	Gregory and Zabel, 1990
particulate size	<.05	Woods, 1994a
dissolved solids	$(DS*M_1)/M_2$	Metcalf and Eddy, 1979
NO_3	$(NO3*M_1)/M_2$	Metcalf and Eddy, 1979
NH_3	$(NH3*M_1)/M_2$	Metcalf and Eddy, 1979
sulphur	$(S*M_1)/M_2$	Metcalf and Eddy, 1979
PO_4	$(PO4*M_1)/M_2$	Metcalf and Eddy, 1979
toxics	$(Tox*M_1)/M_2$	Metcalf and Eddy, 1979

19. Solvent Recycling

Table A1.75 Solvent recycling - input criteria

Solvent Recycling	**Input - liquid**	**Reference**
solvents	200,000 - 800,000 ppm	Woods, 1994a

Table A1.76 Solvent recycling - volatile output formulae

Volatile Output	**Formulae**	**References**
mass	$Vol/1{,}000{,}000*M_1$	Tarrer et.al, 1989
pH	7.0	
COD	3,000,000	Woods, 1994a
solvents	1,000,000	Woods, 1994a
oil	0	Woods, 1994a
water	0	Woods, 1994a
heavy metals	0	Woods, 1994a
particulates	0	
particulate size	0	
dissolved solids	0	Woods, 1994a
NO_3^-	0	Woods, 1994a
NH_3	0	Woods, 1994a
sulphur	0	Woods, 1994a
PO_4	0	Woods, 1994a
toxics	1,000,000	Woods, 1994a

Table A1.77 Solvent recycling - solid output formulae

Sludge Output	**Formulae**	**References**
mass	$M_1-((.999*Vol/1000000)*M_1)$	Tarrer et.al, 1989
pH	pH	
COD	$((COD*M_1)-(2500000*(M_1-M_2)))/M2$	
solvents	$(.001*Vol*M_1)/M_2$	Woods, 1994a
oil	$(Oil*M_1)/M_2$	Woods, 1994a
water	$(Wat*M_1)/M_2$	Woods, 1994a
heavy metals	$(HM*M_1)/M_2$	Woods, 1994a
particulates	$(Part*M_1)/M_2$	Woods, 1994a
particulate size	PS	Woods, 1994a
dissolved solids	$(DS*M_1)/M_2$	Woods, 1994a
NO_3	$(NO3*M_1)/M_2$	Woods, 1994a
NH_3	$(NH3*M_1)/M_2$	Woods, 1994a
sulphur	$(S*M_1)/M_2$	Woods, 1994a
PO_4	$(PO4*M_1)/M_2$	Woods, 1994a
toxics	$(Tox-Vol)*M_1/M_2$	Woods, 1994a

21. Ultrafiltration

Table A1.78 Ultrafiltration - acid input criteria

Ultrafiltration - acid	**Input - liquid**	**Reference**
pH	<6.5	
COD	<10,000 ppm	Woods, 1994a
oil	<10,000 ppm	Woods, 1994a
particulates	<800ppm	Woods, 1994a
particulate size	<.001mm	Woods, 1994a
toxics	<10,000 ppm	Woods, 1994a

Table A1.79 Ultrafiltration - retentate formulae

Retentate - liquid	**Formulae**	**Reference**
mass	$(.99*Part*M_1)/50000$	est. from Palmer et. al, 1988
pH	pH	
COD	max 750000 ppm	Palmer et. al, 1988
solvent	950000*Vol/(Vol+Wat)	Palmer et. al, 1988
oil	250,000*Oil/(Oil+Tox)	Palmer et. al, 1988
water	9500000*Wat/(Vol+Wat)	Palmer et. al, 1988
heavy metals	.95*HM	Palmer et. al, 1988
particulates	max 5,000ppm	Palmer et. al, 1988
particulate size	>.0001 mm	Woods, 1994a
dissolved solids	950000*DS/Wat	Palmer et. al, 1988
NO_3	950000*NO3/Wat	est. from Woods, 1994a
NH_3	950000*NH3/Wat	est. from Woods, 1994a
sulphur	950000*S/Wat	est. from Woods, 1994a
PO_4	950000*PO4/Wat	est. from Woods, 1994a
toxics	250000*Tox/(Oil+Tox)	Woods, 1994a

Table A1.80 Ultrafiltration - permeate formulae

Permeate - liquid	**Formulae**	**Reference**
mass	$M1-(.99*Part*M_1)/50000$	est. from Woods, 1994a
pH	pH	
COD	$((COD*M_1)-(750000*(M_1-M_2)))/M_2$	Palmer et. al, 1988
solvent	$((Vol*M_1)-(950000*Vol/(Vol+Wat)*(M_1-M_2))/M_2$	est. from Woods, 1994a
oil	$((Oil*M_1)-(250000*(Oil/(Oil+Tox))*(M_1-M_2)))/M_2$	est. from Woods, 1994a
water	$((Wat*M_1)-(950000*Wat/(Wat+Vol)*(M_1-M_2))/M_2$	est. from Woods, 1994a
heavy metals	$((HM*M_1)-(950000*HM/Wat*(M_1-M_2))\ /M_2$	est. from Woods, 1994a
particulates	$(Part*M_1)-(5000*(M_1-M_2)))/M_2$	est. from Woods, 1994a
particulate size	<.0001 mm	est. from Woods, 1994a
dissolved solids	$((DS*M_1)-(950000*DS/Wat*(M_1-M_2))/M_2$	est. from Woods, 1994a
NO_3	$((NO3*M_1)-(950000*NO3/Wat*(M_1-M_2))/M_2$	est. from Woods, 1994a
NH_3	$((NH3*M_1)-(950000*NH3/Wat*(M_1-M_2))/M_2$	est. from Woods, 1994a
sulphur	$((S*M_1)-(950000*S/Wat*(M_1-M_2))/M_2$	est. from Woods, 1994a
PO_4	$((PO4*M_1)-(950000*PO4/Wat*(M_1-M_2))/M_2$	est. from Woods, 1994a
toxics	$((Tox*M_1)-(250000*(Tox/(Oil+Tox))*(M_1-M_2)))/M_2$	est. from Woods, 1994a

Table A1.81 Ultrafiltration - base input criteria

Ultrafiltration - base	Input - liquid	Reference
pH	>6.5	
COD	<10,000 ppm	Woods, 1994a
oil	<10,000 ppm	Woods, 1994a
particulates	<800ppm	Woods, 1994a
particulate size	<.001mm	Woods, 1994a
toxics	<10,000 ppm	Woods, 1994a

Table A1.82 Ultrafiltration - retentate formulae

Retentate - liquid	Formulae	Reference
mass	(.99*Part*M_1)/50000	est. from Woods, 1994a
pH	pH	
COD	max 250000	est. from Woods, 1994a
solvent	(Vol*M_1)/M_2	est. from Woods, 1994a
oil	250,000*Oil/(Oil+Tox)	est. from Woods, 1994a
water	(Wat*M_1)/M_2	est. from Woods, 1994a
heavy metals	(HM*M_1-0.1*(M_1-M_2))/M_2	Palmer et.al, 1988
particulates	max 50,000	Palmer et.al, 1988
particulate size	>.0001	est. from Woods, 1994a
dissolved solids	950000*DS/Wat	est. from Woods, 1994a
NO_3	950000*NO3/Wat	est. from Woods, 1994a
NH_3	950000*NH3/Wat	est. from Woods, 1994a
sulphur	950000*S/Wat	est. from Woods, 1994a
PO_4	950000*PO4/Wat	est. from Woods, 1994a
toxics	250000*Tox/(Oil+Tox)	est. from Woods, 1994a

Table A1.83 Ultrafiltration - permeate formulae

Permeate - liquid	Formulae	Reference
mass	M_1-((.99*Part*M_1)/50000)	est. from Woods, 1994a
pH	pH	
COD	((COD*M_1)-(750000*(M_1-M_2)))/M_2	est. from Woods, 1994a
solvent	((Vol*M_1)-(950000*Vol/(Vol+Wat)*(M_1-M_2)))/M_2	est. from Woods, 1994a
oil	((Oil*M_1)-(250000*(Oil/(Oil+Tox))*(M_1-M_2)))/M_2	est. from Woods, 1994a
water	((Wat*M_1)-(950000*Vol/(Vol+Wat)*(M_1-M_2)))/M_2	est. from Woods, 1994a
heavy metals	0.1ppm	Palmer et.al, 1988
particulates	((Part*M_1)-(50000*(M_1-M_2)))/M_2	est. from Woods, 1994a
particulate size	<.0001	est. from Woods, 1994a
dissolved solids	((DS*M_1)-(950000*DS/Wat*(M_1-M_2)))/M_2	est. from Woods, 1994a
NO_3	((NO3*M_1)-(950000*NO3/Wat*(M_1-M_2)))/M_2	est. from Woods, 1994a
NH_3	((NH3*M_1)-(950000*NH3/Wat*(M_1-M_2)))/M_2	est. from Woods, 1994a
sulphur	((S*M_1)-(950000*S/Wat*(M_1-M_2)))/M_2	est. from Woods, 1994a
PO_4	((PO4*M_1)-(950000*PO4/Wat*(M_1-M_2)))/M_2	est. from Woods, 1994a
toxics	(Tox*M_1)-(250000*Tox/(Oil+Tox)*(M_1-M_2)))/M_2	est. from Woods, 1994a

22. Baghouse Filtration

Table A1.84 Baghouse filtration - input criteria

Baghouse Filtration	Input - gas	References
particulates	8 - 80,000 ppm	Woods, 1994a
particulate size	.07 mm	Woods, 1994a

Table A1.85 Baghouse filtration - gas output formulae

Gas Output	Formulae	References
mass	$M1-((.99*Part)/1000000)*M_1$	Iinoya and Dennis, 1987
corrosivity	pH	
volatiles	(Vol*M1)/M2	Brunner, 1991
oil	(.33*Oil*M1)/M2	Brunner, 1991
water	(Wat*M1)/M2	Brunner, 1991
heavy metals	$(.01*HM*M_1)/M_2$	Brunner, 1991
particulates	(.01*Part*M1)/M2	Iinoya and Dennis, 1987
particulate size	<.001mm	Brunner, 1991
CFC	(CFC*M1)/M2	Brunner, 1991
CO_2	(CO2*M1)/M2	Brunner, 1991
SO_2	(SO2*M1)/M2	Brunner, 1991
NO_x	(NOx*M1)/M2	Brunner, 1991
Cl	(Cl*M1)/M2	Brunner, 1991
NH_3	(NH3*M1)/M2	Brunner, 1991

Table A1.86 Baghouse filtration - solid output formulae

Solid Output	Formulae	Reference
mass	$((.99*Part)/1000000)*M_1$	Iinoya and Dennis, 1987
leachate pH	pH	
COD	$(.05*Part*M_1)/M_2$	Brunner, 1991
solvents	0	Brunner, 1991
oil	$(.67*Oil*M_1)/M_2$	Brunner, 1991
water	0	Brunner, 1991
heavy metals	$(.99*HM*M_1)/M_2$	Brunner, 1991
iron	$(.99*Fe*M_1)/M_2$	Brunner, 1991
other metals	$(.99*OM*M_1)/M_2$	Brunner, 1991
soluble solids		
toxics	0	
particle size	>.001mm	Librizzi and Lowery, 1990
paper/cardboard	0	
plastic	0	
ash	$(.99*Part*M_1)/M_2$	

23. Electrostatic Precipitation

Table A1.87 Electrostatic precipitation - input criteria

Electrostatic Precipitation	**Input - gas**	**References**
particulates	<16 ppm	Woods, 1994a
particulate size	>.0001 mm	Woods, 1994a

Table A1.88 Electrostatic precipitation - gas output formulae

Gas Output	**Formulae**	**References**
mass	M_1-((.99*Part)/1000000)*M_1	Iinoya and Dennis, 1987
corrosivity	pH	
volatiles	(Vol*M_1)/M_2	Brunner, 1991
oil	(.4*Oil*M_1)/M_2	Brunner, 1991
water	(Wat*M_1)/M_2	Brunner, 1991
heavy metals	(.01*HM*M_1)/M_2	Brunner, 1991
particulates	(.01*Part*M_1)/M_2	Iinoya and Dennis, 1987
particulate size	<.0001 mm	Librizzi and Lowery, 1990
CFC	(CFC*M_1)/M_2	Brunner, 1991
CO_2	(CO2*M_1)/M_2	Brunner, 1991
SO_2	(SO2*M_1)/M_2	Brunner, 1991
NO_x	(NOx*M_1)/M_2	Brunner, 1991
Cl	(Cl*M_1)/M_2	Brunner, 1991
NH_3	(NH3*M_1)/M_2	Brunner, 1991

Table A1.89 Electrostatic precipitation - solid output formulae

Solid Output	**Formulae**	**Reference**
mass	((.99*Part)/1000000)*M_1	Iinoya and Dennis, 1987
leachate pH	pH	
COD	(2.2*Oil*M_1)/M_2	Brunner, 1991
solvents	0	Brunner, 1991
oil	(.6*Oil*M_1)/M_2	Brunner, 1991
water	0	Brunner, 1991
heavy metals	(.99*HM*M_1)/M_2	Brunner, 1991
iron	(.99*Fe*M_1)/M_2	Brunner, 1991
other metals	(.99*OM*M_1)/M_2	Brunner, 1991
soluble solids		
toxics	0	
particle size	>.0001mm	Librizzi and Lowery, 1990
paper/cardboard	0	
plastic	0	
ash	(.99*Part*M_1)/M_2	

24. Packed Tower

Table A1.90 Packed tower - input criteria

Packed Bed Scrubber	**Input - gas**	**References**
volatiles	<10,000 ppm	Noyes Data Corp., 1971
oil	<10,000 ppm	Noyes Data Corp., 1971
particulates	<10 ppm	Woods, 1994a
particulate size	>.005	Woods, 1994a
SO_2	<10,000 ppm	Noyes Data Corp., 1971
NO_x	<10,000 ppm	Noyes Data Corp., 1971
Cl	<10,000 ppm	Noyes Data Corp., 1971

Table A1.91 Packed tower - gas output formulae

Gas Output	**Formulae**	**References**
mass	M_1-((.99*Part)/1000000)*M_1	Noyes Data Corp., 1972
corrosivity	7	Noyes Data Corp., 1972
volatiles	(.95*Vol*M_1)/M_2	Noyes Data Corp., 1972
oil	(.05*Oil*M_1)/M_2	Noyes Data Corp., 1972
water	(Wat*M_1)/M_2	
heavy metals	(.01*HM*M_1)/M_2	Batstone et. al, 1989
particulates	(.1*Part*M_1)/M_2	Woods, 1994a
particulate size	<.005	Woods, 1994a
CFC	0	
CO_2	0	
SO_2	(.2*SO2*M_1)/M_2	Batstone et. al, 1989
NO_x	(.01*NOx*M_1)/M_2	Librizzi and Lowery, 1990
Cl	(.01*Cl*M_1)/M_2	Librizzi and Lowery, 1990
NH_3	(.01*NH3*M_1)/M_2	Librizzi and Lowery, 1990

Table A1.92 Packed tower - liquid output formulae

Liquid Output	**Formulae**	**References**
mass	.2*M_1	Noyes Data Corp., 1971
pH	pH	Librizzi and Lowery, 1990
COD	0	
solvents	(.05*Vol*M_1)/M_2	
oil	(.95*Oil*M_1)/M_2	Brunner, 1991
water	1000000 -((.95*Oil+.99*HM+.9*Part +.99*NOx+.4*SO2+.99*Cl)*M_1)/M_2	
heavy metals	(.99*HM*M_1)/M_2	
particulates	(.9*Part*M_1)/M_2	Librizzi and Lowery, 1990
particulate size	>.01 mm	Librizzi and Lowery, 1990
dissolved solids	(.99*HM+.99*NOx+.4*SO2+.99*CL)*M1/M_2	
NO_3	(.99*NOx*M_1)/M_2	Librizzi and Lowery, 1990
NH_3	(.99*NH3*M_1)/M_2	Librizzi and Lowery, 1990
sulphur	(.4*S*M_1)/M_2	Batstone et. al, 1989
PO_4	0	
toxics	0	

25. Venturi Scrubber

Table A1.93 Venturi scrubber - input criteria

Venturi Scrubber	**Input - gas**	**References**
particulates	<20,000 ppm	Woods, 1994a
particulate size	<.5 mm	Woods, 1994a

Table A1.94 Venturi scrubber - gas output formulae

Gas Output	**Formulae**	**References**
mass	M_1-((.90*Part)/1000000)*M_1	Brunner, 1991
corrosivity	pH	
volatiles	(Vol*M_1)/M_2	Brunner, 1991
oil	(.02*Oil*M_1)/M_2	Jones, 1971
water	(1.5*Wat*M_1)/M_2	Brunner, 1991
heavy metals	(.1*HM*M_1)/M_2	Brunner, 1991
particulates	(.1*Part*M_1)/M_2	Iinoya and Dennis, 1987
particulate size	<.001 mm	Librizzi and Lowery, 1990
CFC	(CFC*M_1)/M_2	Brunner, 1991
CO_2	(CO2*M_1)/M_2	Brunner, 1991
SO_2	(.99*SO2*M_1)/M_2	Brunner, 1991
NO_x	(.75*NOx*M_1)/M_2	Brunner, 1991
Cl	(.6*Cl*M_1)/M_2	Brunner, 1991
NH_3	(.75*NH3*M_1)/M_2	est. from Brunner, 1991

Table A1.95 Venturi scrubber - liquid output formulae

Liquid Output	**Formulae**	**Reference**
mass	1.6*M_1	Noyes Data Corp., 1971
pH	pH	
COD	(.001*Part*M_1)/M_2	Brunner, 1991
solvents	0	Brunner, 1991
oil	(Oil/Part)*250000	Jones, 1971
water	0	Brunner, 1991
heavy metals	(HM/Part)*250000	Brunner, 1991
particulates	250,000 ppm	Noyes Data Corp., 1972
particulate size	<.001 mm	Librizzi and Lowery, 1990
dissolved solids	0	
NO_3	.25*NOx*M_1/M_2	Brunner, 1991
NH_3	0.25*NH3*M_1/M_2	Librizzi and Lowery, 1990
sulphur	0.005*S*M_1/M_2	Brunner, 1991
PO_4	0.25*PO4*M_1/M_2	Brunner, 1991
toxics	0	

Appendix 2 Standards for Release to Air, Water or Land

The following parameters were primarily determined from Ontario regulations. In some cases, as has been described in Chapter 4, the parameters were not explicit and were determined using U.S. regulations or other available regulations. The regulations have been included in this appendix.

A2.1 Air Emissions

Gas	Limit µg/m^3 (.5 hr avg.)	Limit ppm (.5 hr avg.)
corrosivity		
volatiles	100	0.08
oil	160	0.13
water		
heavy metals	5	0.004
particulates	100	0.08
particulate size		
CFC	0	0
CO_2		
SO_2	830	0.66
NO_x	500	0.4
Cl	300	0.2
NH_3	3600	2.9

A2.2 Effluents to Water Bodies

Liquid	Limits, ppm
pH	5.5 - 9.5
COD	37.5
solvent	0.02
oil	15.0
water	
heavy metals	1.0
particulates	15.0
particulate size	
dissolved solids	
NO_3	
NH_3	10.0
sulphur	400
PO_4	1.0
toxics	0

A.2.3 Disposal to Landfills

Sludge	Limit ppm	Solid	Limit ppm
pH	2-12.5	leachate pH	2-12.5
COD		COD	
solvent	1,000	solvent	1,000
oil	900,000	oil	900,000
water	850,000	water	850,000
heavy metals	100	heavy metals	100
particulates		iron	
particulate size		other metals	
dissolved solids		soluble solids	
TN		toxics	50
sulphur		particle size	
iron		paper/cardboard	
toxics	50	plastic/rubber	
ash		ash	

A.2.4 Land Treatment

Liquid	Limit ppm	Sludge	Limit ppm	Solid	Limit ppm
pH	5.5-9.5	pH	5.5-9.5	leachate pH	5.5-9.5
COD		COD		COD	
solvent	100	solvent	100	solvent	100
oil		oil		oil	
water	1,000,000	water	950,000	water	
heavy metals	10	heavy metals	10	heavy metals	10
particulates		particulates		iron	50,000
particulate size		particulate size		other metals	
dissolved solids	1,000	dissolved solids	1,000	soluble solids	1,000
NO_3	10,000	TN	10,000	toxics	50
NH_3	10,000	sulphur	1,000	particle size	
sulphur	1,000	iron	50,000	paper/cardboard	
PO_4		toxics	50	plastic/rubber	1,000
toxics	50	ash		ash	

Environmental Protection Act

AMBIENT AIR QUALITY CRITERIA REGULATION

R.R.O. 1990, Reg. 337

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1. The desirable ambient air quality criteria for each contaminant set out in Column 1 of the Schedule is that amount of concentration or total amount of contaminant set out opposite thereto in Column 3 of the Schedule in the unit of measurement set out opposite thereto in Column 2 of the Schedule for the time set out opposite thereto in Column 4 of the Schedule.

Schedule

ITEM	COLUMN 1	COLUMN 2	COLUMN 3	COLUMN 4	COLUMN 5
	Name of Contaminant	Unit of Measurement	Average Amount of Concentration or Total Amount of Contaminant	Period of Time	Approximate Equivalent at 10°C and 760 mm Hg pressure
1.	Arsenic	Micrograms of Arsenic per cubic metre of air	25	24 hours	
2.	Cadmium	Micrograms of cadmium per cubic metre of air	2.0	24 hours	
3.	Carbon Monoxide	Parts of carbon monoxide per one million parts of air by volume	30 13	1 hour 8 hours	36,200 ug/m^3 15,700 ug/m^3
4.	Dustfall	Tons of dustfall per square mile per month	20 Total 13	30 days 1 year	
5.	Fluorides (Gaseous) April 15 to October 15	Parts of fluorides per billion parts of air by volume (Expressed as HF)	1.0 0.4	24 hours 30 days	0.86 ug/m^3 0.34 ug/m^3
6.	Total Fluorides (Gaseous and Particulate) April 15 to October 15	Parts of fluorides per one billion parts of air by volume (Expressed as HF)	2.0 0.8	24 hours 30 days	1.72 ug/m^3 0.69 ug/m^3
7.	Total Fluorides (Gaseous and Particulate) October 16 to April 14	Parts of fluorides per one billion parts of air by volume (Expressed as HF)	4.0 1.6	24 hours 30 days	3.44 ug/m^3 1.38 ug/m^3
8.	Fluorides in Forage for Consumption by Livestock	Parts of total fluorides per one million parts forage (dry weight)	35	Individual Sample	
9.	Fluoridation (total) April 15 to October 15	Micrograms of total fluorides collected by 100 sq. centimetres of limed filter paper	40	30 days	
10.	Fluoridation (total) October 16 to April 14	Micrograms of total fluorides collected by 100 sq. centimetres of limed filter paper	80	30 days	
11.	Hydrogen Sulphide	Parts of hydrogen sulphide per one million parts of air by volume	0.02	1 hour	30 ug/m^3
12.	Lead	Micrograms of lead per cubic metre of air	5.0 2.0 geometric mean	24 hours 30 days	
13.	Mercaptans	Parts of mercaptans per one million parts of air by volume (Expressed as methyl mercaptan)	0.01	1 hour	20 ug/m^3

ITEM	COLUMN 1	COLUMN 2	COLUMN 3	COLUMN 4	COLUMN 5
	Name of Contaminant	Unit of Measurement	Average Amount of Concentration or Total Amount of Contaminant	Period of Time	Approximate Equivalent at 10°C and 760 mm Hg pressure
14.	Mercury	Micrograms of mercury per cubic metre of air	2.0	24 hours	
15.	Nickel	Micrograms of Nickel per cubic metre of air	2.0	24 hours	
16.	Nitrogen Dioxide	Parts of nitrogen dioxide per one million parts of air by volume	0.20 0.10	1 hour 24 hours	400 ug/m^3 200 ug/m^3
17.	Oxidants (total)	Parts of total oxidants per one million parts of air by volume	0.10	1 hour	
18.	Ozone	Parts of ozone per one million parts of air by volume	0.08	1 hour	165 ug/m^3
19.	Soiling	Coefficient of Haze per 1,000 feet of air	1.0 0.5	24 hours 1 year	
20.	Sulphation	Milligrams of sulphur trioxide per 100 sq. cm of exposed lead peroxide per day	0.7	30 days	
21.	Sulphur Dioxide	Parts of sulphur dioxide per one million parts of air by volume	0.25 0.10 0.02	1 hour 24 hours 1 year	690 ug/m^3 275 ug/m^3 55 ug/m^3
22.	Suspended Particulate Matter	Micrograms of suspended particulate matter per cubic metre of air	120 60 geometric mean	24 hours 1 year	
23.	Vanadium	Micrograms of vanadium per cubic metre of air	2.0	24 hours	

Environmental Protection Act

GUIDELINES FOR THE CONTROL OF INDUSTRIAL PHOSPHORUS DISCHARGES IN LIQUID EFFLUENTS,

October, 1976.

Statement of Intent.

The primary purpose of these guidelines is to assist Ministry staff in the execution of abatement and approvals functions. They may also be used by industry as an indication of environmental control requirements.

These guidelines are supplementary to the "Guidelines and Criteria for Water Quality Management in Ontario", the "Objectives for the Control of Industrial Wastes Discharges in Ontario", and the requirements of *The Environmental Protection Act.*

The guidelines reflect overall Ministry policy. They should be applied recognizing specific requirements of individual sites, alternative process and abatement technology, and the need to stage programs which will achieve the Ministry's goals in a rapid but realistic manner.

Introduction.

Industrial phosphorus discharges may have impact on receiving waters by virtue of their nutrient value and hence their potential to cause excessive algal growths. This is of particular significance in the lower Great Lakes drainage basin which has been identified by The International Joint Commission as being threatened by nutrient inputs.

Programs for the control of phosphorus discharges from municipal sewerage systems have been implemented in Ontario in response to the Canada-United States Agreement on Great Lakes Water Quality. It, therefore, seems reasonable to apply controls to industrial discharges which are consistent with municipal abatement programs.

General Principles of Phosphorus Controls.

Recognizing that all phosphorus discharges are potentially significant from the standpoint of nutrient input and eutrophication of receiving waters, the following general principals will form the basis for the control of industrial phosphorus discharges:

1. Where *practicable*, industrial phosphorus inputs to natural waters shall be controlled or eliminated;

2. In cases where control technology (either external controls or in-plant abatement) is not practicable, the discharge under consideration shall be assessed on the basis of its potential impact on the receiving stream. Where necessary, and in the absence of available technology, alternative disposal may be required;

3. Without limiting the above general principles, the effluent objective for industrial phosphorus discharges shall be 1 mg/l maximum total phosphorus;

4. Plants with discharges of less than 10 lb/day total phosphorus shall be exempted from these guidelines;

5. Phosphorus control requirements should not discourage the application of biological treatment (with phosphorus nutrient addition) to the abatement of gross pollution.

Where biological treatment is used to abate gross pollution problems, the control of phosphorus discharges from such systems shall be weighed against the benefits to be derived from the reduction of the gross pollution and the impact of the phosphorus discharge on the receiving stream.

Phosphorus controls should complement biological treatment where they are deemed necessary and will be beneficial to the environment.

6. Phosphorus controls should not discourage reduced water usage, abatement of acute toxicity or other effects which are of benefit to the environment.

Phosphorus Control Technology.

The technology that has been applied to the control of municipal phosphorus discharges include chemical precipitation with lime, alum, ferrous and ferric salts and waste pickle liquor. In addition, the controls on levels of phosphorus in laundry detergents that have been implemented under *The Canada Water Act* have had significant impact on municipal discharges.

Chemical precipitation is applicable to some industrial phosphorus discharges but, in common with the municipal situation, the specific technology that is applied must be determined by experiment. Chemical precipitation can be used to best advantage in those situations where it can be integrated into an existing or proposed industrial waste treatment system. For example, those industries which install chemical precipitation equipment for phosphorus removal which will utilize the existing clarifiers or settling basins.

As an alternative, non-phosphorus water conditioning chemicals may be used to eliminate phosphorus discharges provided that adequate water conditioning is achieved and there are no greater adverse effects on the environment.

The disposal of industrial effluents to municipal sewerage systems where phosphorus removal facilities have been incorporated into the municipal sewage treatment process also represents an available option for the control of industrial phosphorus discharges. However, this should only be considered where there is capacity in the sewerage system to accept the effluent and where no adverse effects on the treatment process are anticipated from the industrial effluents.

Annex 2

Control of phosphorus

1. *Programs.* Programs shall be developed and implemented to reduce inputs of phosphorus to the Great Lakes System. These programs shall include:

(a) Construction and operation of waste treatment facilities to remove phosphorus from municipal sewage;

(b) Regulatory measures to require industrial dischargers to remove phosphorus from wastes to be discharged into the Great Lakes System;

(c) Regulatory and advisory measures to control inputs of phosphorus through reduction of waste discharges attributable to animal husbandry operations.

In addition, programs may include regulations limiting or eliminating phosphorus from detergents sold for use within the basin of the Great Lakes System.

2. *Effluent Requirements.* The phosphorus concentrations in effluent from municipal waste treatment plants discharging in excess of one million gallons per day, and from smaller plants as required by regulatory agencies, shall not exceed a daily average of one milligram per litre into Lake Erie, Lake Ontario and the International Section of the St. Lawrence River.

3. *Industrial Discharges.* Waste treatment or control requirements for all industrial plants discharging wastes into the Great Lakes System shall be designed to achieve maximum practicable reduction of phosphorus discharges to Lake Erie, Lake Ontario and the International Section of the St. Lawrence River.

4. *Reductions for Lower Lakes.* These programs are designed to attain reductions in gross inputs of phosphorus to Lake Erie and Lake Ontario of the quantities indicated in the following tables for the years indicated.

GUIDELINES FOR THE TREATMENT AND DISPOSAL OF LIQUID INDUSTRIAL WASTES IN ONTARIO

Ministry of the Environment, December, 1978

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1. Approvals. Only those waste treatment and disposal processes or sites which have received a Certificate of Approval from the Ministry of the Environment may be used for the treatment and disposal of hauled liquid industrial wastes. Approved waste treatment and disposal processes should not be used to treat wastes other than those specified in the approval without obtaining further approval from the Ministry.

2. On-site Disposal. On-site disposal of hauled liquid industrial wastes is not acceptable except where specific approval for the wastes to be disposed and for the disposal method(s) to be employed has been obtained from the Ministry.

3. Landfilling. Untreated hauled liquid industrial wastes should not be deposited into municipally-owned or privately-owned sanitary landfills except where provided for in these guidelines.

4. Exemptions. Wastes covered by other regulations and guidelines are exempted from these guidelines. Such wastes include:
- septic tank wastes;
- septage from holding tanks;
- sludges from domestic sewage treatment plants;
- agricultural wastes (eg., manure);
- PCB wastes;
- Pesticides;
- wastes from milling and mining operations.

Additional exemptions:
- waste slags from metallurgical operations.

5. Allowable Treatment and Disposal. Table 1 indicates the recommended treatment and disposal processes for various categories of hauled liquid industrial wastes.

Although alternative treatment and disposal processes are listed for many of the waste categories, specific wastes may not be amenable to treatment and/or disposal by each of the alternatives listed. For this reason, these guidelines should be used with care.

TABLE 1

Waste Description		Waste Classification	Treatment and/or Disposal
A.	Organic Wastes		
1.	"Rich" Organic liquids	202-209 302-304	- recovery and re-use - reclamation - incineration
2.	"Lean" Organic liquids	201-209 302-304	- recovery and re-use - reclamation - incineration - physical/chemical - biological - deep well disposal - wet air oxidation (WETOX) - solidification
3.	Organic sludges and solids	202-209 301-304	- wet air oxidation (WETOX) - incineration - secure landfill - sludge farming - biological treatment - land disposal
4.	Organic sludges - Plant & animal based	401	- As in A(3) - land disposal - sanitary landfill (Approval of MOE or owner required)
B.	Inorganic Wastes		
1.	Inorganic liquids	101-106	- recovery and re-use - physical/chemical - deep well disposal - solidification
2.	Inorganic sludges and solids	101-106	- solidification - secure landfill
3.	Inert inorganic sludges and solids	402	- sanitary landfill (Approval of MOE or owner required) - land disposal

Waste Description	Waste Classification	Treatment and/or Disposal
C. Oil/Water Mixtures		
1. Oil and water	201	- emulsion breaking - oil separation - electro chemical
a) oil phase		- As for waste oil, D below
b) water phase		- As in A (2) municipal sewer system
c) sludge phase		- incineration - solidification - sanitary landfill (Approval of MOE or owner required) - land disposal
2. Oil interceptor and grit chamber clean out	201	- secure landfill - sanitary landfill (Approval of MOE or owner required) - land disposal
D. Waste Oils	202	- recovery and re-use - reclamation - incineration - road oiling - fuel for cement kiln
E. Special Wastes		
1. Caustic phenolates and sulphides from petro-chemical processing	290	- reclamation - incineration - deep well disposal - chemical oxidation
2. Chromium hexavalent	103	- chemical reduction to trivalent state then as in B(1) or B(2)
3. Cyanides a) solutions 100 ppm CN^-	104	- alkaline chlorination - electrochemical oxidation then as in B(1) or discharge to municipal sewer - incineration
b) solids		- incineration - secure landfill
4. Halogenated organics	204 205 209 302 304 290	- incineration
5. Industrial brines	190	- deep well disposal - as recommended by MOE
6. Mercury and its salts	190	- solidification - secure landfill
7. Semi-metals and compounds - arsenic - antimony - boron - selenium	190	- secure landfill - solidification
8. Radioactive wastes		- to be reviewed with MOE and may be subject to Atomic Energy Control Board regulations
9. Tank truck washing wastes	(all)	- as recommended by MOE
10. Other wastes		- as recommended by MOE

Definitions

1. General.

a) "Hauled Liquid Industrial Wastes" means those wastes generated by manufacturing or processing operations which are hauled away from the place where they are generated to another location, either off-site or on-site, for treatment and/or disposal. For the purposes of these guidelines, "hauled liquid industrial wastes" include industrial waste sludges, semi-solids and solid wastes.

b) "Off-site" means at a site other than the property owned by the company where the manufacturing or processing operations which generate the wastes are located.

c) "On-site" means within the property boundaries associated with the manufacturing or processing operations which generate the wastes.

d) "Liquid" means that the waste is in the liquid or fluid state under normal conditions, can be pumped and must be contained in a suitable vessel.

e) "Sludge" means a mixture of liquids and solids which will flow under normal conditions and can be pumped using standard pumping equipment or vacuum equipment.

f) "Solid" means solid or a mixture of solids and liquids which will not flow under normal conditions and which cannot be pumped using standard pumping equipment.

2. Wastes.

a) "Rich Organic" means organic wastes having a total organic carbon content of greater than 5 percent (TOC > percent). Such wastes would normally contain sufficient BTU value to sustain combustion.

b) "Lean Organic" means organic wastes having a total organic carbon content of less than 5 percent (TOC <5 percent). Such wastes would not normally sustain combustion and would require supplementary heat for complete combustion.

c) "Halogenated Organics" means organic compounds containing chlorine, bromine, iodine or fluorine but primarily relates to chlorinated organic compounds.

d) "Organic Sludges — Plant and Animal" means organic sludges resulting from manufacturing or processing operations involving animals or parts of animals, plants, vegetables or fruits. These wastes will generally be associated with the food and beverage industries, animal and fish processing plants and tannery operations.

e) "Inorganic" means solutions or aqueous mixtures composed primarily of inorganic compounds but which may contain traces of organic contamination.

f) "Inert Inorganic" means inorganic wastes which are not expected to change significantly under the conditions to which they will be exposed in the landfill. Approval is required from the Ministry to dispose of in a landfill other than a secure landfill any such wastes that contain in excess of 100 ppm (on an "as received" basis) of individual metals or semi-metals that are known to present special dangers to health or to the environment. These include:

antimony
arsenic
boron
cadmium
cobalt
copper
lead
mercury
nickel
selenium
tin
vanadium
zinc

g) "Industrial Brines" means aqueous solutions of inorganic compounds having dissolved solids contents of greater than 1 percent (10,000 ppm).

3. Treatment and Disposal.

a) "Sanitary Landfill" means a landfill constructed for the primary purpose of burying domestic and commercial refuse and garbage.

b) "Secure Landfill" or "Secure Chemical Waste Landfill" means a landfill constructed for the disposal of chemical wastes in accordance with the regulations and guidelines of the Ministry of the Environment.

c) "Biological" treatment means any of the biological treatment systems currently in use for the biochemical oxidation of organic materials.

d) "Deep Well Disposal" means pressure injection of wastes into approved geological formations.

e) "Land Disposal" means direct application onto land using methods approved by the Ministry of the Environment.

f) "Incineration" means incineration in an approved waste incinerator.

g) "Physical/Chemical" means any one or combination of a number of unit operations commonly employed in the treatment of wastes and include:

- emulsion breaking
- chemical oxidation
- chemical oxidation
- ion exchange
- ultra filtration
- neutralization
- solids removal and thickening
- carbon absorption
- reverse osmosis
- electro chemical processes

h) "Recovery and Re-use" means where wastes are segregated and directed for re-use either on-site or off-site, and may include minor pre-treatment such as separation of organic and inorganic phases or separation of solids and liquids.

i) "Reclamation" means the recovery of a usable product from a waste following extensive pretreatment such as distillation, chemical treatment, re-refining, etc.

j) "Solidification" or "Chemical Fixation" means any one of a number of processes by which liquid wastes are converted into stable solid products or encapsulated in a manner which prevents their release to the environment.

k) "Sludge Farming" means a process whereby waste sludges are spread onto land, disced into the soil, nutrients are added and the deposited sludges are turned at frequent intervals to ensure continuing bacterial decomposition of the wastes.

Environmental Protection Act

GUIDELINES FOR SEWAGE SLUDGE UTILIZATION ON AGRICULTURAL LANDS

April, 1977; Revised January, 1986

Foreword

These Guidelines are supported by extensive research, which has been ongoing since 1971. This research continues to address concerns such as the potential impacts of sludge spreading practices on human and animal health, land productivity and the environment.

The limits for the concentrations of 11 heavy metals in sludges applied to soil, originally established in the 1978 edition, remain unchanged. Through these limits, metal application to agricultural soils is controlled. The application rates for ammonium plus nitrate nitrogen provide a measure of the plant-available nitrogen in the year of sludge application. These two features ensure that agriculture can benefit from sewage sludge utilization.

The Guidelines were approved for implementation by the Ontario Cabinet in July, 1979. Between 1979 and 1982, a phase-in period enabled municipalities with sludges not meeting criteria to improve those sludges or to develop acceptable disposal alternatives.

The changes in this edition reflect experiences gained since Guidelines implementation was approved. Major new inclusions are criteria for the acceptability of aerobic, dewatered and dried sludges. The rights and responsibilities of those involved in sludge utilization activities – sewage treatment plant operators, sludge haulers and farmers – are now more fully defined. Some significant inclusions are revisions to separation distances, waiting periods and sludge blending criteria and a statement of the need for contingency planning by sewage treatment plant operators.

The Sludge Utilization Committee, which includes representation from the Ministries of Agriculture and Food, Environment, and Health, as well as from the University of Guelph, the Municipal Engineers Association, the Association of Medical Officers of Health and the Ontario Federation of Agriculture, oversees interpretation, implementation and review of the Guidelines.

1.0 Introduction

1.1 Purpose, Objective and Scope

a. ***Purpose.*** The purpose of these Guidelines is to facilitate the recycling and use of sewage sludge on land, while protecting the quality of food, the health of consumers and the quality of the environment. The Guidelines supplement Ontario Regulation 309, made under the *Environmental Protection Act.*

b. ***Objective.*** The objective of these Guidelines is to ensure that, when sewage sludge is applied to land, the nitrogen, phosphorus, organic matter and micronutrients will benefit crops without degrading the environment or risking the health and productivity of the crops, animals and people of Ontario.

c. ***Scope.*** These Guidelines refer to municipal sewage sludge, as included under "processed organic waste" in Ontario Regulation 309, which was made under the *Environmental Protection Act.* They do not refer to "hauled sewage" (i.e., wastes removed from cesspools, septic tank systems, privy vaults, privy pits, chemical toilets, portable toilets and sewage holding tanks) to other unstabilized wastes, or to other organic wastes.

1.2. Sludge, Soil and Crop Monitoring

The Ministry of the Environment monitors nitrogen, phosphorus, total solids and eleven heavy metals in sewage sludge. The Ministry of Agriculture and Food records the background concentrations of metals in soils, crops, animal feed and animal products. In co-operation with the Ministry of the Environment, it also routinely determines certain metal concentrations in soils, to verify acceptability. The areas sampled include those in which naturally-occurring metal concentrations may be expected to be high and fields to which municipal sewage sludge has been applied for extended periods.

In addition, before the Ministry of the Environment issues Certificates of Approval for sludge application, it verifies that the results of soils analyses, conducted within the previous three years, demonstrate that soil pH and soil phosphorus concentrations are acceptable.

1.3. Value of Sewage Sludge

Sewage sludge is a valuable replacement for nitrogen and phosphorus fertilizers. It also supplies other nutrients, such as magnesium, zinc, copper and boron. The organic matter in sewage sludge improves soil structure.

2.0. Criteria Relating to Sewage Sludge Processing

All sewage sludges must be stabilized, before being spread on land, to reduce their odour potential and to reduce the number of pathogenic organisms.

Proper anaerobic and aerobic digestion processes provide appropriate stabilization. Other stabilization methods are discussed in the

Ministry of the Environment's "Guidelines to Govern the Stabilization and/or Dewatering of Municipal Sewage Sludge Prior to Its Utilization/Disposal". Case-by-case judgment on the acceptability of these other methods is usually necessary.

3.0 Criteria Relating to Nitrogen and Phosphorus

Before sludge is applied, the farmer should be advised of ammonium plus nitrate nitrogen and phosphorous concentrations, so that sludge and fertilizer rates may be adjusted.

3.1. Available Nitrogen

Nitrogen is usually the most valuable agricultural constituent of fluid anaerobically digested sewage sludges. These sludges normally contain 0.1 to 0.3% total nitrogen, of which 25% to 50% is in the ammonium form. Aerobic and dewatered sewage sludges usually contain appreciably less total nitrogen, a small portion being in the ammonium and/or nitrate form. The ammonium plus nitrate nitrogen present in sewage sludge provides an approximate measure of the nitrogen available for crop use during the year of application. Unless the sludge is immediately incorporated into the soil, up to 50% of its ammonium nitrogen can be lost by volatilization. Conversion by soil micro-organisms, of some of the organic nitrogen in the sludge to ammonium and nitrate, partially compensates for this volatilization loss.

3.2. Nitrogen Application Rates

3.2.1. ***Types of Crop.***

a. Application rates for sewage sludge are based on the nitrogen fertilizer recommendation for the crop, as described in the OMAF Publications 296 (Field Crop Recommendations) and 360 (Fruit Production Recommendations), which are revised annually.

b. Although many crops benefit from annual nitrogen application, the sludge application rate should not exceed 135 kg. of ammonium plus nitrate nitrogen per hectare, over a five year period or over a four year period for commercial sod.

The intent of this requirement is to control the rate of accumulation of phosphorus and metals in the soil and to provide for their wider distribution.

c. Criteria for the use of sludge for specific crops are given in Table 1. Corn, for grain or silage, grass for hay or pasture, and commercial sod, which require substantial amounts of nitrogen, are best suited to use sewage sludge as a nitrogen source. If care is taken in the rate and time of application, sewage sludge can be applied to cereals, which require less nitrogen, and to other crops, including legumes such as alfalfa, trefoil and soybeans, which require little or no nitrogen. The quantity applied, in any one growing season, should be based on:

i. ammonium plus nitrate nitrogen content and

ii. the nitrogen fertilizer recommendation for the crop (see OMAF Publications 296 and 360). Legumes are an exception in that the allowable sludge application rates may provide more nitrogen than is recommended, without crop damage or impairment of groundwater quality. In no case may the nitrogen application rate exceed that specified in Section 3.2.1b. above.

3.2.2. ***Time of Application.*** Sewage sludge is most effective as a nitrogen source when applied in spring. Late summer and fall applications are permitted, but subsequent nitrogen losses by leaching and denitrification will usually be greater than when the sludge is spring applied. Nitrogen, applied in late summer and fall, is about 50% as available to crops as that in spring applications. The rates of sludge applications in late summer and fall can be increased proportionally. Exceptions are grass and commercial sod, which can use appreciable amounts of nitrogen in the fall.

In no case may the nitrogen application exceed that specified in Section 3.2.1b. Criteria for specific crops are shown in Table 1.

3.3. Nitrogen Analyses

Analyses, to determine the ammonium plus nitrate nitrogen concentrations in sludge must be performed regularly. The frequency of these analyses should permit the estimation of this nitrogen concentration within 25% of the actual concentration.

3.4. Phosphorus

The acid soluble phosphorus content of the sludge should be determined. This phosphorus is approximately 40% as available to plants as fertilizer phosphorus. Sewage sludge is a rich source of plant-available phosphorus.

4.0. Criteria Relating to Contaminants

4.1. Metals in Sludge of Concern to Agriculture

The metals in sewage sludges of concern to agriculture are arsenic, cadmium, cobalt, chromium, copper, mercury, molybdenum, nickel, lead, selenium and zinc. Data and criteria for these metals are shown in Tables 2 and 3. In addition, a synopsis of background information is presented in Appendix II.

4.1.1. ***Acceptability Criteria and Spreading Rates.*** Only sludges with low metal concentrations are suitable for use on land. Analyses must be provided to show that the sludges used conform with the criteria set out below.

a. *Anaerobically Digested Sludges.* The nitrogen to metal ratios, as shown in Table 2 column 5, relate ammonium plus nitrate nitrogen concentrations to acceptable metal concentrations. The averages of metal concentrations in the sludge during the preceding 12 months are divided by the average of ammonium plus nitrate nitrogen concentrations during the same period. Alternatively, at the discretion of local MOE staff, the average of the last 3 metals analyses may be divided by the average of ammonium plus nitrate nitrogen concentrations during the same period. Sludges, with ratios equal to or greater than those in column 5, are suitable for use on land; those with lower ratios are judged unsuitable.

Application rates are based on the concentrations of plant-available nitrogen i.e. ammonium plus nitrate nitrogen. The nitrogen application rate should not exceed that specified in Sections 3.2.1b and c.

b. *Aerobically Digested and Other Stabilized Aerobic Sludges.* Ontario studies have shown that these sludges have low ammonium plus nitrate nitrogen concentrations and do not normally meet the nitrogen to metal ratios required for anaerobic sludges (Table 2, column 5). However, they contain substantial amounts of phosphorus, micronutrients and organic matter, which are valuable to agriculture.

For the use of aerobic sludges on land to be acceptable, their metal concentrations should not exceed those specified in Table 3. The averages of metal concentrations in the sludge during the preceding 12 months are divided by the average total solids concentrations during the same period. Alternatively, at the discretion of local MOE staff, the average of the last 3 metals analyses may be divided by the average of total solids concentrations during the same period may be used. Sludges, with concentrations equal to or less than those in Table 3 are suitable for use on land; those with higher ratios are judged unsuitable. Refer to the calculation at the bottom of Table 3.

Aerobic sludges may be applied at rates up to 8 tonnes of solids per hectare per five years. The nitrogen application rate should not exceed that specified in Section 3.2.1b and c.

c. *Dewatered and Dried Sludges.* These sludges contain substantial amounts of phosphorus, organic nitrogen, micronutrients and organic matter, which are valuable to agriculture. However, there are substantial losses of plant-available nitrogen when sewage sludges are dewatered or dried. For this reason, fluid sludge is preferable to dewatered or dried sludge for use on land.

All dried and dewatered sludge used on land must conform with Table 3. Anaerobically digested sludges used on land must, prior to dewatering or drying, also be stabilized and conform with the criteria set out in Table 2.

Dewatered and dried sludges may be applied at rates up to 8 tonnes of solids per hectare per 5 years. Refer to the calculation at the bottom of Table 3. The nitrogen application rate should not exceed that specified in Sections 3.2.1b and c.

The farmer must be advised of ammonium plus nitrate nitrogen and phosphorus concentrations in dried or dewatered sludge, so that he can adjust sludge and fertilizer applications accordingly.

d. *Composted Sludges.* Guidelines for composting sewage sludge are being developed. In the meantime, enquiries should be directed to MOE Regional or District Offices.

4.1.2. *Marginally Acceptable Sludges.* A marginally acceptable sludge is one which fails to meet the acceptability criteria for metals, but which is within 10% of those criteria. Such sludges can be applied on a temporary basis. Application rates must then be proportionally reduced. If, after repeated sampling, those sludges do not meet the metals criteria, action must be taken to make them acceptable. Alternatively they must be disposed of by means other than utilization.

4.2. A Program to Limit Metal Accumulation in Soils

Only anaerobically digested sewage sludges with ammonium plus nitrate nitrogen to metal ratios equal to or greater than those in Table 2, column 5, or aerobic sludges with metal concentrations no greater than those in Table 3 may continue to be used on land.

The application of a sewage sludge complying with these Guidelines could elevate the metal concentrations of a typical Ontario soil to the maximum limits recommended within 25 to 55 years. If metal concentrations in sludges are further reduced, sludge application can continue for a longer period of time. For example, if the nitrogen to metal ratios for an anaerobic sludge are no greater than those in Table 2 Column 7, its application to the same area of land can continue for at least 250 years.

4.3. Industrial Organic Contaminants

There are significant gaps in knowledge, with respect to the fate of organic contaminants in sewage sludges applied to land. There is no evidence at present that organic contaminants in municipal sewage sludge applied to land poses a risk to human health.

Research programs are being undertaken in Canada and the United States to improve methods for determining the nature, extent, fate and effects of toxic organic compounds in the environment.

5.0. Criteria Relating to Spreading Sites

Under the *Environmental Protection Act*, all sludge spreading sites must be certified by the Ministry of the Environment. Prior to site certification and sludge use, factors such as site location, land and soil characteristics and proposed site management methods must be assessed to minimize potential hazards to surface watercourses, groundwater, wells and residences.

5.1. Separation Distances

5.1.1. *Surface Watercourses.* For the purposes of these Guidelines, a surface watercourse is defined as a natural or established surface watercourse or an open municipal drain along which water flows on a regular basis. Points of direct access (such as catch-basins to drainage tiles or municipal drains) should be treated as watercourses for separation distance purposes.

The minimum distance between the spreading site and a surface watercourse should normally be determined from Table 4, which takes into account land slope and soil permeability. If sludge is incorporated into the soil at the time of application, it may be applied closer to a watercourse than indicated in the Table. However, it should not be applied within 10 metres of any watercourse or body of water.

Ministry of the Environment staff will advise on separation distances from bodies of water or drainage channels other than surface watercourses as defined above.

5.1.2. *Groundwater.* The ground water table should not be less than 0.9 metres below the soil surface at the time of sewage sludge application.

5.1.3. *Bedrock.* Sewage sludge application should not normally be allowed where the unconsolidated materials overlying bedrock are less than 1.5 metres thick. Under special circumstances, and based on site-specific information which demonstrates that the risk of ground and surface water contamination is minimal, sites with lesser thickness of the unconsolidated materials may be used.

5.1.4. *Residences.* According to Ontario Regulation 309, the minimum separation distances from residences in residential areas and individual residences not in residential areas shall be 1500 feet (450 metres) and 300 feet (90 metres) respectively. If the Regulation should, in the future, permit it and where there is little cause for concern, these distances may be reduced. In no case should they be less than 50 metres and 25 metres respectively.

When sludge is applied to land in the proximity of residences, concerns may arise due to the potential for odours, air-borne drift of sludge particles and surface run-off. The extent of these concerns will depend upon the sludge application method and land slope.

When sludge is spray irrigated, these concerns may be greater than when surface spreading is used. Reduced separation distances may, in future, be permissible when soil injection methods are used.

5.1.5. *Water Wells.* According to Ontario Regulation 309, the minimum separation distance from any water well shall be 300 feet (90 metres). If the Regulation should, in the future, permit it and where there is little cause for concern, this distance may be reduced. In no case should it be less than 15 metres.

5.2. Soil Criteria

5.2.1. *Organic Soils.* Sewage sludge may be applied to 'mineral' soils but not to 'organic' soils. 'Organic' soils are soils which contain 17% or more of organic carbon by weight and which have a depth of 0.4 metres or more of unconsolidated organic material. Soils which do not meet these specifications are termed 'mineral'.

5.2.2. *Metals.* Sewage sludge may not be applied to soils whose metal concentrations are equal to or greater than those in Table 2, column 3.

5.2.3. *Phosphorus.* Sludges may not be applied to soils containing more than 60 miligrams of sodium bicarbonate extractable phosphorus per litre in the top 15 centimetres.

5.2.4. *Soil pH.* Most metals are more soluble and available to plants in acid soils than in neutral or calcareous soils. Thus, sewage sludge should be applied only to soils with pH values of 6.0 or greater. However, sludges derived from the lime treatment of sewage for phosphorus removal and lime stabilized sludges may be applied to soils of lower pH, when they will raise the soil pH to 6.0. Soil pH may also be raised by the addition of agricultural lime.

5.2.5. *Soils Tests.* Certificates of Approval will not be issued, nor will sludge spreading be permitted, unless satisfactory analyses for phosphorus and soil pH are available from soil samples taken within the previous three years.

5.2.6. *Snow Covered and Frozen Ground.* To minimize runoff, it is preferable that sludge should not be spread on frozen or ice covered soil. Sludge spreading is acceptable when there is little or no frost in the soil and the surface is snow-covered. For flat fields having a sustained slope of not more than 3%, spreading may be allowed on frozen soil, provided that the risks of runoff have been determined to be minimal. In such cases, separation distances from surface water courses should be at least 120 metres. Where surface run-off is expected as a result of snow-melt, a more critical evaluation of the site will be required.

5.3. Runoff Elimination and Soil Compaction Reduction

Soil tilage and sewage sludge application should, where possible, follow the contours of the land. Traffic by sewage sludge spreading vehicles should be minimized to reduce soil compaction.

Sewage sludge is best applied to unploughed soil when the residues of the previous crop are present to help control runoff, particularly when sludge is applied during the winter.

5.4. Waiting Periods After Spreading

Following sludge application, waiting periods in accordance with Table 1 are necessary. These waiting periods are required because, even after stabilization, sewage sludge contains some pathogenic organisms.

6.0. Sludge Handling and Spreading

6.1. Sludge Application

The maximum depth of fluid sludge which may be spread at any one time is 1.3 cm. There may be no subsequent application until the preceding application has dried. Criteria for maximum application rates are provided in Sections 3.0 and 4.0.

Uniform spreading of sludge is essential to ensure that each part of the field receives the same rates of sludge nutrients and metals Spreading vehicles should have calibrated equipment which can be relied on to control the rate of sludge application. Unsealed tanks, for which gravity flow and ground speed are the only means of adjusting rates, will not spread sludge uniformly.

Sewage sludge should not be spread if the vehicle would cause undue compaction or damage soil structure. Spreading vehicles with flotation tires are preferred. Even flotation tires can cause serious soil compaction when the soil is wet.

The overall quality of spreading is a major factor affecting the willingness of farmers to continue using sewage sludge.

6.2. Storage and Blending

6.2.1. ***Requirements for Storage.*** A Certificate of Approval is required for a sludge storage facility. Sludge spreading may be impracticable during inclement weather and during the required waiting periods between spreading and cropping or pasturing. Sufficient storage must be available to retain sludge during these periods.

In Ontario, earthen lagoons are generally used for sludge storage or blending, but other facilities are also used. Sludge must meet the Guidelines' criteria when it is spread on land. Therefore, it must be well-mixed, so that it is of uniform quality before it is withdrawn from storage.

6.2.2. ***Sludge Blending.*** Sludge storage presents an opportunity for blending. Two or more sludges with unacceptable nitrogen to metal ratios or metals content may, after blending, form an acceptable sludge mixture. In such circumstances, proper mixing is essential. Periodic verification, that sludge taken from the blending facility is uniform and meets the guidelines' criteria, is required.

6.2.3. ***Sludge-Manure Blending.*** The blending of acceptable sewage sludge and liquid livestock manure is acceptable, provided adequate storage and land for spreading are available. The spreading rate should be related to the nitrogen requirement of the crop. Not more than 1.3 cm depth of the blended material may be applied at any one time. The total amount of sludge applied per 5 years must not exceed that specified in Section 3.2.1b or Section 4.1.1b. It is the farmer's responsibility to spread blended sludge in accordance with the Guidelines.

6.3. Responsibilities and Rights.

Some of the responsibilities and rights of those involved in sludge utilization are outlined below.

6.3.1. ***Operating Agencies.*** The responsibilities of agencies operating sewage treatment plants are set out below.

a. Record-keeping. Records are to be kept of:

i. The location of all fields receiving sewage sludge;

ii. The sewage sludge applied to each field; and

iii. Sludge Analyses. A report, similar to that shown in Appendix I, is to be provided to the sludge hauler. The report shall include data on the sludge's average nutrient content per cubic metre.

The farmer shall, on request, be advised of the annual average quantities of metals per cubic metre of sludge.

b. *Sample Submission.* The number of sewage sludge samples analyzed must be sufficient to establish representative values for all pertinent parameters. Sampling frequency is subject to approval by MOE Regional staff.

c. *Monitoring Application Rates.* Steps should be taken to verify that the sewage sludge application rates conform with thsoe specified by Certificates of Approval.

d. *Contingency Planning.* Sewage treatment plant operating authorities are required to prepare contingency plans for situations where sewage sludge quality may temporarily fail to meet the requirements of these Guidelines. These situations may be the result of digester failure or cleanouts and plant maintenance or expansion. These plans must provide for alternative methods for treatment and/or disposal.

Exemption from the Guidelines (see Section 7.0) will be considered only in unusual circumstances.

e. *Marginal Sludges.* Operating authorities will review the acceptability of their sludges immediately after individual analyses become available. Measures should be taken to prevent sludges from becoming unacceptable.

Whenever marginal sludges are utilized on agricultural land, the farmer is to be advised of the deviations in sludge quality.

6.3.2. ***Sludge Haulers.*** The hauler must spread the sludge uniformly over the surface of the land at the rate required by the farmer. (See Section 6.3.3.) The actual nitrogen application rate (in kilograms per hectare) and/or the sludge application rate (in cubic metres per hectare) must not exceed those specified by the Ministry of the Environment.

The hauler must maintain all required separation distances and comply with other site requirements. Staking of distances from wells, watercourse and residences can sometimes facilitate this.

The hauler must ensure that the farmer receives a report, similar to that shown in Appendix I, as soon as practicable after completion of sludge application to any one field.

The rights of the farmer must be respected with regard to timing and rate of application (see Section 6.3.3).

6.3.3. ***Farmers.*** The farmer, the sludge hauler and the sewage treatment plant operator should work together to develop a sludge utilization program for each field used. The farmer has the right and the responsibility to insist on program flexibility, so that sludge application rates may be adjusted to suit the nitrogen and phosphorus requirements of the crop. In addition, the farmer may direct that sludge spreading operations be discontinued immediately.

The farmer also has the responsibility to see that appropriate waiting periods between sludge spreading and cropping or pasturing are observed.

Farmers will receive a copy of a report similar to that shown in Appendix I.

7.0. Exemption from the Guidelines

When sludge quality deviates from the requirements of these Guidelines, sludge application to agricultural land may be considered, on an interim basis, in unusual circumstances only. These unusual circumstances will not normally include situations which can be foreseen and for which contingency plans, as discussed in Section 6.3.1d, are to be developed.

Exemptions from the Guidelines will be considered on a case-by-case basis, through consultations between staff of the Ministry of the Environment and the Ministry of Agriculture and Food.

8.0. Complaints and Guidelines Interpretation

Questions on Guidelines' enforcement and their interpretation should be directed to:

a. OMAF local staff, when the questions relate to spreading methods, the need for supplemental fertilizers, crop quality, or animal health.

b. MOE local staff, when the questions relate to site approvals, sludge haulage, sludge quality or environmental issues.

c. The local Medical Officer of Health, when the questions relate to public health.

These agencies consult with one another as may be appropriate to ensure that agricultural, environmental and health considerations are taken into account. When necessary, these agencies also consult with the Sludge Utilization Committee.

Table 1

(not reproduced)

TABLE 2

METAL CRITERIA FOR FLUID[a] ANAEROBICALLY DIGESTED SEWAGE SLUDGES

1 Metal	2 Mean Metal Content of Uncontaminated Ontario Soils ug/g)[b]	3 Maximum Permissible Metal Content in Soil (ug/g)[b]	4 Maximum Permissible Metal Addition to Soil kg/ha)[d]	5 Minimum Ammonium plus Nitrate Nitrogen (NH_4^+-N plus NO_3^--N) to metal Ratios Required in Sewage Sludge	6 Number of Years To Reach Maximum Recommended Metal Content in Soil (col. 3), Based on cols. 2, 3 and 5[c,d]	7 Minimum ammonium plus Nitrate Nitrogen (NH_4^+-N plus NO_3^--N) to Metals Ratios Required To Give Maximum Permissible Metal Content in Soil (col. 3) in 250 years[d]
ARSENIC	7	14	14	100	50	480
CADMIUM	0.8	1.6	1.6	500	30	4200
COBALT	5	20	30	50	55	220
CHROMIUM	15	120	210	6	45	32
COPPER	25	100	150	10	55	45
MERCURY	0.1	0.5	0.8	1500	45	8400
MOLYBDENUM	2	4	4	180	25	1700
NICKEL	16	32	32	40	45	210
LEAD	15	60	90	15	50	75
SELENIUM	0.4	1.6	2.4	500	45	2800
ZINC	55	220	330	4	50	20

a Dewatered and dried sludges are to meet the Column 5 criteria prior to dewatering and drying.

b Based on dry weight at 100°C. The terms ug/g and mg/kg are interchangeable.

c Based on 135 kg. of ammonium plus nitrate nitrogen per hectare per five years and sewage sludge having minimum ratios. Number of years is rounded off to the nearest five years.

d Columns 4, 6 and 7 apply to soils of mean metal content (column 2) and require adjustment for soils lower or higher in metal content.

TABLE 3

METAL CRITERIA[a] FOR ALL AEROBIC SEWAGE SLUDGES AND FOR ALL DRIED AND DEWATERED ANAEROBIC SEWAGE SLUDGES

Metal	Maximum Permissible Metal Concentration (mg/kg of solids)[b]
Arsenic	170
Cadmium	34
Cobalt	340
Chromium	2800
Copper	1700
Mercury	11
Molybdenum	94
Nickel	420
Lead	1100
Selenium	34
Zinc	4200

[a] For permissible number of years to reach maximum metal concentrations in soils, refer to Table 2, column 6.

[b] Acceptability will be judged on the basis of the ratio of the average metal concentration during the preceding 12 months to the average concentration of solids during the same period or, at the discretion of local MOE staff and when solids and metals analyses are conducted once a month, on the basis of the last 3 results.

CALCULATIONS FOR AEROBIC SLUDGE USE ON LAND

1. To determine sludge acceptability, calculate 'Actual Metal Concentrations' and compare with the above Permissible Values

i.e. $$\frac{\text{Metal Concentration (mg/l)} \times 10^6}{\text{Sludge Solids concentration (mg/l)}} = \frac{\text{mg of metal}}{\text{Kg of solids}}$$

2. Calculate maximum application rate per 5 year period.

i.e. $$\frac{8 \times 10^6}{\text{Sludge Solids (mg/l)}} = \frac{\text{Cubic Metres of Sludge}}{\text{Land Area in Hectares}}$$

OBJECTIVES FOR THE CONTROL OF INDUSTRIAL WASTE DISCHARGES IN ONTARIO,

Ministry of the Environment.

The Ministry of the Environment requires all industries discharging wastes to public waters to undertake effluent improvement programs to meet the following objectives:

Protection of Receiving Water. In keeping with the overall policy of protecting water quality while recognizing an essential use for treated wastewater disposal, the Ministry may require industries contributing wastes not specified in the following, to limit, destroy, remove or modify any waste constituents that may be in question. This may apply to waste constituents that are not readily removed by conventional treatment and are only reduced by dilution and other natural stream purification processes.

In order to maintain acceptable water quality conditions in the receiving water, it will be necessary for industry to provide more intensive waste treatment as the density of industrial and other development increases.

Desirable Effluent Discharge Characteristics.

1. ***5-day Biochemical Oxygen Demand (BOD).*** Unless otherwise specified by the Ministry, the concentration of BOD in wastewaters at the point of discharge to the receiving waters shall not exceed 15 milligrams per litre (mg/l) at any time. In determining the acceptability of BOD concentrations in wastewater discharges other than 15 mg/l, the Ministry will apply the following criteria:

— the BOD in the receiving stream after initial dilution shall not exceed 4 mg/l at any time consistent with specified minimum levels of flow.

— the concentration of dissolved oxygen (DO) in the receiving stream shall not fall below 6 mg/l for receiving waters inhabited by cold water fishes or below 5 mg/l for receiving waters inhabited by warm water fishes.

2. ***Suspended Solids.*** The concentration of suspended solids in wastewater at the point of discharge to a receiving water shall not exceed the concentration of suspended solids in the industrial water supply by more than 15 parts per million by weight, or as otherwise specified by the Ministry.

3. ***Oils and Greases.*** The concentration of oils and greases of vegetable, animal or mineral origin in wastewater shall not exceed 15 parts per million by weight at the point of discharge to the receiving water.

For certain receiving waters, the requirements may be reduced below the 15 ppm limit to prevent objectionable aesthetic conditions arising.

4. ***Metals.*** Unless specified otherwise by the Ministry, the concentrations of component heavy metals in wastewater discharges shall not exceed the limits specified below:

— cadmium	0.001 mg/l (essentially zero)
— chromium	1.0 mg/l
— copper	1.0 mg/l
— lead	1.0 mg/l
— mercury	0.001 mg/l (essentially zero)
— nickel	1.0 mg/l
— tin	1.0 mg/l
— zinc	1.0 mg/l

Note: The *total quantity* of metals discharged will also be considered and *dilution* with clean water streams to achieve the above concentrations is not acceptable.

5. ***Phenols.*** Unless otherwise specified by the Ministry, the concentration of phenol in wastewaters at the point of discharge shall not exceed 20 parts per billion (ppb). In determining the acceptability of phenol concentrations in wastewater discharges other than 20 ppb, the Ministry will apply the following criteria:

— phenol or phenolic equivalents should not exceed an average of 2 ppb or a maximum of 5 ppb in the receiving waters following initial dilution in a defined mixing zone.

6. ***Toxic Substances.*** Materials or waste components that are toxic to aquatic life or render the water unsuitable for potable or recreational uses shall be eliminated or destroyed.

7. ***Ammonia.*** Unless otherwise specified by the Ministry, the concentration of ammonia (NH, as N) in wastewaters at the point of discharge to the receiving waters shall not exceed 10 milligrams per litre (mg/l) at any time.

In view of the known acute toxicity of ammonia to aquatic life, a more stringent effluent quality requirement may be applied consistent with the availability of practicable technology.

8. ***pH.*** The pH or relative acidity or basicity of wastewaters shall be controlled and maintained within the range of 5.5 to 9.5.

9. ***Sulphate, Chlorides and Dissolved Solids.*** The policy of the Ministry is to minimize the build-up of sulphates, chlorides and dissolved solids in the receiving waters. Therefore, the quantities of these materials in wastewater discharges should be kept as low as possible consistent with the application of best *available, practicable technology.*

10. ***Taste and Odour.*** Waste materials or components of wastewaters that impart tastes and odours to the receiving waters or to fish and thereby render the waters or the fish unsuitable for use shall be eliminated or destroyed prior to the discharge of the wastewaters.

11. ***Temperature.*** Unless otherwise specified by the Ministry, the temperature of wastewaters (including cooling waters) at the point of discharge, shall not exceed the temperature of the receiving waters by more than 11 °C (20°F).

More stringent requirements may be imposed where it is considered that a change in the general level of temperature in the receiving stream, resulting from a heated discharge, may exceed the temperature tolerance range of an established fish species.

12. ***Aesthetic Qualities.*** Treatment or control shall be effected to ensure that waste discharges do not impair the aesthetic qualities of the receiving water by imparting colour, by giving rise to accumulations of solids, oils or greases, by inducing foaming, or by other adverse effects.

Appendix 3 Case Study Data

A3.1 Process Descriptions

1. Phoenix Park Gas Processing Plant (Roger Moore, Operations Manager)

1. Dehydration of incoming raw gas, using 3A mole sieve (mole sieve is regenerated using residue gas heated by a gas fired heater; stabilized to atmospheric pressure)
2. Gas flows to propane recovery tower, demethanizes liquids in cooling section, deethanizes at higher temperature and pressure resulting in 98% propane recovery with a 200 psi pressure drop; tower also removes any H_2S
3. Depropanizer and debutanizer remove propane and butane; remaining liquid product blended with natural gasoline.

2. Trinidad and Tobago Methanol Gas Company Limited (Mr. R. Roopnarine, Shift Supervisor)

Low pressure synthesis

1. Desulphurization, with mercaptans removed by NiMo catalyst and removal of sulphur by zinc oxide ($ZnO + H_2S \rightarrow ZnS + H_2O$)
2. Steam reforming in furnace, 400 tubes, 40ft long with Ni based catalyst; $CH_4 + H_2O \Leftrightarrow CO + 3H_2$ then $CO + H_2O \Leftrightarrow CO_2 + H_2$ and $CH_4 + 2H_2O \Leftrightarrow CO_2 + 4H_2$ @ 860°C, 17 atm; net reaction endothermic; waste heat recovered by producing steam through a series of heat exchangers
3. Condensate stripping with recovery of process condensate (H_2O); treated with ion exchange resins
4. Synthesis gas compression; $CO + 2H_2 \Leftrightarrow CH_3OH$ then $CO_2 + 3H_2 \Leftrightarrow CH_3OH + H_2O$; net reaction exothermic; CO_2 purchased to utilize all H

5. Synthesis reactor; compressed gas → quench reactor (2 reactors; one on stream 1990); Cu based catalyst

Methanol condensed, removed → 78-80% MeOH

6. Distillation; two columns in series - produces product methanol, fusel oil, wastewater; methanol stored in tanks on site

Nitrogen process

1. Compressor takes in air which is compressed through freon cooling system to remove water.
2. Molecular sieve removes CO_2
3. Cryogenic system cools the remaining gases to -183°C and O_2 is removed from the bottom of the column; N_2 is removed from the top of the column.

3. Fertilizers of Trinidad and Tobago (Reynolds Piggott)

1. Sulphur removed from natural gas
2. Reformer, N catalyst, 1500°F
3. Reformer, 1800°F produces heat for steam turbines; gas now H, CO_x, N
4. CO converted to CO_2 (shift converter), dried by contact with triethylene glycol
5. CO_2 removal by MEA - 60% to urea, MeOH plant, another 20% to new plant
6. Methanator - removes final CO_x
7. Ammonia converter - 12% converted; rest of gas recycled back

4. Trinidad and Tobago Urea Company (Shaheed Mohammed, Manager, Technical and Engineering)

1. Ammonia and carbon dioxide compressed to 150 - 200 kg/m3, at 180-200°C, to form ammonium carbamate; $2NH_3 + CO_2 \rightarrow NH_4CO_2NH_2$
2. Dehydrated to form urea; $NH_4CO_2NH_2 \rightarrow CO(NH_2) + H_2O$
3. Carbamate and ammonia stripped, returned to reaction
4. Water flash evaporated to 90% urea solution; water stripped, fed to boiler feed system

5. Vacuum evaporator produces 95.5% urea
6. Urea formaldehyde injected to reduce hydroscopic tendencies
7. Urea granulated using hot air
8. Extracted, cooled with dehumidified air, sieved, transferred and stored for shipment

5. Caribbean ISPAT Ltd. (Malcolm London, Safety Officer)

1. Natural gas is reformed into carbon monoxide and hydrogen with spent process gas over a heated catalyst
    1a. Limestone is burnt in a kiln to produce lime; $CaCO_3 + O \rightarrow CaO_2 + CO_2$
2. The reformed gas, lump ore, burnt lime and oxide pellet is introduced into the gas reduction furnace, a counter current gas-solid contact shaft furnace which promotes deoxidation of iron in the solid state. End product (DRI) is a porous solid containing 92-95% iron and inert impurities

2a. Dust collected from the furnace is bound with sodium silicate and lime and compressed into brickettes

3. DRI and scrap metal is melted in 2 electric arc furnaces, capacities of 100 tonnes, or a ladle furnace (high C steel), capacity 100 tonnes, then cast into billets. Calcium carbide and rice husks are added as conditioners; anthracite is added depending upon the carbon content desired and lime is added.
4. Billets are heated in a walking beam reheat furnace ($T = 1200^{o}C$); reduced by rolling mills into wire rod
5. Wire rods are cooled through straight water boxes and air cooling conveyors and trimmed
6. Wire rods are inspected and further trimmed; they are then baled and moved to the storage yard. They are then reinspected and moved to the docks for loading.

A3.2 Input and Waste Components

The following tables detail the four major components of input and waste materials for each plant. Only inputs that are considered to be 'simple' are included such as wastes which are not manufactured or are not a specific mixture of substances, such as a commercial biocide which would not be 'simple'. These are the inputs which will be used for comparison with the wastes to determine if wastes can be used as inputs. Input tables also indicate the maximum and minimum percents of the specific component allowed for that process, while waste tables list the percents of the components found.

Table A3.1 Input components for the Phoenix Park Gas Processing Plant

Input	Component 1	Percent			Component 2	Percent			Component 3	Percent			Component 4	Percent		
		avg.	min	max		avg.	min	max		avg	min	max		avg	min	max
raw natural gas	methane	93	90	100	ethane	3.3	0	5	propane	1.2	0	2	butane	0.63	0	1
methanol	methanol	100	100	100												
gas heating water	water	100	99.99	100												
washwater	water	99	97	100	dirt	1	0	3								
sanitary water	water	99.9	99	100												

Table A3.2 Waste components from the Phoenix Park Gas Processing Plant

Waste	Component 1	%	Component 2	%	Component 3	%	Component 4	%
water	water	99.9						
carbon dioxide/H_2O	carbon dioxide	55.5	water	45.5				
canister filters	fibre	60	steel	20	plastic	5	oil/dirt	15
dust filters	fibre	60	aluminum	20	plastic	5	oil/dirt	15
paper filters	paper	99						
gas heating water	water	99						
compressor oil	oil	99						
plant washings	water	99	dirt	1				
sanitary water	water	99						
sewage sludge	water	95	solids	5				
molecular sieve	Al2O3	90	water	8	hydrocarbons	2		

Table A3.3 Input components for the Trinidad and Tobago Methanol plant

Input	Component 1	Percent			Component 2	Percent		
		avg.	min.	max.		avg.	min.	max.
calcium hypochlorite	calcium hypochlorite	99	99	100				
dispersant	dispersant	99	99	100				
freon	freon	100	100	100				
phosphate	phosphate	98	95	100				
sulphuric acid	sulphuric acid	98	95	100				
water	water	99.9	99.9	100				
solvent	solvent	100	100	100				
carbon dioxide	carbon dioxide	99.99	99.9	100				
natural gas	methane	95.86	92	99	ethane	3.42	1	5
water	water	100	100	100				
boiler water	water	100	100	100				
phosphate	Na_3PO_4	88	85	90	$NaPO_4$	12	15	10
sodium hydroxide	sodium hydroxide	100	100	100				
sulphuric acid	sulphuric acid	99	95	100				

Input	Component 3	Percent			Component 4	Percent		
		avg.	min.	max.		avg.	min.	max.
calcium hypochlorite								
dispersant								
freon								
phosphate								
sulphuric acid								
water								
solvent								
carbon dioxide								
natural gas	propane	0.052	0.001	0.1	carbon dioxide	0.556	0.2	0.7
water								
boiler water								
phosphate								
sodium hydroxide								
sulphuric acid								

Table A3.4 Waste components from the Trinidad and Tobago Methanol plant

Wastes	**Component 1**	**%**	**Component 2**	**%**	**Component 3**	**%**	**Component 4**	**%**
cool. water	water	99.9						
boiler blowdown	water	99						
freon	freon	100						
solvent	solvent	99	dirt	1				
process water	water	99.9						
nickel catalyst	nickel	10	Al_2O_3	90				
zinc oxide	zinc oxide	40	zinc sulphate	60				
lubricating oil	oil	98	dirt	2				
oil filter	fibre	60	steel	20	plastic	15	dirt	5
regeneration water	water	100						
spent anion resin	anion resin	99						
spent cation resin	cation resin	99						
carbon dioxide/water	carbon dioxide	55.5	water	45.5				

Table A3.5 Input components for Fertrin and the Trinidad and Tobago Urea Company plant

Input	**Component**	**Percent**			**Component**	**Percent**		
	1	**avg.**	**min.**	**max.**	**2**	**avg.**	**min.**	**max.**
air	nitrogen	78	78	78	oxygen	20.95	20	21
natural gas	methane	95.9	92	99	ethane	3.4	1	5
water	water	100	100	100				
carbon dioxide	carbon dioxide	100	99	100				
water	water	100	100	100				
monoethanolamine	monoethanolamine	100	100	100				
triethylene glycol	triethylene glycol	100	100	100				
water	water	100	100	100				
solvent	solvent	100	100	100				
activated carbon	activated carbon	100	100	100				
water	water	100	100	100				
sodium hydroxide	sodium hydroxide	95	80	100				
sulphuric acid	sulphuric acid	95	80	100				
salt water	salt water	100	100	100				
sulphuric acid	sulphuric acid	100	100	100				

Input	**Component**	**Percent**			**Component**	**Percent**		
	3	**avg.**	**min.**	**max.**	**4**	**avg.**	**min.**	**max.**
air	carbon dioxide	0.033	0.03	0.03	argon	0.93	0.9	0.94
natural gas	carbon dioxide	0.556	0.3	0.7	nitrogen	0.108	0.1	0.15
water								
carbon dioxide								
water								
monoethanolamine								
triethylene glycol								
water								
solvent								
activated carbon								
water								
sodium hydroxide								
sulphuric acid								
salt water								
sulphuric acid								

Table A3.6 Waste components from Fertrin and the Trinidad and Tobago Urea Company plant

Waste	**Component 1**	**%**	**Component 2**	**%**	**Component 3**	**%**	**Component 4**	**%**
ammonia	ammonia	100						
urea process water	water	99	urea	0.14	ammonia	0.41		
monoethanolamine	monoethanolamine	80	acid organics	14	vanadium	1.5	antimony	0.06
triethylene glycol	triethylene glycol	99						
NH_3 cooling water	water	99						
solvent	solvent	90	dirt/sediment	10				
activated carbon	activated carbon	99						
canister filters	steel	20	fibre	45	plastic	15	oil	25
molecular sieve	Al_2O_3	90	water	5	ammonia	5		
water	water	99.9						
heating water	water	99						
sanitary water	water	99	solids/dirt	1				
spent cation resin	cation resin	99						
spent anion resin	anion resin	99						
iron oxide	iron oxide	100						
zinc oxide	zinc oxide	100						
regenerate	water	90						
urea cooling water	water	99						
urea heating water	water	99						
scrap steel	steel	95						
salt water	salt water	99						

Table A3.7 Input components for Caribbean ISPAT Ltd.

Input	**Component**	**Percent**			**Component**	**Percent**		
	1	**avg.**	**min**	**max**	**2**	**avg.**	**min**	**max**
iron ore	iron	67.35	67	70	aluminum oxide	0.25	0	2.2
natural gas	methane	95	92	100	ethane	3.24	0	5
oxygen	oxygen	100	100	100				
water	water	100	100	100				
solvent	xylene	25	20	30	toluene	25	20	30
solvent	napthalene	20	20	30	xylene	20	20	30
limestone	calcium carbonate	58.75	55	60	magnesium carbonate	38.85	35	40
oxygen	oxygen	100	100	100				
alloy	alloy	100	100	100				
calcium carbide	calcium carbide	100	100	100				
coal	coal	100	100	100				
lime	lime	100	100	100				
oxygen	oxygen	100	100	100				
rice husks	rice husks	100	100	100				
scrap steel	steel	95	90	100				
silicon/manganese	manganese	62.6	60	65	silicon	20	18	22

Input	**Component**	**Percent**			**Component**	**Percent**		
	3	**avg.**	**min**	**max**	**4**	**avg.**	**min**	**max**
iron ore								
natural gas								
oxygen								
water								
solvent	petroleum distillates	25	20	30	detergent	25	20	30
solvent	toluene	20	20	30				
limestone	calcium oxide	32.9	3.15	40	magnesium oxide	18.5	18.5	20
oxygen								
alloy								
calcium carbide								
coal								
lime								
oxygen								
rice husks								
scrap steel								
silicon/manganese	phosphate	0.22	0	0.3				

Table A3.8 Waste components from Caribbean ISPAT Ltd.

Waste	Component 1	%	Component 2	%	Component 3	%	Component 4	%
CO_2/ particulates-DRI	carbon dioxide	99.9	particulates	0.02				
nitrogen	nitrogen oxide	83.1	sulphur dioxide	16.9				
cooling tower sludge	iron	7	water	90				
steel cooling water	water	99						
CO2/particulates-lime	carbon dioxide	49	calcium oxide	51	magnesium oxide	1	silicon oxide	2.5
lubricating oil	oil	97						
oil filters	oil	50	steel	12.5	plastic	12.5	fibre	25
cesium source	cesium	20	lead	80				
equipment	steel	90	plastic	10				
scrap steel	steel	95						
tires	rubber	80	steel	20				
CO_2/particulates-steel	iron oxide	19.5	calcium oxide	5.8	magnesium oxide	2.1	carbon dioxide	60
mill scale	iron	72.8	calcium	0.56	magnesium	0.14	silicon	0.23

A3.3 Input and Waste Material Parameters

The parameters measured for the materials depend upon the material type - gas, liquid, sludge or solid. These parameters are those that were deemed necessary to determine the treatments possible for waste materials and to define the requirements for input materials. Input and waste materials are listed by type in the following tables, but only include non-manufactured inputs such as water or scrap steel. Tables A3.13 - A3.15 define the measured parameters and the maximum and minimum allowed for those parameters for that input. Tables A3.16 - A3.19 list the measured parameters of the waste materials. To identify the plant producing the waste, a column has been added and the following acronyms have been used:

Phoenix Part Gas Processors	PPGP
Trinidad and Tobago Methanol Company	TTMeth
Fertilizers of Trinidad and Tobago/Trinidad and Tobago Urea Company	Fertrin
Caribbean ISPAT Ltd.	ISPAT

Since one input may be required by more than one company, inputs are not identified by company.

Table A3.9 Particle size and codes used in following tables

Particle size	Code	Particle size	Code
>30 mm	5	.001 - .01	2
30 -.5mm	4	<.001 mm	1
.01-.5 mm	3	no particles	0

Table A3.10 Parameters for input materials for the selected plants - Gases.

Input	Corrosion			Volatiles ppm			Oil ppm		
	present	min	max	present	min	max	present	min	max
air	6.5	6	7	0	0	0	0	0	0
carbon dioxide	7	6.5	7.5	0	0	0	0	0	0
oxygen	7	6.5	7.5	0	0	0	0	0	0
raw natural gas	6	5.5	8	990000	980000	100000	50000	0	50000
freon	7	6	8	0	0	0	0	0	0

Input	Particulates ppm			Particle size			Water ppm		
	present	min	max	present	min	max	present	min	max
air	50	0	100	2	1	3	0	0	0
carbon dioxide	0	0	0	0	0	0	0	0	0
oxygen	0	0	0	0	0	0	0	0	0
raw natural gas	1000	0	5000	2	1	3	10000	0	50000
freon	0	0	0	0	0	0	0	0	0

Input	SO_2 ppm			NOx ppm			Cl ppm		
	present	min	max	present	min	max	present	min	max
air	0	0	0	0	0	0	0	0	0
carbon dioxide	0	0	0	0	0	0	0	0	0
oxygen	0	0	0	0	0	0	0	0	0
raw natural gas	500	0	5000	780	0	2500	0	0	0
freon				0	0	0	0	0	0

Input	Heavy Metalsppm			CFCs ppm			CO_2 ppm		
	present	min	max	present	min	max	present	min	max
air	0	0	0	0	0	0	300000	300000	300000
carbon dioxide	0	0	0	0	0	0	1000000	1000000	100000
oxygen	0	0	0	0	0	0	0	0	0
raw natural gas	10	0	20	0	0	0	5700	0	5000
freon	0	0	0	1000000	1000000	1000000	0	0	0

Input	NH_3 ppm		
	present	min	max
air	0	0	0
carbon dioxide	0	0	0
oxygen	0	0	0
raw natural gas	0	0	0
freon	0	0	0

Table A3.11 Parameters for input materials for selected plants - **Liquids**

Input	PH			COD ppm			Solvent ppm		
	present	min	max	present	min	max	present	min	max
heat.water	7	6.5	7.5	20	0	50	0	0	10
salt water	6	6	8	10	0	15	0	0	1
san.water	6.8	6	8	50	0	50	0	0	1
sodium hydroxide	14	14	14	0	0	0	0	0	0
solvent	7	6.5	7.5	3000000	2000000	3300000	1000000	1000000	1000000
sulphuric acid	1	1	1	0	0	0	0	0	0
washwater	7	6	8.5	0	0	10	0	0	1
water	7	6	8	20	0	25	0	0	10

Input	Oil ppm			Particulates ppm			Particle size		
	present	min	max	present	min	max	present	min	max
heat.water	1	0	5	10	0	20	2	1	4
salt water	1	0	1	5	0	100	2	1	3
san.water	1	0	1	100	0	100	2	1	4
sodium hydroxide	0.05	0	0	0	0	0	0	1	4
solvent	0	0	0	0	0	0	0	1	4
sulphuric acid	0	0	0	0	0	0	0	1	4
washwater	0	0	1	100	0	500	2	1	4
water	0	0	1	10	0	20	2	1	4

Input	NH_4 ppm			NO_3 ppm			Toxicity ppm		
	present	min	max	present	min	max	present	min	max
heat.water	0	0	1	0	0	10	0	0	0.01
salt water	0	0	10	0	0	10	0	0	2000
san.water	0	0	1	0	0	10	0	0	0.01
sodium hydroxide	0	0	0	0	0	0	0	0	0
solvent	0	0	0	0	0	0	1000000	1000000	1000000
sulphuric acid	0	0	0	0	0	0	0	0	0
washwater	0	0	1	0	0	10	0	0	0.01
water	0	0	1	0	0	10	0	0	0.01

Input	Dissolved solids ppm			Heavy Metals ppm			PO4 ppm		
	present	min	max	present	min	max	present	min	max
heat.water	30	0	60	0	0	50	0	0	100
salt water	20000	0	30000	0	0	0.1	0	0	100
san.water	5000	0	6000	0	0	0.1	0	0	100
sodium hydroxide	420000	400000	420000	0	0	0	0	0	0
solvent	0	0	0	0	0	0	0	0	0
sulphuric acid	0	0	0	0	0	0	0	0	0
washwater	5000	0	10000	0	0	0.1	0	0	100
water	100	0	120	0	0	0.01	0	0	100

Input	Sulphur ppm		
	present	min	max
heat.water	0	0	0.1
salt water	0	0	5
san.water	0	0	5
sodium hydroxide	0	0	0
solvent	0	0	0
sulphuric acid	500000	45000	500000
washwater	0	0	5
water	0	0	5

Table A3.12 Parameters for input materials for selected plants - **Solids**

Input	Leachate pH			COD ppm			Solventsppm		
	present	min	max	present	min	max	present	min	max
alloy	7	7	7	0	0	0	0	0	0
calcium carbide	7	7	7	0	0	0	0	0	0
calcium hypochlorite	11	10	12	0	0	0	0	0	0
coal	6.5	6	8.5	0	0	0	0	0	0
iron ore	7	7	7	0	0	0	0	0	0
lime	9	8	9.5	0	0	0	0	0	0
limestone	9	9	11	0	0	0	0	0	0
rice husks	7	7	7	1000000	1000000	1000000	0	0	0
scrap steel	7	7	7	0	0	0	0	0	0
silicon/manganese	7	7	7	0	0	0	0	0	0
sodium hydroxide	14	12.5	14	0	0	0	0	0	0

Input	Soluble solids ppm			Heavy metals ppm			Iron ppm		
	present	min	max	present	min	max	present	min	max
alloy	0	0	0	800000	800000	800000	0	0	0
calcium carbide	1000000	1000000	1000000	0	0	0	0	0	0
calcium hypochlorite	99	99	99	0	0	0	0	0	0
coal	0	0	0	0	0	0	11000	11000	12000
iron ore	0	0	0	0	0	0	673500	670000	700000
lime	5000	5000	5000	0	0	0	0	0	0
limestone	10000	10000	10000	0	0	0	0	0	0
rice husks	0	0	0	0	0	0	0	0	0
scrap steel	0	0	0	200	0	400	970000	950000	1000000
silicon/manganese	0	0	0	0	0	0	0	0	0
sodium hydroxide	1000000	1000000	1000000	0	0	0	0	0	0

Input	Oil ppm			Other Metals ppm			Particle size		
	present	min	max	present	min	max	present	min	max
alloy	0	0	0	1000000	990000	1000000	4	1	5
calcium carbide	0	0	0	0	0	0	4	1	5
calcium hypochlorite	0	0	0	0	0	0	4	1	5
coal	0	0	0	40000	35000	45000	4	1	5
iron ore	0	0	0	326500	300000	330000	4	1	5
lime	0	0	0	120000	100000	150000	4	1	5
limestone	0	0	0	220000	200000	250000	4	1	5
rice husks	0	0	0	0	0	0	4	1	4
scrap steel	0	0	0	30000	10000	50000	4	1	5
silicon/manganese	0	0	0	630000	600000	700000	4	1	5
sodium hydroxide	0	0	0	0	0	0	4	1	5

Table A3.12 (cont) Parameters for input materials for selected plants - Solids

Input	**Ash**	**ppm**		**Paper/cardboard**	**ppm**		**Plastic/rubber**	**ppm**	
	present	**min**	**max**	**present**	**min**	**max**	**present**	**min**	**max**
alloy	1000000	950000	1000000	0	0	0	0	0	0
calcium carbide	1000000	950000	1000000	0	0	0	0	0	0
calcium hypochlorite	1000000	950000	1000000	0	0	0	0	0	0
coal	100000	70000	110000	0	0	0	0	0	0
iron ore	1000000	950000	1000000	0	0	0	0	0	0
lime	1000000	950000	1000000	0	0	0	0	0	0
limestone	550000	500000	600000	0	0	0	0	0	0
rice husks	10000	8000	11000	0	0	0	0	0	0
scrap steel	1000000	950000	1000000	0	0	0	0	0	0
silicon/manganese	1000000	950000	1000000	0	0	0	0	0	0
sodium hydroxide	1000000	950000	1000000	0	0	0	0	0	0

Table A3.14 Parameters (ppm unless not applicable) of waste materials - Gases

Waste	**Plant**	**Corrosivity**	**Volatiles**	**Oil/ grease**	**Particulates**	**Particle Size**	**Water**
ammonia gas	Fertrin	8	0	0	0	1	0
carbon dioxide/ water	PPGP/ TTMeth	7	0	0	500	1	455000
CO_2/ particulates-lime	ISPAT	10	0	0	10000	3	0
CO_2/ particulates-DRI	ISPAT	5	0	0	10000	3	0
freon	TTMeth	7	1000000	0	0	1	0
CO_2/particulates-steel	ISPAT	5.5	0	0	14000	3	0
compressor oil	PPGP	4.5	200000	980000	0	3	0
nitrogen	ISPAT	3.4	0	0	0	1	0

Waste	**Heavy metals**	**CFCs**	**CO_2**	**SO_2**	**NOx**	**Cl**	**NH_3**
ammonia gas	0	0	0	0	0	0	1000000
carbon dioxide/ water	0	0	555000	2	82	0	0
CO_2/ particulates-lime	0	0	990000	0	0	0	0
CO_2/ particulates-DRI	5000	0	990000	0	0	0	0
freon	0	1000000	0	0	0	0	0
CO_2/particulates-steel	105000	0	600000	0	0	0	0
compressor oil		0	0	0	0	0	0
nitrogen	0	0	0	169000	831000	0	0

Table A3.15 Parameters (ppm unless not applicable) of waste materials - **Liquids**

Waste	Plant	PH	COD	Solvents	Oil	Particulates	Particle Size
boiler blowdown	TTMeth	9.4	0	40	0	1000	4
NH_3 cooling water	TTMeth	6.7	380	40	0	87	4
cooling water	Fertrin	7	6	0	6	0	4
gas heating water	PPGP	9.6	0	0	0	0	4
heating water	Fertrin	7	2	0	0	10	4
lubricating oil	TTMeth/ ISPAT	6	3000000	20000	990000	200	3
plant washings	PPGP	4	232	0	60	100000	4
water	PPGP/ Fertrin	6.5	60	120	60	100	2
regenerate	Fertrin	6.7	0	0	0	0	2
regeneration water	TTMeth	8.4	80	0	0	232	2
salt water	Fertrin	5.5	10	0	0	1500	3
sanitary water	PPGP	6	220	150	50	200	4
solvent	TTMeth/ Fertrin	7	3300000	990000	10000	150	4
steel cooling water	ISPAT	7.5	0	0	100	150	4
urea heating water	Fertrin	8.4	0	20	73	50	4
urea process water	Fertrin	8.9	0	15	7	0	3
urea cooling water	Fertrin	7	0	0	0	10	3
process water	TTMeth	10.9	200	18	3	50	3

Waste	Dissolved solids	Heavy metals	PO_4	Sulphate	NH_4	NO_2	Toxics
boiler blowdown	30	0	5.9	0	0	0	0
NH_3 cooling water	360	1	13.8	0	0	0	0
cooling water	2620	82	10	0	1258	0	2620
gas heating water	0	0	5	0	0	0	0
heating water	3	0	2	0	0	0	2
lubricating oil	500	500	0	0	0	0	970000
plant washings	1000	0	0	0	0	0	0
water	300	5	0	0	0	0	65
regenerate	10000	0	0	2500	0	0	0
regeneration water	5600	0.1	11	1110	0	0	0
salt water	30000	0	0	3000	0	0	1800
sanitary water	500	20	0	10	25	0	25
solvent	20	20	0	0	0	0	990000
steel cooling water	500	20	0	20	0	0	0
urea heating water	0	0	0	0	0	0	0
urea process water	13000	7	4	0	4150	22	0
urea cooling water	250	1	13	0	0	0	0
process water	280	4	0	3	0	0	40

Table A3.16 Parameters (ppm unless not applicable) of waste materials - Sludges

Waste	Plant	Water	COD	Solvents	Oil	Particulates	Particle Size	PH
cooling tower sludge	ISPAT	900000	300	0	200	8000	4	7.5
monoethanolamine	Fertrin	0	940000	0	0	50000	4	11
sewage sludge	PPGP	900000	180000	150	100	100000	4	4.5
triethylene glycol	Fertrin	10000	2000000	0	0	50000	4	6

Waste	Toxics	Ash	Iron	Sulphur	Total N	Dissolved solids	Heavy metals
cooling tower sludge	0	60000	7000	140	0	416	1000
monoethanolamine	1000000	100000	0	0	56000	940000	20000
sewage sludge	0	200000	250	20	300	500	20
triethylene glycol	100	50000	0	0	200	1000	100

Table A3.17 Parameters (ppm unless not applicable) of waste materials - Solids

Waste	Plant	Leachate pH	COD	Soluble salts	Particle size	Oil
activated carbon	TTMeth	10	940000	200000	3	0
canister filters	PPGP/Fertrin/TTMeth	5.5	350000	100	5	50000
cesium source	ISPAT	7	0	0	5	0
nickel catalyst	TTMeth		0	0	5	0
dust filters	PPGP		850000	100	5	100
equipment	ISPAT	7	0	0	5	30000
iron oxide	Fertrin	8.5	0	0	5	0
mill scale	ISPAT	5	0	100	5	0
molecular sieve	PPGP/Fertrin/TTMeth		20000	0	5	100
oil filters	ISPAT	6	500000	200	5	500000
paper filters	PPGP		995000	50	5	5000
scrap steel	ISPAT/Fertrin	7	0	0	0	0
spent anion resin	TTMeth/Fertrin		540000	200	5	0
spent cation resin	TTMeth/Fertrin		540000	200	5	0
tires	ISPAT	7	500000	0	5	0
zinc oxide	TTMeth		0	0	5	0

Waste	Heavy metals	Solvent	Iron	Other metals	Paper/Card.	Plastics/Rub.	Ash
activated carbon	4000	0	0	0	0	0	
canister filters	20	50000	595000	0	0	50000	700000
cesium source	1000000	0	0	0	0	0	0
nickel catalyst	1000000	0	0	0	0	0	1000000
dust filters	20	150000	20	200000	0	50000	
equipment	100	0	870000	30000	0	100000	920000
iron oxide	0	0	660000	0	0	0	1000000
mill scale	440	0	72.84	1140	0	0	1000000
molecular sieve	5	20000	0	468000	0	0	
oil filters	250	5000	125000	500	0	125000	250000
paper filters	10	2000	100	0	990000	0	
scrap steel	0	0	950000	50000	0	0	1000000
spent anion resin	0	0	0	0	0	900000	100000
spent cation resin	0	10	0	0	0	900000	100000
tires	0	0	200000	0	0	0	250000
zinc oxide	730000	100000	0	0	0	0	1000000

Appendix 4 Program Inference Engine

A4.1 Program Flow Chart

Main Program

this program selects a waste, determines if it is the same as previous wastes; if so it copies those results; if not it determines if there are any inputs that have the same major components then moves to the treat subroutine; once all inputs are checked, regulation standards are then checked

```
For each waste (Wn) determine if this waste is the same as any previously assessed waste
for each previously assessed waste:
  compare major compounds
  if same
    compare parameters
    if same
      copy all options to temporary option table, with current waste and mass
      using the mass ratios for each treatment for the assessed waste, (Wa) calculate the mass for each
        treatment step for each option
      $M_{Wn2} = (M_{Wa2}/M_{Wa1}) *M_{Wn1}$
      copy the options to the final option table
  if waste is not the same as any assessed waste
    copy waste, mass and plant to temporary option table
    for each input
      compare major components with 'simple' inputs
      if same
        place in temporary option table as 'result'
        compare characteristics
        if same
          copy mass to final mass field
        if not the same
          note characteristics which are different
          find all treatments which change those characteristics for waste state using newlist
            subroutine
          place in potential treatment table
          move to treat subroutine
      find the next input
    continue loop until all inputs are assessed
    for all disposal options selected by user
      compare waste characteristics with disposal characteristics
      if same
        copy mass to final mass field
      if not the same
        determine changes to be made
        find all treatments that change those characteristics for the waste state
        move to treat subroutine
      find next disposal option
    continue loop until all disposal options are assessed
  find next waste
  continue program until all wastes are assessed
```

Treat subroutine

this subroutine determines the changes needed to treat a waste to the selected result; treatments which provide those changes are selected and assessed to determine if their input criteria match the waste; if so they are put into a treatment train and the outputs calculated; these are compared to the result criteria; if they match, the train is placed in the final option file; if not, the treatments to provide needed changes are selected, up to 10 treatments; once all treatments are found, the subroutine returns to the ***main program*** *to test another result*

```
for all records in the temporary option table
  copy waste characteristics to output table
  for up to 10 treatments
    compare treatment input characteristics to output characteristics
    find the number of changes needed by each treatment to fit the waste characteristics using
  findtreat subroutine
    move to last completed record
    move to next record
    calculate treatment output parameters  using check subroutine and place in output table
    if treatment list is empty or the state of the output is different from the input
       generate a new treatment list using newlist subroutine
    compare output parameters with result parameters
    if not same
      determine changes necessary
      empty potential treatment table
      find treatments which will make those changes for output state
      place in potential treatment table
    if same
      record noted as complete
      quit loop
  repeat loop for up to 10 treatments
  if record not complete  and
    (at treatment 10 or mass = 0 or no treatments available or
            material state < > result state and state has changed once before or
            record is longer than previous 3 shortest treatments or
    change result to 'none' or
    note record as complete) then
  empty potential treatment table
  compare treatment options with output records
  remove those outputs which are not in treatment option record
  calculate treatment outputs for last treatment option and place in output table
  compare outputs with result characteristics
  if not same
    determine changes necessary
    find treatments which will make those changes for output state
    place in potential treatment table
if not at end of table
  move to next record in temporary option table
  repeat loop
if at end of table all options have been completed
  delete records with result of "none"
  add temporary option records to final option table
  empty temporary option table
return to main program
```

Findtreat subroutine

this subroutine finds the number of changes needed by each treatment to fit the waste characteristics

```
For up to three loops
  determine the characteristics of each treatment in potential treatment table which must be changed to fit the treatment inputs
  sort the treatments according the number of changes required
  for each treatment which requires no change
    duplicate last temporary option record
    place present treatment in next treatment field
  for treatments requiring < 6 changes
    determine treatments which can provide those changes
    add treatments to end of potential treatment table unless already there
  for treatments requiring > 6 changes
    if the first treatment then no changes are available
      change result to 'none'
      record noted as complete
    exit for another waste (if first treatment) or treatment
  delete all sorted wastes
repeat loop up to three times
return to treat subroutine
```

Newlist subroutine

this subroutine generates a list of treatments which will change the material characteristics which need changing to fit the result

```
if material state is not the same as result state
  find all treatments which treat material state and whose output state includes result state
  add treatments to treatment list
for all parameters
  if material parameter does not lie within result parameters
    find all treatments whose output formulae indicates that parameter is changed that treat material state
    add treatments to treatment list unless already there
  move to next parameter
repeat loop for all parameters
return to either main program or treat subroutine
```

Check subroutine

this subroutine determines the output parameters from a treatment

```
find outputs from treatment - one or two outputs
calculate output parameters using formulae subroutine
if two outputs
  compare each output with result characteristics
  place closer output in output table
  place second output mass in output table
return to treat subroutine
```

Formulae subroutine

this subroutine finds the string to be calculated

```
while right hand bracket can be found
  find first right hand bracket
  find the corresponding left hand bracket
  calculate the value of the bracketed string using calc subroutine
  delete brackets
```

```
repeat until there are no more brackets
calculate the value of the final string using calc subroutine
return to treat subroutine
```

Calc subroutine

this subroutine translates and calculates a formulae from a string

```
while addition or subtraction operator can be found
  locate the first addition or subtraction operator
  separate the string into substrings
    for the first substring segment find the first multiplication or division operator
      calculate the value of the two variables on each side of the operator
    repeat until no more multiplication or division operators
repeat until no more addition or subtraction operators
calculate the final result
return to formulae subroutine
```

Determining the Shortest Treatment Trains

this program finds all shortest, 2nd shortest or 3rd shortest treatment trains

```
n= "3, 2 or 1 shortest train needed?"
open list of treatments
for y from 1 to n
  for each waste
    copy all treatment trains for waste to table 1
    for x from 10 to 1
      if locate treatment(x) = blank then
        add to table 2
        delete record from table 1
        quitloop
      else
        x = x-1
    empty table 1
    find next waste
  y=y+1
```

Determining the Lowest Secondary Wastes

this program finds the trains with lowest, 2nd lowest or 3rd lowest wastes

```
n= "3, 2 or 1 lowest secondary wastes needed?"
open list of treatments
for y from 1 to n
  for each waste
    copy all treatment trains for waste to table 1
    find lowest secondary waste
    select all records with that volume of secondary waste
    add to table 2
    delete selected records from table 1
    empty table 1
    find next waste
  y=y+1
```

Matching Treatment Trains

this program matches treatment trains

```
open table of treatment records (main table)
```

```
select trains where wastes are reused to inputs
copy to reuse table
delete all trains for those wastes
copy all trains that recycle wastes to inputs to table 1
while the main table has records
  while there are records in table 1
    copy from table the greatest number of trains with the same result and treatment
      10 to table 2a
    if there are more than 50 trains in table 2a
      go to treatnine then return
    while there are records in table 2a
      copy trains which have the greatest number of matching treatments to table 3a
      copy trains which have the second greatest number of matching treatments to table 3b
      copy trains which have the third greatest number of matching treatments to table 3c
      delete records of wastes in table 3a from table 2
    delete records of wastes in table 3a from table 1
  delete records of wastes in table 3a from main list
  copy remaining records in main table to table 1
  repeat until all records are deleted from main table
copy records from reuse table to tables 3a, 3b, 3c
select records in table 3a that are not in 3b
copy to table 3b
select records in table 3b that are not in 3c
copy to table 3c
```

Subroutine treatnine

this subroutine selects trains whose treatment nine match
used when the number of trains with matching results and treatment ten are >50

```
select all wastes and ninth treatments
sort by ninth treatments
determine which ninth treatments have the greatest number of records
copy those records to table 2
return to program
```

A4.2 Program Code

This code was written in ObjectPAL, programming code for Paradox.

Main Program

```
Method open(var eventInfo Event); selects all
wastes and compares to all inputs, then
;to final regulations
var
totop, twast, wastes, woption, chwas   table
  fintc, twastc, toutc, wasoptc      TCursor
  swastc, sfinrestc, chwastc         TCursor
  an, stop, notc, wastc, wlistc      TCursor
  optc, tchatc, sinptc, inptc          TCursor
  nout                                   TCursor
  ftreat, ltd                     Array[4] string
  sinp, acc, wasa       DynArray[] Anytype
  x, y, n                                smallint
  perc,  nrec, fieldmin, fieldmax, q  string
  cmp, fn, fstring                       string
  cmp2, state, ans, same, accept, swas, sin,
  optable                                string
  treatdlg, opdlg                       form
  qopt, qtreat                          query
  any, l                              AnyType
  c, num                              longint
  newl                                library
endvar
twastc.open("wastes"); total waste table
twastc.home()
twastc.edit()
tchatc.open("tchar")
tchatc.edit()
n=1
l = 0
same = "yes"
nrec = "no"
end = "no"
num = twastc.nRecords()
optc.open("totop")
optc.home()
notc.open("notreat")
notc.edit()
;find the last waste that was assessed
if not(optc.isEmpty()) or not(notc.isEmpty()) then
  while optc.locate("waste", twastc.waste)
    or notc.locate("waste", twastc.waste)
    or twastc.fate = "offsite waste
      treatment"
    if twastc.atLast() then
      end = "yes"
      quitloop
    else
      twastc.nextrecord()
    endif
  endwhile
endif
optc.close()
notc.close()
while end = "no"
 wasoptc.open("woption")
  if not(wasoptc.isempty()) then
    wasoptc.empty()
  endif
  chwastc.open("chwas")
  if not(chwastc.isempty()) then
    chwastc.empty()
  endif
  chwastc.close()
  twastc.CopyToArray(wasa)
  state = wasa["state"]
  ;copy waste characteristics to arrays
  swastc.open("swas")
  swastc.edit()
  swastc.locate("waste", wasa["waste"])
  swastc.copytoArray(acc)
  swastc.close()
  nout.open("nout")
  if not(nout.isempty()) then
    nout.empty()
  endif
  nout.edit()
  nout.InsertRecord()
  nout.copyfromArray(acc)
  nout.treatment = wasa["waste"]
  nout.mass = wasa["mass"]
  nout.wmass = 0
  nout.PostRecord()
  nout.copyToArray(acc)
  nout.close()
  ;check if this waste is the same as any previous
 waste
  optc.open("totop")
  if not(optc.isEmpty()) then
    optc.edit()
    ans = "no"
    qopt = Query
    totop.db |waste |State1
                  |Check  |check ~state
    endQuery
    executeQBE(qopt)
    an.open(":priv:answer.db"))
    if an.locate("waste", wasa["waste"])
    then
```

```
  same = "yes"
endif
an.home()
while not(an.eot())
  if not(same= "yes") then
    for y from 1 to 4
      ltd[y] = "not"
    endfor
    twastc.locate("waste",
     an.waste, "state", an.state1)
    for x from 1 to 4
      cmp = "comp" + string(x)
      for y from 1 to 4
        if ltd[y] = "not" then
          cmp2 = "comp" + string(y)
          perc="percent"+string(y)
          if (wasa[cmp] = twastc.(cmp2) or
          twastc.(perc) ="")
            then
            same = "yes"
            ltd[y] = "done"
          else
            same = "no"
          endif
        endif
      endfor
      if same = "no" then
        quitloop
      endif
     endfor
     ltd.empty()
   endif
   if same = "yes" then
     if not(an.waste =
        wasa["waste"]) then
       ;check if this waste has the same
       characteristics
       swastc.open("swas")
       swastc.edit()
       swastc.locate("waste", an.waste)
       same = "yes"
       for x from 3 to swastc.nfields()
         fn = swastc.fieldname(x)
         if swastc.(fn) < > acc[fn] then
           same = "no"
           quitloop
         endif
       endfor
     endif
     if same = "yes" then ;wastes are the
 same and can be  handled together
     ;copy to wasoptc, calculate the masses
```

```
       optc.locate("waste",
       an.waste, "state1", an.state1)
 wasoptc.open("woption")
       while not(optc.eot())
         wasoptc.edit()
         wasoptc.InsertRecord()
         wasoptc.copyrecord(optc)
         wasoptc.waste = wasa["waste"]
         wasoptc.plant = wasa["plant"]
         wasoptc.mass1 = wasa["mass"]
         for x from 2 to 10
           if not(optc.("mass"
            +string(x)).isblank()) then
             wasoptc.("mass" +string(x)) =
             (optc.("mass"+string(x))/
             optc.("mass"+string(x-1)))*
             wasoptc.("mass" +string(x-1))
           else
             wasoptc.rmass =(optc.rmass/
             optc.("mass"+string(x-1)))
             *wasoptc.("mass"+string(x-1))
             quitloop
           endif
           wasoptc.PostRecord()
         endfor
         if not(optc.locatenext("waste",
      an.waste, "state1", an.state1)) then
           quitloop
         endif
        endwhile
        wasoptc.add("totop")
        wasoptc.empty()
        nrec = "yes"
        quitloop
      endif
    endif
    an.NextRecord()
  endwhile
  wasoptc.close()
  an.empty()
  an.close()
endif
if nrec = "no" then
  same = "no"
  twastc.locate("waste", wasa["waste"],
"plant", wasa["plant"])
  ;check against all input options
  inptc.open("inputs")
  inptc.edit()
  inptc.locate("inptype", "raw")
  q="no"
  while not(inptc.eot())
```

```
  optc.open("totop")
  optc.home()
  optc.edit()
  numb = inptc.recNo()
  input = inptc.input
  if not(optc.isempty()) or
not(inptc.atFirst()) then
    inptc.locate("input", input)
    while inptc.recNo() < numb
      inptc.MoveToRecNo(numb)
      if not(optc.isempty()) then
        if optc.locate("Waste",
      wasa["waste"], "Result",
  inptc.input) then
          optc.rmass = inptc.mass
           +optc.rmass
        endif
      endif
      if inptc.atLast() then
        quitloop
      else
        if not(inptc.locatenext("inptype",
    "raw")) then
          q = "quit"
          quitloop
        else
          numb = inptc.recNo()
          input = inptc.input
          inptc.locate("input", input)
        endif
      endif
    endwhile
    if q = "quit" then
      quitloop
    endif
  endif
  optc.close()
  s=0
  for y from 1 to 4
    ltd[y] = "not"
  endfor
  for x from 1 to 4
    cmp = "Comp" + string(x)
    for y from 1 to 4
      if ltd[y] = "not" then
        cmp2 = "Comp" + string(y)
        perc="Percent"+string(y)+"min"
        if inptc.(cmp2).isblank() or
      (inptc.(cmp2) = twastc.(cmp) and
  inptc.(perc) > 0) then
          s = s+1
          ltd[y] = "done"
```

```
        endif
      endif
    endfor
    if (s = 4) then
      same = "yes"
      quitloop
    endif
  endfor
  if (same = "yes") then
  ;input components match wastes
  ;consider treatment options
    wasoptc.open("woption")
    if not(wasoptc.locate("result",
inptc.input)) then
      wasoptc.edit()
      wasoptc.InsertRecord()
      wasoptc.waste = twastc.waste
      ;compare the inputs to the waste
      wasoptc.mass = twastc.mass
      wasoptc.plant = twastc.plant
      wasoptc.result = inptc.input
      wasoptc.rstate = inptc.state
      wasoptc.rval = inptc.cost
      wasoptc.PostRecord()
      same = "no"
      sinptc.open("sinp")
      sinptc.locate("input",wasoptc.result)
      sinptc.copytoArray(sinp)
      sinptc.close()
      nout.open("nout")
      nout.edit()
      nout.insertafterRecord()
      nout.CopyfromArray(sinp)
      nout.treatment = sinp["input"]
      nout.PostRecord()
      nout.close()
      newl.open("newlist.lsl")
      same = newl.newlist(state, sinp,
  ftreat)
      switch ;check the treatment files
        case same = "no" :
          wasa["result"] = inptc.RecNo()
          chwastc.open("chwas")
          if not(chwastc.isEmpty()) then
            chwastc.close()
            wasoptc.close()
            treat(sinp)
          else
            if not(wasoptc.isempty()) then
              wasoptc.empty()
            endif
          endif
```

```
        inptc.moveToRecNo(wasa["result"])
          otherwise : ;same = yes
          ; place in treatment list and
      continue;find another input
            optc.open("totop")
            optc.edit()
            optc.InsertRecord()
            optc.copyRecord(wasoptc)
            optc.rmass = optc.mass
            if not(optc.postRecord()) then
              optc.deleteRecord()
            endif
            if not(wasoptc.isempty()) then
              wasoptc.empty()
            endif
            wasoptc.close()
        endswitch
      endif
    endif
    if not(inptc.locatenext("inptype",
    "raw")) or inptc.atLast() then
      quitloop
    endif
    nout.open("nout")
    if not(nout.nrecords() = 1 and
nout.treatment = wasa["waste"]) then
      if not(nout.isempty()) then
        nout.empty()
      endif
      nout.edit()
      nout.InsertRecord()
      nout.CopyFromArray(acc)
    endif
    nout.close()
  endwhile
endif
;all inputs assessed; test disposal options
fintc.open("fresult")
fintc.home()
while not(fintc.eot())
;determine the disposal methods acceptable
  state = wasa["state"]
  wasoptc.open("woption")
  wasoptc.edit()
  if not(wasoptc.isempty()) then
    wasoptc.empty()
  endif
  wasoptc.insertRecord()
  wasoptc.waste = wasa["waste"]
  wasoptc.mass = wasa["mass"]
  wasoptc.plant = wasa["plant"]
  wasoptc.result = fintc.result
```

```
  wasoptc.rstate = fintc.state
  wasoptc.PostRecord()
  tchatc.open("tchar")
  tchatc.edit()
  tchatc.locate("treatment", fintc.result,
"ttype", "R", "state", fintc.state)
  tchatc.copyToArray(sinp)
  sinp["state"] = tchatc.state
  sinp["input"] = tchatc.treatment
  nout.open("nout")
  nout.home()
  nout.edit()
  nout.insertafterRecord()
  nout.copyfromArray(sinp)
  for x from 5 to nout.nfields()
    fn = nout.fieldname(x) + "max"
    nout.(x) = sinp[fn]
  endfor
  nout.treatment = sinp["input"]
  nout.close()
  newl.open("newlist.lsl")
  same = newl.newlist(state, sinp, ftreat)
  if same = "no" then
    chwastc.open("chwas")
    if not(chwastc.isempty()) then
      chwastc.close()
      wasoptc.close()
      treat(sinp)
      ;determine the acceptable treatments
    else
      if not(wasoptc.isempty()) then
        wasoptc.empty()
      endif
    endif
  else ; same = yes so place in totop file
    optc.open("totop")
    optc.edit()
    optc.InsertRecord()
    optc.copyRecord(wasoptc)
    if not(optc.PostRecord()) then
      optc.deleteRecord()
    endif
    if not(wasoptc.isempty()) then
      wasoptc.empty()
    endif
    optc.close()
  endif
  fintc.NextRecord()
  nout.open("nout")
  if not(nout.nrecords() = 1 and
nout.treatment = wasa["waste"]) then
    if not(nout.isempty()) then
```

```
        nout.empty()
      endif
      nout.edit()
      nout.InsertRecord()
      nout.CopyFromArray(acc)
    endif
    nout.close()
  endwhile
  optc.open("totop")
  if not(optc.locate("waste", wasa["waste"])) then
  ;if a result has not been found for this waste
    notc.open("notreat")
    notc.edit()
    notc.insertRecord()
    notc.waste = wasa["waste"]
    notc.plant = wasa["plant"]
    if not(notc.PostRecord()) then
      notc.deleteRecord()
    endif
    notc.close()
  endif
  twastc.locate("waste", wasa["waste"],
  "plant", wasa["plant"])
  if twastc.atLast() then
    end = "yes"
    quitloop
  else
    optc.open("totop")
    notc.open("notreat")
    notc.edit()
    ;find the last waste that was assessed
    twastc.nextrecord()
    while optc.locate("waste", twastc.waste)
      or notc.locate("waste", twastc.waste)
      or twastc.fate="offsite waste treatment"
      if twastc.atLast() then
        end = "yes"
        quitloop
      else
        twastc.nextrecord()
      endif
    endwhile
    notc.close()
    optc.close()
  endif
endwhile
twastc.close()
close("done")
endmethod

proc treat(var sinp DPassAr)
;finds all treatment options for a specified
waste;sinp contains the input characteristics
var
  antc, toutc, nout, wasoptc          TCursor
  chw2tc, inptc, swastc, tchatc       TCursor
  ntreat, wastop, chwas                   table
  count, ans                 Array[] AnyType
  change, k, m, cont, x, n,
  lastmed, per                         smallint
  z, c, lev, low, rec, num, y         longint
  treat,q,ans1,tre,fieldmin, fieldmax  string
  prev, pmin, pmax, keep, exit, swas,
  pre                                  string
  quit, end, fn, mass, state, result   string
  wasno, lasrec                       longint
  ti, any                            AnyType
  para                  DynArray[] AnyType
  func                                library
  ftreat                  Array[10] String
  edat, dat                              Form
  newl                                library
  optc, chwastc , twastc, ntc, stop   TCursor
endvar
ti = time()
tchatc.open("tchar"); this lists input characteristics
of treatments
tchatc.edit()
tchatc.home()
toutc.open("tout")
;this lists formulae for treatment outputs
wasoptc.open("woption")
;temporary file for dumping in waste ;options
prior to being evaluated
wasoptc.edit()
nt = 10
ntreat = create "ntreat.db"
  with "Num" : "N"
  key  "Num"
  endcreate
ntc.open("ntreat")
ntc.edit()
ntc.insertRecord()
ntc.num = 10
ntc.PostRecord()
lasrec = 0
lastreat = "none"
chc = "no"   ;a check stop
change = 0     ;records the number of state
changes in a train
prev = "no"  ;determines if only a state change is
occurring
twastc.open("wastes")
```

```
twastc.edit()
twastc.locate("waste", wasoptc.waste, "plant",
wasoptc.plant)
state = twastc.state
mass = twastc.mass
waste = twastc.waste
wasno = twastc.REcNO()
totno = twastc.NREcords()
twastc.close()
nout.open("nout") ; this holds the calculated
output results from each treatment
nout.edit()
nout.copytoArray(para)
; determine the first treatment input that matches
the waste characteristics
l=0
low=6
n=0
c=0
k=0
;find the number of changes needed by each
treatment to fit the waste characteristics
end = findtreat(c, k, ftreat)
if end = "no" then
  ;all possible first treatments have been   found;
now determine the rest
  ; the first treatment is followed to its   conclusion
  ; then it is backtracked and the second is   then
considered
  wasoptc.home()
  exit = "no"
  k=1
  count.setsize(wasoptc.nfields())
  while not(wasoptc.isempty())
    lev = wasoptc.RecNo()
    while k<= 10 ; this controls the level
    ; check against the final result needed
      wasoptc.("mass"+string(k))=
  para["Mass"]
      wasoptc.("state" + string(k)) =
  para["state"]
      tre ="treat"+string(k)
      ftreat[k] = wasoptc.(tre)
      tchatc.Locate("treatment",
  wasoptc.(tre))
      treat = tchatc.treatment
      dat.open("datadlg")
      ;this prints an update to the screen
      dat.ti1 = time() - ti
      dat.recno1 = lev
      dat.treatn = k
      dat.wasno1 = wasno
      dat.totno1 = totno
      dat.waste1 = wasoptc.waste
      dat.input1 = wasoptc.result
      dat.treat1 = treat
      dat.wait()
      lasrec = lev
      lastreat = treat
      toutc.locate("treatment", treat)
      ; check these results against those of
    the result
      p="n"
      nout.close()
      ans = check(para, sinp, treat, lev)
      y=ans.size()
      nout.home()
      nout.copytoArray(para)
      if ans[1] <> "yes" then
        chw2tc.open("chwas2")
        chw2tc.home()
        if ans[1]="state" and ans.size()=1
        then
          if prev = "no" then
            prev = "yes"
          else
            if state = nout.state then
            ;previous change was also to only
             change the state
              wasoptc.result = "none"
              c = wasoptc.recNO()
              prev = "no"
              quitloop
            endif
          endif
        else
          prev = "no"
        endif
        if chw2tc.isempty() or (state <>
         nout.state and
          not(state = sinp["state"] and change
           <> 0)) then
          ;changing state
          chw2tc.close()
          state = nout.state
          newl.open("newlist.lsl")
          same = newl.newlist(state, sinp,
          ftreat)
          chw2tc.open("chwas2")
          change = k
        endif
        chwastc.open("chwas")
        if ans[1] = "no" or
        ;there was no acceptable result
```

```
 state < > nout.state or
;too many state changes
 k = 10 or
;path is too long
 (ntc.nrecords()=3 and k > nt) or
 nout.mass = 0 or
; no mass left
 chw2tc.isempty() then
; no treatments available
  wasoptc.result = "none"
  c = wasoptc.recNO()
  quitloop
endif
chwastc.edit()
chwastc.empty()
while not(chw2tc.eot())
  while (ftreat.contains
  (chw2tc.treatment)) and
  not(chw2tc.atLast())
    chw2tc.NextRecord()
  endwhile
  if ftreat.contains(chw2tc.treatment)
  and (chw2tc.atLast()) then
    quitloop
  endif
  tchatc.locate("treatment",
  chw2tc.treatment)
  for l from 1 to 2
    if l= 2 then
      if not(tchatc.locatenext
      ("treatment", chw2tc.treatment))
      then
        quitloop
      endif
    endif
    for x from 1 to ans.size()
      if tchatc.(ans[x]).isAssigned()
      and not(tchatc.(ans[x]).isblank())
  and tchatc.(ans[x]) = "y" then
        chwastc.InsertRecord()
        chwastc.copyRecord(chw2tc)
        l=2
        quitloop
      endif
    endfor
  endfor
  chw2tc.NextRecord()
endwhile
chw2tc.close()
chwastc.edit()
chwastc.home()
;determine the treatments required
```

```
  if not(chwastc.isempty()) then
    if chwastc.Locate("treatment",
    wasoptc.(tre)) then
      ; find the treatment and delete it
      chwastc.edit()
      chwastc.deleteRecord()
    endif
    ftreat[k] = wasoptc.(tre)
    nout.close()
    chwastc.close()
    wasoptc.close()
    end = findtreat(c, k, ftreat)
    ;move to subroutine findtreat
    nout.open("nout")
    nout.edit()
    if end = "no" then
      chwastc.open("chwas")
      chwastc.edit()
      while chwastc.locate("nchan", "")
        chwastc.deleteRecord()
      endwhile
      if exit = "yes" then
        quitloop
      endif
      wasoptc.open("woption")
      wasoptc.edit()
      wasoptc.MoveToRecNo(c+1)
      ; now move to last completed
      woption and find fits
      if wasoptc.("treat"+
      string(k+1)).isblank() then
      ;another treatment was not found
        wasoptc.result = "none"
        c=wasoptc.RecNo()
        quitloop
      endif
    else
      c = c+1
      quitloop
    endif
  else
    wasoptc.result = "none"
    c=wasoptc.RecNo()
    quitloop
  endif
  ;consider the next treatment in the list
else ; a match to result was found
  wasoptc.rmass = nout.mass
  wasoptc.wmass = 0
  nout.home()
  while(nout.recNo() <
  nout.nRecords()-1)
```

```
        wasoptc.wmass = nout.wmass +
        wasoptc.wmass
        nout.NextRecord()
      endwhile
      c = wasoptc.recNO()
      if k <> nt then
        while not(ntc.eot())
          if ntc.nrecords() <> 0 then
            if ntc.num = k then
              quitloop
            endif
          endif
          if ntc.atLast() or ntc.nrecords() =0
          then
            ntc.edit()
            ntc.insertRecord()
            ntc.num = k
            ntc.postRecord()
            if ntc.movetoRecNo(4) then
              ntc.deleteRecord()
            endif
            ntc.end()
            nt = ntc.num
            quitloop
          endif
          ntc.NextRecord()
        endwhile
      endif
      quitloop
    endif
    ;refresh chwaste and remove all in ftreat
    nout.home()
    k=k+1
  endwhile
  wasoptc.open("woption")
  wasoptc.edit()
  nout.edit()
  if (wasoptc.MoveToRecNo(c+1)) then
    ; move to next uncompleted train
    ;find the last treatment in the option
    ftreat.empty()
    cont = 1
    eq = "yes"
    while (wasoptc.("treat"+
    string(cont)).isAssigned())
    and not(wasoptc.("treat"+
    string(cont)).isblank())
      ftreat[cont] = wasoptc.("treat"+
      string(cont))
      if eq = "yes" then
        nout.MoveToRecNo(nout.nrecords()-
        (cont+1))
        if not(nout.treatment =
        wasoptc.("treat"+ string(cont))) then
          eq = "no"
          while nout.nrecords() > (cont+1)
            nout.home()
            nout.deleteRecord()
          endwhile
        endif
      endif
      cont=cont+1
      if cont = 11 then
        quitloop
      endif
    endwhile
    k = cont-1
    if change > k then
      change = 0
    endif
    nout.home()
    nout.copytoArray(para)
  else
    quitloop
  endif
  if exit = "yes" then
    quitloop
  endif
  lev = wasoptc.RecNO()
endwhile ; end of woption
nout.end()
while not(nout.bot())
  nout.PriorRecord()
endwhile
nout.edit()
nout.locate("treatment", waste)
nout.copyToArray(para)
nout.empty()
nout.InsertRecord()
nout.copyfromArray(para)
nout.PostRecord()
nout.close()
;delete all unacceptable woption results
; then add to totop, delete woption and  chwas
and exit
edat.open("enddlg")
;this types conclusions to screen
edat.til = time() - ti
edat.trecno = lev
edat.wasno = wasno
edat.totno = totno
edat.waste = wasoptc.waste
edat.input = wasoptc.result
edat.wait()
```

```
  executeQBEFile("qwopt.qbe")
  antc.open(":priv:answer.db")
  if not(antc.isempty()) then
    antc.add("totop")
  endif
  antc.close()
endif ; exit from first section
wasoptc.empty()
chwastc.open("chwas")
if not(chwastc.isempty()) then
  chwastc.empty()
endif
chwastc.close()
chwas.attach("chwas2.db")
chwas.delete()
ntc.close()
ntreat.delete()
return
endproc

proc findtreat(var c longint, var k smallint, var
ftreat PassAr)string
;this subroutine finds the possible treatments
var
  stop, chwastc, nout, tchatc,
  toutc, wasoptc                    tcursor
  chwas                             table
  x, n,m                            smallint
  l, y, rec                         longint
  quit, exit, fn, pmin, pmax        string
  count                       Array[] Anytype
  acc                       Array[47] Anytype
endvar
chwastc.open("chwas")
chwastc.edit()
chwastc.home()
wasoptc.open("woption")
wasoptc.edit()
wasoptc.MoveToRecNO(c+1)
nout.open("nout")
nout.home()
count.setsize(10)
wasoptc.copytoArray(acc)
tchatc.open("tchar")
tchatc.edit()
exit = "no"
n=1
chwastc.locate("nchan", "")
while n<=3 ;continue for three loops
  while not(chwastc.eot())
  ;for all nchan = ""
    tchatc.locate("treatment",
  chwastc.treatment, "state", chwastc.state)
  m=0
  for x from 5 to nout.nfields() ;determine if
the output fits the next treatment
    fn = nout.fieldname(x)
    if nout.(fn).isAssigned() and
    not(nout.(fn).isblank()) then
    pmin = fn + "min"
    pmax = fn +"max"
    if not(tchatc.(pmin).isAssigned()) or
    (tchatc.(pmin).isblank()) then
      tchatc.(pmin) = 0
    endif
    if (tchatc.(pmax).isblank()) then
      switch
      case fn="pH" or fn="LpH" or
         fn="Cor":
           tchatc.(pmax) = 14
      case fn = "COD":
           tchatc.(pmax) = 3300000
      case fn = "PS":
           tchatc.(pmax) = 5
      otherwise:
           tchatc.(pmax) = 1000000
      endswitch
    endif
    if (nout.(fn) < tchatc.(pmin) or
    nout.(fn)>tchatc.(pmax)) then
      if m<6 then
        chwastc.(m+4) = fn
        ;no fit so determine which parameters
        need to change
      endif
      m = m+1
    endif
    endif
  endfor
  chwastc.nchan = m
  chwastc.locatenext("nchan", "")
  m=0
endwhile
chwastc.close()
chwas.attach("chwas")
sort chwas
  on "nchan"
endsort
chwastc.open("chwas")
chwastc.edit()
chwastc.home()
while not(chwastc.eot())
  switch
  case(chwastc.nchan > 6) or
```

```
(chwastc.nchan.isblank()):
  ;more than 6 changes required
  quitloop
case not(chwastc.nchan.isblank()) and
chwastc.nchan = 0 :
  ;this lies within the specified parameters
  ; add treatment to option list
  if not(wasoptc.("treat" +
  string(k+1)).isblank()) then
    wasoptc.insertBeforeRecord()
    wasoptc.copyfromArray(acc)
  endif
  wasoptc.("treat" + string(k+1)) =
  chwastc.treatment
  if chwastc.atLast() then
    quitloop
  else
    chwastc.NextRecord()
  endif
  l = chwastc.recNo()
  ;now calculate and check this against the
  result
 case (chwastc.nchan <=6) :
  toutc.open("tout")
  if chwastc.nRecords() > =
  toutc.nRecords() or n=3 then
    quitloop
  else
    count.setsize(chwastc.nrecords())
    quit = "no"
    chwastc.copytoArray(count)
    rec=chwastc.recNo()
    for x from 4 to (chwastc.nchan +3)
      tchatc.locate("state", nout.state,
      "ttype", "T")
      while not tchatc.eot()
        while chwastc.locate("treatment",
        tchatc.treatment)
          or ftreat.contains(tchatc.treatment)
          if not(tchatc.locatenext("state",
          nout.state, "ttype", "T")) then
            quit = "yes"
            quitloop
          endif
        endwhile
        if quit = "yes" then
          quit = "no"
          quitloop
        endif
        if tchatc.(count[x]).isAssigned() and
        not(tchatc.(count[x]).isBlank())
          and tchatc.(count[x])= "y"  then
            chwastc.edit()
            chwastc.insertRecord()
            chwastc.treatment =
            tchatc.treatment
            chwastc.state = tchatc.state
            chwastc.PostRecord()
            quitloop
          endif
          if not(tchatc.locatenext("state",
          nout.state, "ttype", "T")) then
            quitloop
          endif
        endwhile
      endfor
      chwastc.MoveToRecNo(rec)
      chwastc.nchan = 11
      if not(chwastc.NextRecord()) then
        quitloop
      endif
    endif
  endswitch
 endwhile ; the end of the sort chwas loop
 while chwastc.locate("nchan", "0")
   chwastc.nchan = 10
 endwhile
 if not(chwastc.locate("nchan", "")) then
 ;no more to assess
   if not(chwastc.locate("nchan", "10")) then
 ;no treatments for this result
     wasoptc.result = "none"
     exit = "yes"
   endif
   quitloop
 endif
 n=n+1
endwhile
;all chwastc records have been completed
wasoptc.close()
nout.close()
chwastc.empty()
return(exit)
endproc
```

proc check(var para DPassAr, var sinp DPassAr, var treat string, var lev longint) Pass2Ar

```
;this procedure checks the output against the final
result needed
var
  stop, toutc, nout, sintc             TCursor
  s, z, x                                smallint
  mini, maxi, state, fnam              string
```

```
  sta, sta1, sta2, sta3  DynArray[] AnyType
  ans, ans1, ans2, ans3        Array[] String
  tot                        Array[3] number
  l, num, avg, res                   number
  y, n,f                             longint
  func                                library
endvar
ans1.setsize(35)
ans2.setsize(35)
ans3.setsize(35)
nout.open("nout")
nout.home()
toutc.open("tout")
toutc.edit()
func.open("function.lsl")
sta1.empty()
sta2.empty()
toutc.Locate("treatment", treat)
;find the first output from the treatment
for s from 1 to 3
  sta["state"] = toutc.state
  fstring = toutc.mass
  sta["Mass2"] = func.formulae(fstring, para)
  if sta["Mass2"] < 0 then sta["Mass2"] = 0 endif
;calculate the parameters and dump into nout table
  para["Mass2"] = sta["Mass2"]
  if sta["Mass2"]< >0  then
    for f from 5 to nout.nFields() ;
      fnam = nout.FieldName(f)
      if para[fnam] = 0 then
        sta[fnam] = 0
      else
        fstring = toutc.(fnam)
        if fstring.isAssigned() and
         not(fstring.isblank()) then
          if (fstring.advMatch("[+]") or
          fstring.advMatch("[-]") or
          fstring.advMatch("[*]") or
          fstring.advMatch("[/]") or
          advMatch(fstring, "[A-z]")) = False
          then
            num = number(fstring)
            if not(nout.(fnam).isAssigned()) or
            (nout.(fnam).isBlank()) then
              sta[fnam]=num
            else
              if nout.(fnam) > num or fnam =
              "pH" then
                sta[fnam]=num
              else
                sta[fnam]=nout.(fnam)
              endif
            endif
          else
            sta[fnam] = func.formulae(fstring,
            para)
            switch
              case  sta[fnam] < 0:
                sta[fnam] =0
              case (fnam="pH") and
               sta[fnam]>14 :
                sta[fnam] = 14
              case fnam = "COD" and
              sta[fnam] > 3300000 :
                sta[fnam] = 3300000
              case fnam = "PS" and
              sta[fnam] > 5:
                sta[fnam]= 5
              case sta[fnam] > 1000000  :
                sta[fnam] = 1000000
            endswitch
          endif
        endif
      endif
    endfor
  sta["mass"] = sta["Mass2"]
  switch
    case s=1:
      sta1 = sta
    case s=2:
      sta2 = sta
    case s=3:
      sta3 = sta
  endswitch
  else
    s=s-1
  endif
  sta.empty()
  if not(toutc.locatenext("treatment", treat)) then
    if s=0 then
      ans.setsize(1)
      ans[1] = "no"
    endif
  quitloop
  endif
endfor
if not(ans.contains("no")) then
  nout.edit()
  nout.home()
  nout.InsertBeforeRecord()
  nout.treatment = toutc.treatment
  for x from 1 to s
    y=0
    res=0
```

```
tot[x] = 0
ans.setsize(35)
switch
case x = 1:
  sta=sta1
case x = 2:
  sta=sta2
case x = 3:
  sta=sta3
endswitch
while sta["Mass2"] = 0
  if x=1 then
    if s=2 then
      sta1=sta2
      s=1
      sta = sta2
    else
      if s=3 then
        sta2 = sta3
        s=2
      else
        if s=1 then
          nout.mass = 0
          ans.setsize(1)
          ans[1] = "no"
          quitloop
        endif
      endif
    endif
  endif
  if x=2 then
    if s=3 then
      sta2=sta3
      sta = sta2
      s=2
    else
      quitloop
    endif
  endif
  if x=3 then
    s=2
    quitloop
  endif
endwhile
if sta["state"] <> sinp["state"] then
  y=y+1
  ans[y] = "state"
  tot[x] = 1000 + tot[x]
endif
if not(ans.contains("no")) then
  for z from 5 to nout.nfields()
    res = 0
    fnam = nout.fieldname(z)
    mini = fnam + "min"
    maxi = fnam + "max"
    if sinp[mini].isblank() then
      sinp[mini] =0 endif
    if sinp[maxi].isblank() then
      sinp[maxi] = 1000000 endif
    if (sta.contains(fnam)) then
      if not(sta[fnam].isblank()) then
        ;calculate the final result
        if (sinp[mini] > sta[fnam]) or
        (sinp[maxi] < sta[fnam]) then
          y=y+1
          avg = (sinp[mini] + sinp[maxi])/2
          res=abs((avg-sta[fnam])/100) + 10
          ans[y] = fnam
        .endif
      endif
    else
      res=100
    endif
    tot[x] = res+tot[x]
  endfor
if y=0 then
  tot[x] = 0
endif
ans.setsize(y)
  switch
    case x = 1:
      if tot[1] = 0 or s=1 then
        nout.copyfromArray(sta)
        if s=1 and tot[1]<>0 then
          ans1.setsize(y)
          ans1=ans
          quitloop
        else
          if s=1 and tot[1] = 0 then
            quitloop
          endif
        endif
        if s=2 then ;tot=0
          nout.wmass = sta2["mass"]
        else
          if s=3 then
            nout.wmass = sta2["mass"] +
            sta3["mass"]
          endif
        endif
      else
        ans1.setsize(y)
        ans1=ans
      endif
```

```
      case x = 2:
        if tot[2] = 0 then
          nout.copyfromArray(sta)
          if s=2 then
            nout.wmass = sta1["mass"]
          else
            if s=3 then
              nout.wmass = sta1["mass"] +
              sta3["mass"]
            endif
          endif
          quitloop
        else
          ans2.setsize(y)
          ans2=ans
        endif
      case x = 3:
        if tot[3] = 0 then
          nout.copyfromArray(sta)
          nout.wmass = sta1["mass"] +
          sta2["mass"]
        else
          ans3.setsize(y)
          ans3=ans
        endif
    endswitch
    endif
  endfor
endif
if tot.contains(0) then
  ans.setsize(1)
  ans[1] = "yes"
endif
if not(ans.contains("yes") or ans.contains("no") or
s=1) then
  l=tot[1]
  for x from 2 to s
    l=min(l, tot[x])
  endfor
  if s=2 then
    tot[3]= l+1000
  endif
  switch
    case l=tot[1] and (l< > tot[2]
    and l< > tot[3]):
      nout.copyfromArray(sta1)
      if s=2 then
        nout.wmass = sta2["mass"]
      else
        if s=3 then
          nout.wmass = sta2["mass"] +
          sta3["mass"]
        endif
      endif
      ans.setsize(size(ans1))
      ans = ans1
    case l=tot[2] and (l< > tot[1] and
    l< > tot[3]):
      nout.copyfromArray(sta2)
      if s=2 then
        nout.wmass = sta1["mass"]
      else
        if s=3 then
          nout.wmass = sta1["mass"] +
          sta3["mass"]
        endif
      endif
      ans.setsize(size(ans2))
      ans = ans2
    case l=tot[3] and (l< > tot[1] and
    l< > tot[2]):
      nout.copyfromArray(sta3)
      nout.wmass = sta1["mass"] +
      sta2["mass"]
      ans.setsize(size(ans3))
      ans = ans3
    case l=tot[1]:
      if s=2 or l=tot[2]  then
        if sta1["state"] = sinp["state"] or
        (sta2["state"]< > sinp["state"]
        and sta1["mass"] > sta2["mass"]) then
          nout.copyFromArray(sta1)
          nout.wmass = sta2["mass"]
          if s=3 then
            nout.wmass = nout.wmass +
            sta3["mass"]
          endif
          ans.setsize(size(ans1))
          ans = ans1
        else
          nout.copyFromArray(sta2)
          nout.wmass = sta1["mass"]
          if s=3 then
            nout.wmass = nout.wmass +
            sta3["mass"]
          endif
          ans.setsize(size(ans2))
          ans = ans2
        endif
      else
        if sta1["state"] = sinp["state"] or
        (sta3["state"]< > sinp["state"]
        and sta1["mass"] > sta3["mass"]) then
          nout.copyFromArray(sta1)
```

```
          nout.wmass = sta2["mass"] +
          sta3["mass"]
          ans.setsize(size(ans1))
          ans = ans1
        else
          nout.copyFromArray(sta3)
          nout.wmass = sta1["mass"] +
          sta2["mass"]
          ans.setsize(size(ans3))
          ans = ans3
        endif
      endif
    case l=tot[2]:
      if sta2["state"] = sinp["state"] or
      (sta3["state"]< > sinp["state"]
        and sta2["mass"] > sta3["mass"]) then
        nout.copyFromArray(sta2)
        nout.wmass = sta1["mass"] +
        sta3["mass"]
        ans.setsize(size(ans2))
        ans = ans2
      else
        nout.copyFromArray(sta3)
        nout.wmass = sta1["mass"] +
        sta2["mass"]
        ans.setsize(size(ans3))
        ans = ans3
      endif
    otherwise :
      nout.copyFromArray(sta1)
      nout.wmass = sta2["mass"]
      if s=3 then
        nout.wmass = sta3["mass"]
      endif
      ans.setsize(size(ans1))
      ans = ans1
  endswitch
endif
nout.PostRecord()
nout.close()
return(ans)
endproc
```

Subroutine Newlist - finds the total list of possible treatments for a material

method newlist(var state string, var sinp DPassAr, var ftreat PassAr) string

```
var
  stop, nout, tchatc, toutc, chwastc,
  chw2tc, sinptc                          tcursor
  x                                       longint
  same, fieldmax, fieldmin, fn, quit      string
  wasa                       DynArray[] Anytype
endvar
tchatc.open("tchar")
toutc.open("tout")
chwastc.open("chwas")
chwastc.edit()
if not(chwastc.isempty()) then
  chwastc.empty()
endif
quit = "no"
nout.open("nout") ; find necessary changes
nout.home()
same = "yes"
for x from 4 to nout.nfields()
  if x = 4 then
    if state < > sinp["state"] then
      wasa["state"] = "state"
      same = "no"
    else
      wasa["state"] = "="
    endif
  else
    fn = nout.fieldname(x)
    fieldmin = nout.fieldname(x) + "min"
    fieldmax = nout.fieldname(x) + "max"
    if sinp.contains(fieldmin) then
      if nout.(fn).isAssigned() and
      not(nout.(fn).isblank()) then
        if sinp[fieldmin].isblank() then
          sinp[fieldmin] =0 endif
        if sinp[fieldmax].isblank() then
          sinp[fieldmax] =1000000 endif
        if (sinp[fieldmin]> nout.(fn)) or
        sinp[fieldmax] < nout.(fn) then
          wasa[fn] = fn
          same ="no"
        else
          wasa[fn] = "="
        endif
      endif
    endif
  endif
endfor
if same = "no" then
tchatc.locate("state", state, "ttype", "T")
while not(tchatc.eot())
  while chwastc.locate("Treatment",
  tchatc.treatment) or
  ftreat.contains(tchatc.treatment)
    if not(tchatc.locatenext("state", state,
    "ttype", "T")) then
```

```
      quit = "yes"
      quitloop
    endif
  endwhile
  if quit = "yes" then
    quit = "no"
    quitloop
  endif
  i="no"
  ;determines unique treatments that will be
  effective in treating this waste
  for x from 4 to nout.nFields()
    if x = 4 and state < > sinp["state"] then
      if toutc.locate("treatment",
      tchatc.treatment, "state", sinp["state"])
      then
        i = "yes"
      endif
    else
      if x>4 then
        fn = nout.fieldname(x)
        if not(tchatc.(fn).isBlank()) and
        wasa.contains(fn) then
          if wasa[fn] < > "=" and
          tchatc.(fn)="y" then
            i="yes"
          endif
        endif
      endif
    endif
    if i = "yes" then
      chwastc.edit()
      chwastc.InsertRecord()
      chwastc.treatment = tchatc.treatment
      chwastc.state = tchatc.state
      chwastc.PostRecord()
      quitloop
    endif
  endfor
  if not(tchatc.locatenext("state", state,
  "ttype", "T")) or tchatc.atLast() then
    quitloop
  endif
endwhile
endif
nout.close()
chwastc.copy("chwas2.db")
return(same)
endmethod
```

Subroutine Formulae - Calculating Formulae Strings

```
proc deblank(var fact PassAr)PassAr ;this
removes any blanks
var
  x,y   smallint
endvar
y=1
x=1
for x from 1 to fact.size()
  if (fact[x].isAssigned()) and not(fact[x].isblank())
then
    if fact[x] < > fact[y] then
    fact[y] = fact[x]
    endif
    y=y+1
  endif
endfor
fact.setsize(y-1)
return(fact)
endproc

proc calc(var short string, var para DPassAr)
number
;calculating the formulae string
var
  lfunc, par, func          array[] Anytype
  fact                        array[] Anytype
  s, y,x                      smallint
  num                         number
  int                         longint
  sub, mul, div, add        string
endvar
;find location of function characters
s=short.size()
func.setsize(short.size())
;this holds the function characters
lfunc.setsize(short.size())
;this holds the numbers or variables
fact.setsize(short.size())
x=0
add = "+"
sub = "-"
mul = "*"
div = "/"
y=1
while not(short.isblank())
  x=x+1
  a = short.search(add)
  s = short.search(sub)
  if a<s and a < > 0 or (s=0) then
    l = a
  else
```

```
  l=s
 endif
 m = short.search(mul)
 if (m<l and m <> 0) or (l = 0) then
  l=m
 endif
 d = short.search(div)
 if (d<l and d <> 0) or (l=0) then
  l=d
 endif
 if l=0 then
  quitloop
 endif
 lfunc[x] = l
 func[x] = short.substr(lfunc[x])
 fact[x] = short.substr(1, (lfunc[x])-1)
 if advMatch(fact[x], "[A-z]") = False then
  fact[x] = number(fact[x])
 else
  fact[x] = para[fact[x]]
  ;insert the value of the variable
  com = ","
  c=fact[x].search(com)
  while c <> 0
   fact[x] = fact[x].substr(1, (c-1)) +
   fact[x].substr(c +1, (fact[x].size()-c))
   c=fact[x].search(com)
  endwhile
  fact[x] = number(fact[x])
 endif
 y=lfunc[x]+1
 l=0
 short = short.substr((lfunc[x]+1), short.size()-
(lfunc[x]-1))
endwhile
fact[x] = short
if advMatch(fact[x], "[A-z]") = False then
 fact[x] = number(fact[x])
else
 fact[x] = para[fact[x]]
 com = ","
 c=fact[x].search(com)
 while c <> 0
  fact[x] = fact[x].substr(1, (c-1)) +
fact[x].substr(c +1, (fact[x].size()-c))
  c=fact[x].search(com)
 endwhile
 fact[x] = number(fact[x])
endif
;now number can be calculated
y=2
while func[y-1].isAssigned()
 switch
  case func[y-1] = mul :
   fact[y] = fact[y-1] * fact[y]
   fact[y-1].blank()
   func[y-1].blank()
  case func[y-1] = div :
   if fact[y-1] = 0 or fact[y] = 0 then
    fact[y] = 0
   else
    fact[y] =fact[y-1]/fact[y]
   endif
   fact[y-1].blank()
   func[y-1].blank()
 endswitch
 y=y+1
endwhile
fact = deblank(fact)
func = deblank(func)
;add the numbers
fs=func.size()
y = 2
if func.size()>0 then
 while (y-1) <= fs
  if not(fact[y-1].isblank()) and
  not(fact[y].isblank()) then
   switch
    case func[y-1] = add :
     fact[y] = fact[y-1] + fact[y]
     fact[y-1].blank()
    case func[y-1] = sub :
     fact[y] = fact[y-1]-fact[y]
     fact[y-1].blank()
   endswitch
  endif
 y=y+1
 endwhile
 fact = deblank(fact)
endif
num = fact[1]
return(num)
endproc
```

method formulae(var fstring string, var para DPassAr) number

```
;selects the string within parentheses
var
 rp, lp, x            smallint
 num                   number
 short, l, r          string
endvar
r=")"
l="("
```

```
short = fstring
while advMatch(fstring, "[)]") = True
  rp = fstring.search(r)
  short = fstring.substr(1, rp-1)
  while advMatch(short, "[(]") = True
    lp = short.search(l)
    short =short.substr(lp+1,short.size()-(lp))
  endwhile
  sh = short
  num = calc(short, para)
  ;calculate the value of short
  loc = fstring.search(sh)
  if loc > 2 then
    first = fstring.substr(1,loc-2)
  else
    first = ""
  endif
  if fstring.size()>rp then
    second = fstring.substr(rp+1, fstring.size()-rp)
  else
    second = ""
  endif
  fstring = first + string(num) + second
  short = fstring
endwhile
num = calc(short, para)
return(num)
endmethod
```

Determining the Shortest Treatment Trains

method pushButton(var eventInfo Event)

```
var
  stop, shtc, temtc, to3tc, totc, temp TCursor
  ans, y, x                                smallint
  chk, chkf                                Form
  temt                                     table
  a, q, treat, fin                         string
endvar
ans = 0
a = string(0)
while ans <1 or ans > 3
  a.view("3, 2 or 1 shortest train needed?")
  ;the user specifies which shortest train is needed
  ans = int(a)
endwhile
to3tc.open("totop3")
to3tc.edit()
totc.open("totop2")
totc.home()
temt = create "temp"
  like "totop2"
endcreate
temp.open("temp")
temp.edit()
temp.empty()
temtc.open("tempf")
if not(to3tc.isempty()) then
  to3tc.home()
  temtc.locate("waste", to3tc.waste)
  temtc.nextrecord()
else
  temtc.home()
endif
;this table lists all the wastes
while not(temtc.eot())
  totc.locate("waste", temtc.waste)
  while totc.waste = temtc.waste
    temp.insertRecord()
    temp.copyrecord(totc)
    if not(totc.nextrecord()) then
      quitloop
    endif
  endwhile
  chk.open("ch1fm")
  chk.num = totc.RecNo()
  chk.rec = totc.nrecords()
  chk.waste = temp.waste
  chk.wait()
  temp.PostRecord()
  k = 10
  for y from 1 to ans
    for x from k to 1 step -1
      treat = "treat" + string(x)
      if temp.locate(treat, "") then
        k = x
        while not(temp.eot())
          while temp.(treat).isblank()
            to3tc.InsertRecord()
            to3tc.copyrecord(temp)
            if y <= 3 then
              shtc.open("shtr3")
              shtc.edit()
              shtc.insertrecord()
              shtc.copyrecord(temp)
              shtc.close()
            endif
            if y <= 2 then
              shtc.open("shtr2")
              shtc.edit()
              shtc.insertrecord()
              shtc.copyrecord(temp)
              shtc.close()
```

```
            endif
            if y = 1 then
              shtc.open("shtr1")
              shtc.edit()
              shtc.insertrecord()
              shtc.copyrecord(temp)
              shtc.close()
            endif
            if temp.atLast() then
              temp.deleterecord()
              quitloop
            else
              temp.deleterecord()
            endif
          endwhile
          if not(temp.locatenext(treat, "")) then
            quitloop
          endif
        endwhile
        quitloop
      endif
    endfor
    to3tc.PostRecord()
    if ans < > 3 and y = ans then
      chkf.open("chkfm")
      chkf.tot = to3tc.nrecords()
      fin = chkf.wait()
      if fin = "no" then
        while ans < 1 or ans > 3
          a.view("3, 2 or 1 lowest secondary
          wastes needed?")
          ans = int(a)
        endwhile
      else
        quitloop
      endif
    else
      if y = 3 then
        quitloop
      endif
    endif
  endfor
  temp.empty()
  if temtc.atLast() then
    quitloop
  else
    temtc.nextRecord()
  endif
endwhile
temp.close()
to3tc.empty()
msginfo("Complete", "Shortest trains determined")
to3tc.close()
endmethod
```

Determining the Lowest Secondary Wastes

```
method pushButton(var eventInfo Event)
var
  m2tc,temtc,stop,temp,top3tc,totc Tcursor
  chkf, chk, treatf                    form
  temt                                  table
  a, q, fin                            string
  ans, x, y                              smallint
endvar
ans = 0
a = string(0)
while ans < 1 or ans > 3
;user defines the lowest secondary wastes needed
a.view("3, 2 or 1 lowest secondary wastes
needed?")
  ans = int(a)
endwhile
totc.open("totop2")
top3tc.open("totop3")
temtc.open("tempf")
if not(top3tc.isempty()) then
  top3tc.home()
  temtc.locate("waste", top3tc.waste)
  temtc.nextrecord()
else
  temtc.home()
endif
top3tc.edit()
temt = create "temp"
  like "totop2"
endcreate
temp.open("temp")
temp.edit()
temp.empty()
while not(temtc.eot())
  totc.locate("waste", temtc.waste)
  chk.open("ch1fm")
  chk.num = totc.RecNo()
  chk.rec = totc.nrecords()
  chk.waste = totc.waste
  chk.wait()
  while totc.waste = temtc.waste
    temp.insertRecord()
    temp.copyrecord(totc)
    if not(totc.nextrecord()) then
      quitloop
    endif
  endwhile
```

```
for x from 1 to ans
  temp.home()
  wmass = temp.wmass
  while not(temp.eot())
    while not(temp.eot())
      temp.nextrecord()
      if temp.wmass < wmass then
        wmass = temp.wmass
      endif
      if temp.atlast() then
        quitloop
      endif
    endwhile
    temp.locate("wmass", wmass)
    while temp.wmass = wmass
      top3tc.insertrecord()
      top3tc.copyrecord(temp)
      if x < = 3 then
        m2tc.open("min2w3")
        m2tc.edit()
        m2tc.insertrecord()
        m2tc.copyrecord(temp)
        m2tc.close()
      endif
      if x < = 2 then
        m2tc.open("min2w2")
        m2tc.edit()
        m2tc.insertrecord()
        m2tc.copyrecord(temp)
        m2tc.close()
      endif
      if x = 1 then
        m2tc.open("min2w1")
        m2tc.edit()
        m2tc.insertrecord()
        m2tc.copyrecord(temp)
        m2tc.close()
      endif
      if temp.atLast() then
        temp.deleterecord()
        quitloop
      else
        temp.deleterecord()
      endif
    endwhile
    if not(temp.locatenext("wmass", wmass))
    then
      quitloop
    endif
  endwhile
  top3tc.PostRecord()
  if ans < > 3 and x = ans then
      top3tc.open("totop3")
      chkf.open("chkfm")
      chkf.tot = top3tc.nrecords()
      fin = chkf.wait()
      top3tc.close()
      if fin = "no" then
        while ans < 1 or ans > 3
          a.view("3, 2 or 1 lowest secondary
          wastes needed?")
          ans = int(a)
        endwhile
      else
        quitloop
      endif
    else
      if x = 3 then
        quitloop
      endif
    endif
  endfor
  temp.empty()
  if temtc.atLast() then
    quitloop
  else
    temtc.nextRecord()
  endif
endwhile
temp.close()
;top3tc.open("totop3")
;top3tc.copy("totop2")
top3tc.empty()
msginfo("Complete", "Minimum secondary waste
determined")
top3tc.close()
endmethod
```

Matching Treatment Trains

method pushButton(var eventInfo Event)

```
var
  deltc, extc, optc, rectc, tem3tc, ttc, tem1tc,
  tem2tc                                   TCursor
  restc, rntc, stop, res1tc, tem4tc, temtc,  foptc,
totc                                TCursor
  delrec, res                                      query
  test                         Dynarray[] Anytype
  fopt,tot,tem,del,tempf3,tempf4, exam Table
  treat                                            string
  x, y                                            smallint
  chk2, chck                                        form
  fm                                               number
endvar
```

```
done = "no"
rntc.open("rnumb")
rntc.edit()
tempf3 = create "tempf3"
  like "totop2"
endcreate
exam = create "exam"
  like "totop2"
endcreate
;remove those which can be directly reused
executeQBEFile("delre.qbe")
del.attach(":priv:deleted.db")
del.add("reuse1.db", True, False)
executeQBEFile("delrew.qbe")
if rntc.isempty() then
  rntc.InsertRecord()
  rntc.rnum = 1
endif
totc.open("totop2")
totc.home()
while not(totc.nrecords()=0)
  ttc.open("tot")
  ttc.empty()
  ttc.close()
  ;sort for the first result and treat10
  ;find the result/T10 servicing the most wastes
left in the total file
  rectc.open("recycle")
  rectc.empty()
  rectc.close()
  executeQBEFile("rec1wq.qbe", "recycle")
  rectc.open("recycle")
  if rectc.isempty() then
    done = "yes"
    rectc.close()
    executeQBEFile("stanwq.qbe", "recycle")
    executeQBEFile("delreuq.qbe")
    del.attach(":priv:deleted.db")
    del.add("reuse1.db", True, False)
    executeQBEFile("delrew.qbe")
    rectc.open("recycle")
  endif
  rectc.home()
  rectc.edit()
  while not(rectc.eot())
    while not(totc.locate("waste", rectc.waste,
     "result", rectc.result))
      rectc.deleterecord()
      if rectc.isempty() and done = "no" then
        done = "yes"
        rectc.close()
        executeQBEFile("stanwq.qbe",
        "recycle")
        executeQBEFile("delreuq.qbe")
        del.attach(":priv:deleted.db")
        del.add("reuse1.db", True, False)
        executeQBEFile("delrew.qbe")
        rectc.open("recycle")
        quitloop
      else
        if done = "yes" then
          quitloop
        endif
      endif
      rectc.nextRecord()
    endwhile
    if rectc.isempty() then
      quitloop
    endif
    input = totc.result
    treat = totc.treat10
    res = Query
      totop2.db|waste  |treat10   |Result    |
               |check|check ~treat |check input  |
    endquery
    executeQBE(res, "res1.db")
    res1tc.open("res1")
    tem3tc.open("tempf3")
    if tem3tc.isempty() or
    tem3tc.nrecords()<res1tc.nrecords() then
      tem3tc.close()
      res1tc.copy("tempf3")
    else
      tem3tc.close()
    endif
    res1tc.empty()
    res1tc.close()
    rectc.NextRecord()
  endwhile
  if rectc.isempty() then
    quitloop
  endif
  rectc.close()
  tem3tc.open("tempf3")
  tem3tc.copy("res1")
  tem3tc.empty()
  tem3tc.close()
  totc.close()
  ;copy all trains to tem1 table
  executeQBEFile("train.qbe", "tem1.db")
  totc.open("totop2")
  chck.open("chckfm")
  chck.no = totc.nrecords()
  chck.close()
```

```
temtc.open("tem1")
temtc.home()
if temtc.nrecords() >50 then
  temtc.close()
  treatnine()
endif
extc.open("exam")
if not(extc.isempty()) then
  extc.empty()
endif
temtc.open("tem1")
temtc.home()
temtc.MoveToRecNo(rntc.rnum)
extc.edit()
extc.insertrecord()
extc.copyRecord(temtc)
rntc.edit()
while rntc.rnum <= temtc.nrecords()
  a=temtc.nrecords()
  chk2.open("ch2fm")
  chk2.result = temtc.result
  chk2.treat10 = temtc.treat10
  chk2.waste = temtc.waste
  chk2.num = rntc.rnum
  chk2.rec = a
  chk2.wait()
  temtc.close()
  extc.close()
  executeQBEFile("match.qbe", "tempf4")
  executeQBEFile("delw.qbe")
  temtc.open("tem1")
  temtc.home()
  ;find out the total number of treatments
  ;find num. of treatments
  t=0
  n=0
  tem4tc.open("tempf4")
  tem4tc.home()
  tem4tc.edit()
  while not(n>10)
    ;follow each treatment through
    extc.open("exam")
    if n>0 then
    ;to determine the matching level of the
     waste ;now find the next matching train
    ;use x and switch
      for y from n to 10
        switch
        case y=1:
          if extc.locate("treat1",tem4tc.treat1,
       "treat2", tem4tc.treat2,"treat3",
  tem4tc.treat3,"treat4",tem4tc.treat4,
          "treat5", tem4tc.treat5,"treat6",
          tem4tc.treat6,"treat7",tem4tc.treat7,
          "treat8", tem4tc.treat8,"treat9",
          tem4tc.treat9,"treat10",
          tem4tc.treat10) then
            n=y
            quitloop
          endif
        case y=2:
          if extc.locate("treat2",tem4tc.treat2,
          "treat3",tem4tc.treat3,"treat4",
          tem4tc.treat4,"treat5",tem4tc.treat5,
          "treat6",tem4tc.treat6, "treat7",
          tem4tc.treat7,"treat8",tem4tc.treat8,
      "treat9", tem4tc.treat9, "treat10",
          tem4tc.treat10) then
            n=y
            quitloop
          endif
        case y=3:
          if extc.locate("treat3",tem4tc.treat3,
          "treat4",tem4tc.treat4,"treat5",
          tem4tc.treat5,"treat6",tem4tc.treat6,
      "treat7",tem4tc.treat7,"treat8",
          tem4tc.treat8,"treat9",tem4tc.treat9,
          "treat10", tem4tc.treat10) then
            n=y
            quitloop
          endif
        case y=4:
          if extc.locate("treat4",tem4tc.treat4,
          "treat5", tem4tc.treat5,"treat6",
          tem4tc.treat6,"treat7",tem4tc.treat7,
          "treat8",tem4tc.treat8,"treat9",
          tem4tc.treat9,"treat10",
          tem4tc.treat10) then
            n=y
            quitloop
          endif
        case y=5:
          if extc.locate("treat5",tem4tc.treat5,
      "treat6", tem4tc.treat6,"treat7",
          tem4tc.treat7,"treat8",tem4tc.treat8,
          "treat9",tem4tc.treat9, "treat10",
          tem4tc.treat10) then
            n=y
            quitloop
          endif
        case y=6:
          if extc.locate("treat6",tem4tc.treat6,
          "treat7",tem4tc.treat7,"treat8",
          tem4tc.treat8,"treat9",tem4tc.treat9,
```

```
    "treat10", tem4tc.treat10) then
      n=y
      quitloop
    endif
  case y=7:
    if extc.locate("treat7",tem4tc.treat7,
"treat8", tem4tc.treat8, "treat9",
    tem4tc.treat9,"treat10",
    tem4tc.treat10) then
      n=y
      quitloop
    endif
  case y=8:
    if extc.locate("treat8",tem4tc.treat8,
"treat9", tem4tc.treat9,"treat10",
    tem4tc.treat10) then
      n=y
      quitloop
    endif
  case y=9:
    if extc.locate("treat9",tem4tc.treat9,
    "treat10", tem4tc.treat10) then
      n=y
      quitloop
    endif
  otherwise:
    n=10
    quitloop
  endswitch
 endfor
else
 n=12
endif
;now determine the number of treatments
for x from n to 1 step-1
  if x = 12 then
    x=10
  endif
  treat = "treat" + string(x)
  if not(tem4tc.(treat).isblank()) then
    t = t+1
  else
    quitloop
  endif
endfor
if n<=10 then
  extc.edit()
  extc.insertRecord()
  extc.copyRecord(temtc)
  ;add all the same treatments to t4 table
  temtc.close()
  extc.close()
```

```
    executeQBEFile("delmat.qbe")
deltc.open(":priv:deleted.db")
    deltc.add("tempf4", True, False)
    tem4tc.locate("waste", deltc.waste)
    tem4tc.close()
    deltc.close()
    ;delete all wastes found in T4
    executeQBEFile("delw.qbe")
    tem4tc.open("tempf4")
    tem4tc.home()
    tem4tc.edit()
    ;now find the next treatment
    temtc.open("tem1")
    temtc.home()
    ;add this to exam table
    if not(temtc.isempty()) then
      extc.open("exam")
      extc.edit()
      extc.InsertRecord()
      extc.copyRecord(temtc)
      extc.close()
     endif
   endif
   n=x+1
   if temtc.nrecords() = 0 then
     temtc.close()
     executeQBEFile("train.qbe",
     "tem1.db")
     executeQBEFile("delw.qbe")
     temtc.open("tem1")
     if not(temtc.nrecords() = 0) and
     temtc.nrecords()>50 then
       treatnine()
     endif
     if temtc.nrecords() = 0 then
       quitloop
     endif
    endif
  endwhile
  ;calculate mass/treatment ratio
  tem4tc.home()
  fm = 0
  while not(tem4tc.eot())
    fm = fm + (tem4tc.mass-tem4tc.wmass)
    tem4tc.nextrecord()
  endwhile
  fm = fm/t
  ttc.open("tot")
  ttc.edit()
  t=0
  ;first determine if this option is the same
  as any other
```

```
if not(ttc.isempty()) then
  tem3tc.open("tempf3")
  tem3tc.empty()
  tem3tc.close()
  for x from 1 to ttc.nrecords()
    optc.open(ttc.option)
    optc.copy("tempf3")
    optc.close()
    tem4tc.close()
    executeQBEFile("comp.qbe","tempf3")
    ;compares t4 and t3
    tem3tc.open("tempf3")
    tem4tc.open("tempf4")
    if tem3tc.nrecords()=tem4tc.nrecords()
    then
      ;if same then move on
      next = "yes"
      tem4tc.empty()
      quitloop
    else
      next = "no"
      tem3tc.empty()
    endif
    tem3tc.close()
  endfor
else
  next = "no"
endif
if next = "no" then
  k = ttc.nrecords()+1
  ttc.insertRecord()
  ttc.fmass = fm
  op = string(k)+ "option"
  sort("tot.db")
    on "fmass" D
  endsort
  if ttc.nrecords()<4 then
    ttc.option = op
  else
    ttc.MoveToRecNo(4)
    if not(ttc.option.isblank()) then
      op = ttc.option
    endif
    ttc.deleterecord()
    ttc.locate("option", "")
    ttc.option = op
  endif
  tem4tc.copy(op)
endif
ttc.close()
tem4tc.close()
tempf4.attach("tempf4")
```

```
  tempf4.delete()
  ;now refresh tem1 table
  temtc.close()
  executeQBEFile("train.qbe", "tem1.db")
  temtc.open("tem1")
  if temtc.nrecords() > 50 then
    temtc.close()
  executeQBEFile("train2.qbe","tem1.db")
    temtc.open("tem1")
  endif
  extc.open("exam")
  extc.edit()
  extc.empty()
  temtc.open("tem1")
  while rntc.rnum <= temtc.nrecords()
    rntc.rnum = rntc.rnum+1
    if not(temtc.MoveToRecNo(rntc.rnum))
    then
      quitloop
    endif
    extc.insertRecord()
    extc.copyRecord(temtc)
    temtc.locate("treat1",extc.treat1,
    "treat2"extc.treat2,"treat3",extc.treat3,
"treat4",extc.treat4,"treat5",extc.treat5,
    "treat6",extc.treat6,"treat7",extc.treat7,
    "treat8",extc.treat8,"treat9",extc.treat9,
"treat10",extc.treat10)
    if rntc.rnum = temtc.recno() then
      quitloop
    else
      extc.empty()
    endif
    if rntc.rnum > temtc.nrecords() then
      quitloop
    endif
  endwhile
  rntc.PostRecord()
endwhile
;wastes option found for that result
;delete wastes from main table
optc.open("1option")
optc.home()
totc.home()
totc.edit()
while not(optc.eot())
  while totc.locate("waste", optc.waste)
    totc.deleterecord()
    totc.home()
  endwhile
  optc.NextRecord()
endwhile
```

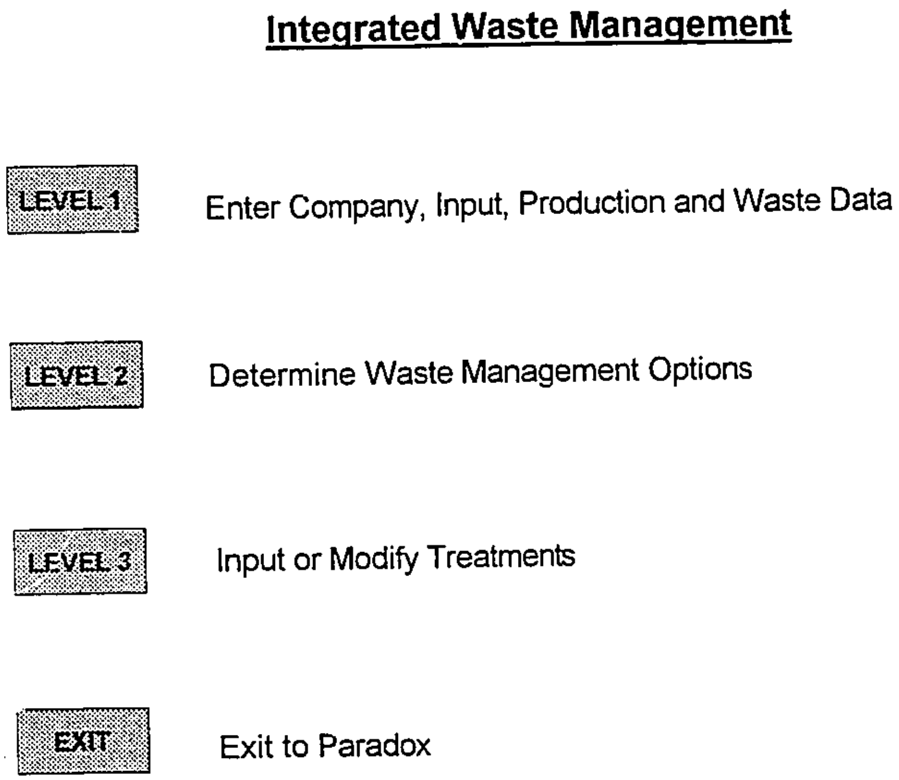
```
  optc.close()
  ;copy to final option tables
  for x from 1 to 3
    op = string(x) + "option"
    fop = string(x) + "fopt"
    foptc.open(fop)
    foptc.edit()
    optc.open(op)
    optc.add(foptc, True, False)
    optc.empty()
    optc.close()
    foptc.close()
  endfor
  ;find another result
  rntc.rnum = 1
  rntc.PostRecord()
  temtc.close()
  tem3tc.open("tempf3")
  tem3tc.empty()
  tem3tc.close()
endwhile
;this adds the common trains and reuseable wastes
to the final options so each
;option should have trains for all wastes
rectc.open("reuse1")
for x from 1 to 3
  fop = string(x) + "fopt"
  rectc.add(fop, True, False)
  switch
  case x = 2:
    executeQBEFile("fop1q.qbe")
    fopt.attach(":priv:answer.db")
    fopt.add("fopt2.db", True, False)
  case x = 3:
    executeQBEFile("fop2q.qbe")
    fopt.attach(":priv:answer.db")
    fopt.add("fopt3.db", True, False)
  endswitch
  fopt.attach(fop)
  sort fopt
    on "Result" D, "treat10" D, "treat9" D,
    "treat8" D, "treat7" D, "treat6" D,
    "treat5" D, "treat4" D, "treat3" D,
    "treat2" D, "treat1" D
  endsort
endfor
rectc.close()
rntc.empty()
rntc.close()
tem.attach("tem1")
tem.delete()
tem.attach("tempf1")
tem.delete()
tem.attach("tempf2")
tem.delete()
rectc.open("recycle")
rectc.empty()
rectc.close()
rectc.open("reuse1")
rectc.empty()
rectc.close()
extc.open("exam")
extc.empty()
extc.close()
endmethod

proc treatnine() ;this subroutine selects trains
whose treatment nine match
;used when the number of trains with matching
results and treatment ten are >50
var
  stop, wltc, wl2tc, temtc, restc      TCursor
  fin, res, tre                        Query
  totlist, wlist, wlist2, rest         Table
  tot                                  longint
endvar
res = Query
  tem1.db|waste  |treat9|
         |check |check |
endquery
executeQBE(res, "res2.db")
restc.open("res2")
restc.home()
a = restc.nrecords()
totlist = create "wlist2"
  with "treat9" : "A35", "total" :"N"
endcreate
q="no"
while not(restc.eot())
  n=restc.RecNo()
  treat9 = restc.treat9
  restc.close()
  tre = Query
  res2.db    |waste |treat9   |
             |check |~treat9  |
  endquery
  executeQBE(tre, "wlist.db")
  wltc.open("wlist")
  wl2tc.open("wlist2")
  wl2tc.edit()
  wl2tc.insertRecord()
  wl2tc.treat9 = treat9
  wl2tc.total = wltc.nrecords()
  wl2tc.close()
```

```
  wltc.empty()
  wltc.close()
  restc.open("res2")
  if restc.atLast() then
    quitloop
  endif
  restc.MoveToRecNo(n+1)
  while restc.treat9 = treat9
    if restc.AtLast() then
      q="yes"
      quitloop
    endif
    restc.nextrecord()
  endwhile
  if q="yes" then
    quitloop
  endif
endwhile
sort "wlist2"
  on "Total" D
endsort
wl2tc.open("wlist2")
wl2tc.home()
tot = wl2tc.total
treat9 = wl2tc.treat9
wl2tc.close()
fin = Query
wlist2.db  |treat9|total      |
           |check |check~tot  |
  endquery
executeQBE(fin, "wlist2.db")
executeQBEFile("match3", "tem1")
temtc.open("tem1")
a = temtc.nrecords()
temtc.close()
restc.close()
rest.attach("res2")
rest.delete()
wlist.attach("wlist")
wlist.delete()
return
endproc
```

Appendix 5 **Data Input Forms**

The following figures show most of the data forms which make up the KBDSS. Those that have not been included are those which are similar to ones shown here or are small inset forms which request the user to wait while the program runs. Further refinements of the system require some upgrading to increase its user-friendliness and to improve on data display.



Integrated Waste Management

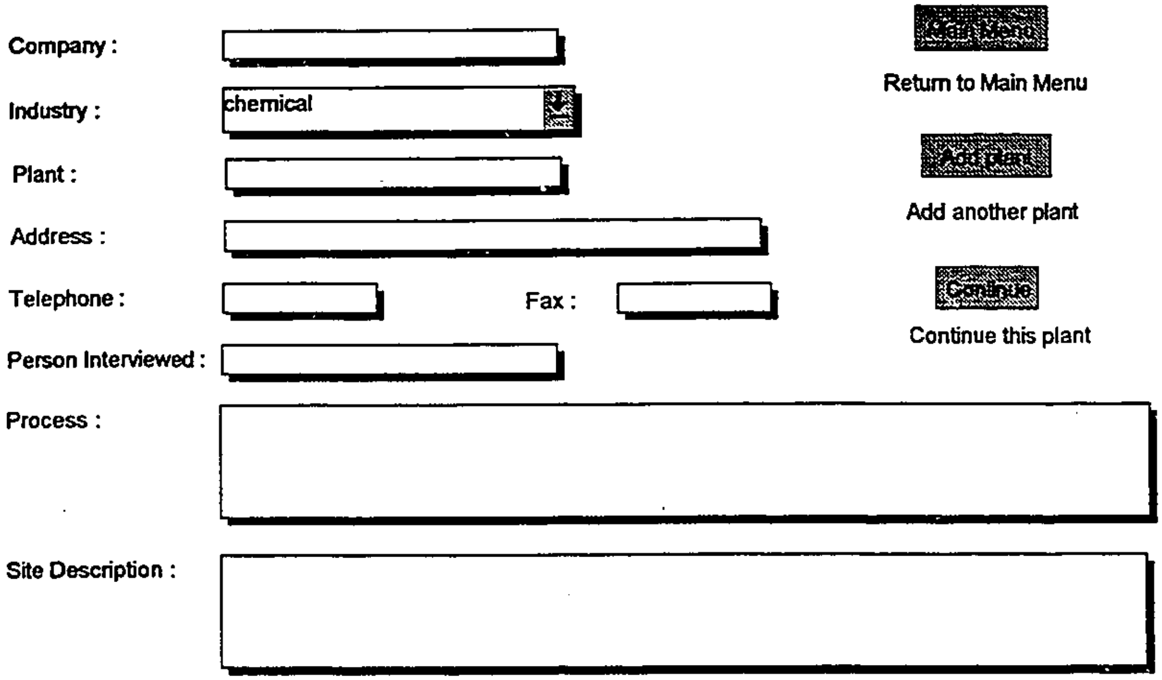
LEVEL 1 Enter Company, Input, Production and Waste Data

LEVEL 2 Determine Waste Management Options

LEVEL 3 Input or Modify Treatments

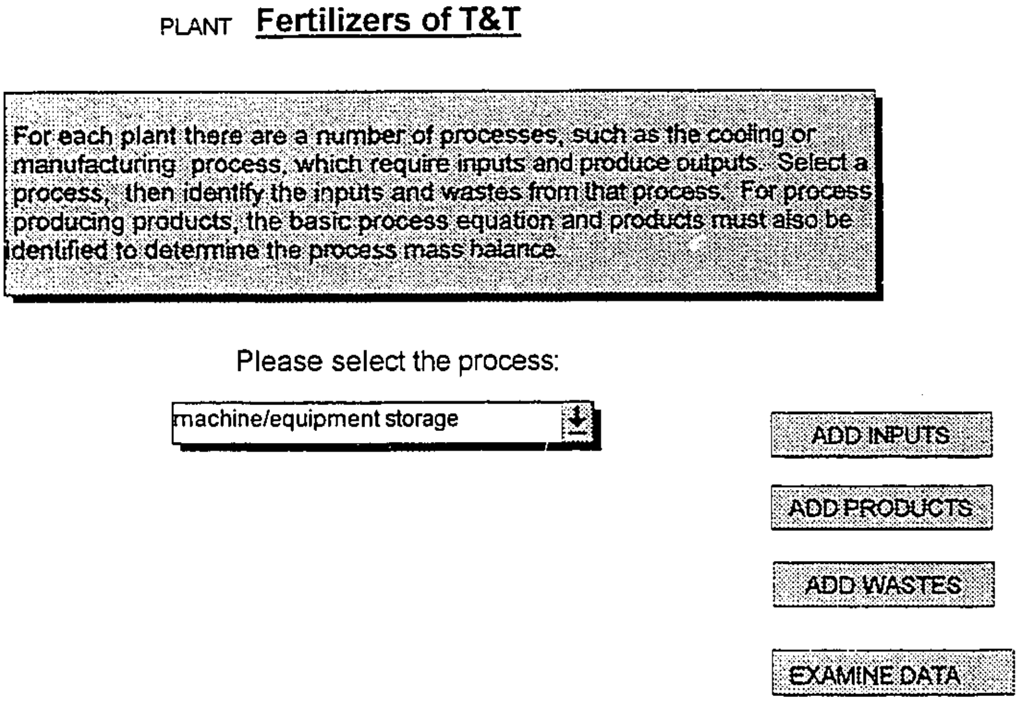
EXIT Exit to Paradox

Figure A5.1 Main Menu.



Industry : chemical

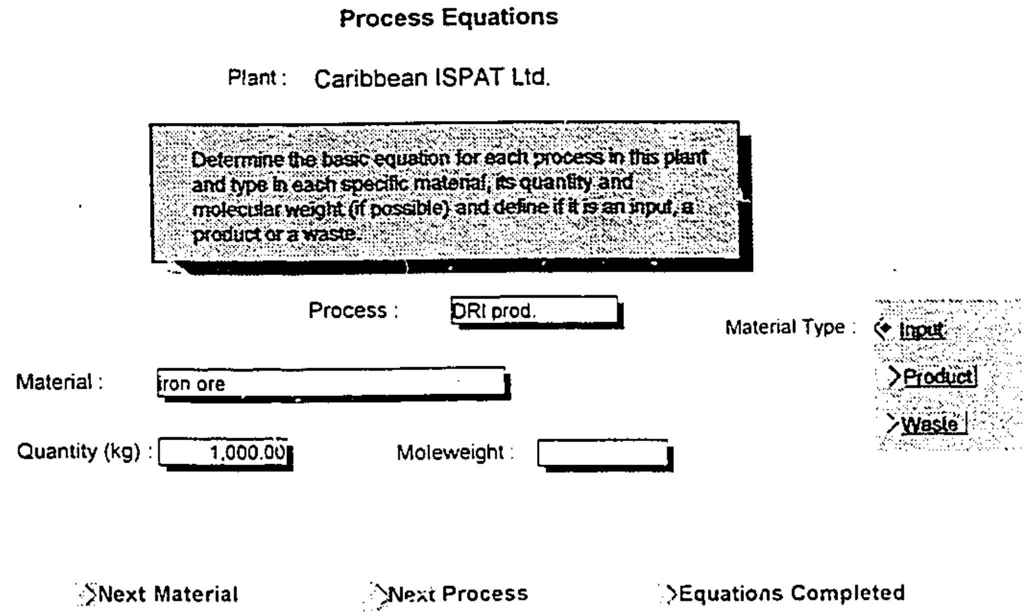
Figure A5.2 Input form for company data


PLANT Fertilizers of T&T

For each plant there are a number of processes, such as the cooling or manufacturing process, which require inputs and produce outputs. Select a process, then identify the inputs and wastes from that process. For process producing products, the basic process equation and products must also be identified to determine the process mass balance.

Please select the process: machine/equipment storage

Figure A5.3 Selection of process



Process Equations

Plant : Caribbean ISPAT Ltd.

Determine the basic equation for each process in this plant and type in each specific material, its quantity and molecular weight (if possible) and define if it is an input, a product or a waste.

Process : DRI prod.

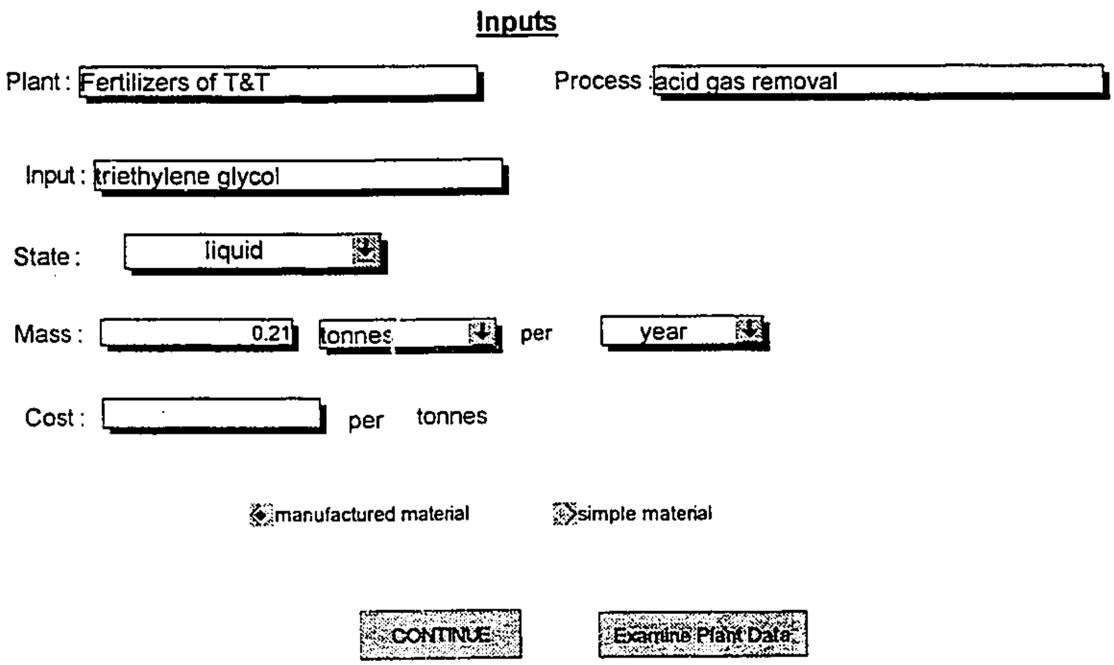
Material : iron ore

Quantity (kg) : 1,000.00

Moleweight :

Material Type : ● Input ○ Product ○ Waste

Figure A5.4 Defining manufacturing processes



Inputs

Plant : Fertilizers of T&T

Process : acid gas removal

Input : triethylene glycol

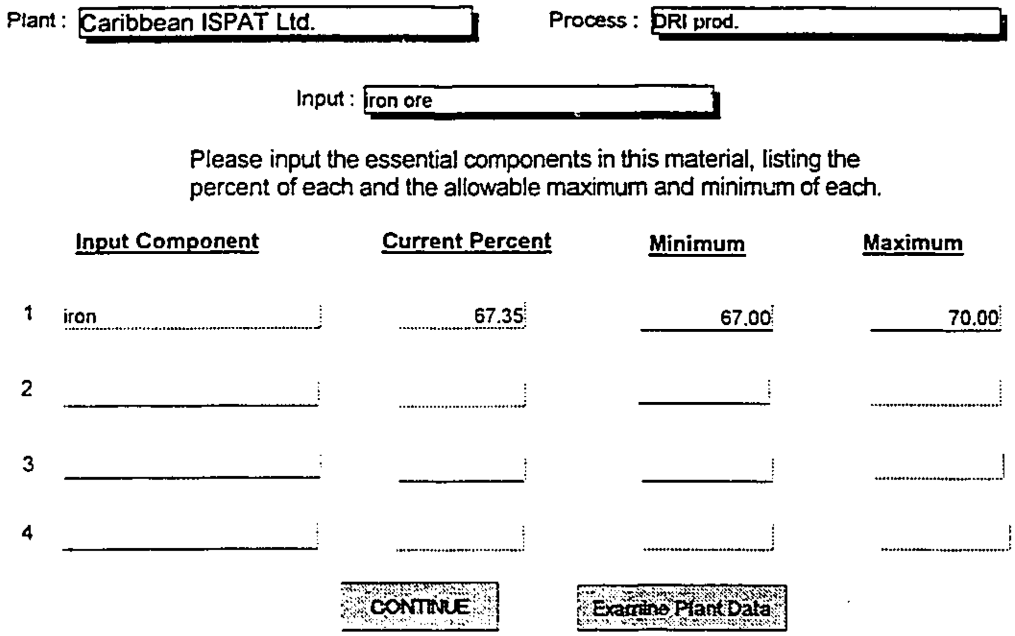
State : liquid

Mass : 0.21 tonnes per year

Cost : per tonnes

● manufactured material ○ simple material

Figure A5.5 General data form for inputs



Plant : Caribbean ISPAT Ltd.

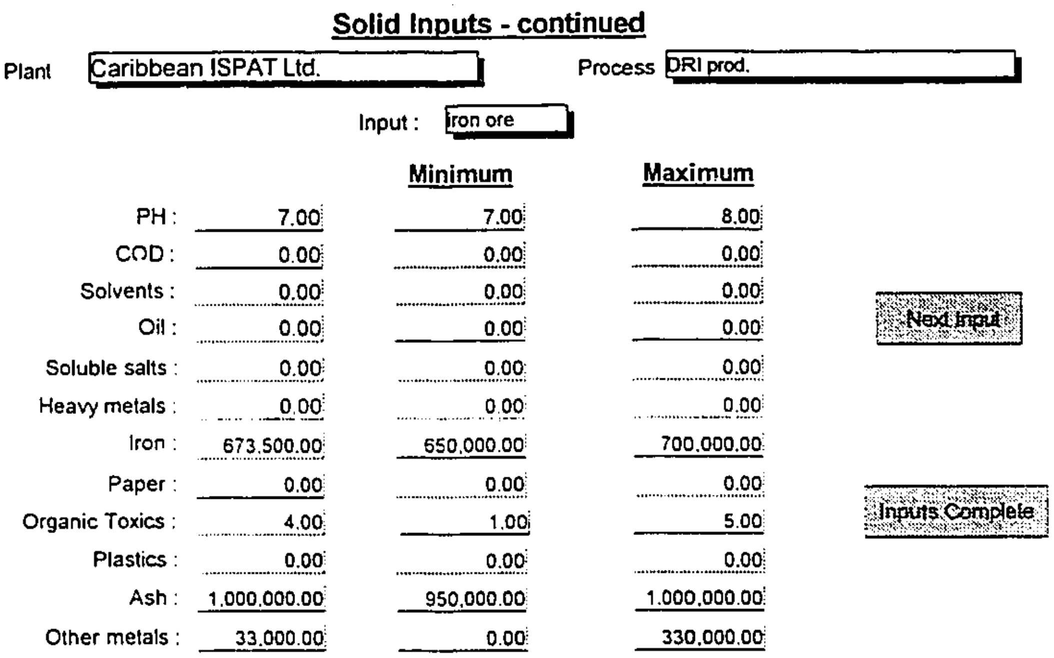
Process : DRI prod.

Input : iron ore

Please input the essential components in this material, listing the percent of each and the allowable maximum and minimum of each.

	Input Component	Current Percent	Minimum	Maximum
1	iron	67.35	67.00	70.00
2				
3				
4				

Figure A5.6 General data form for inputs - form 2



Solid Inputs - continued

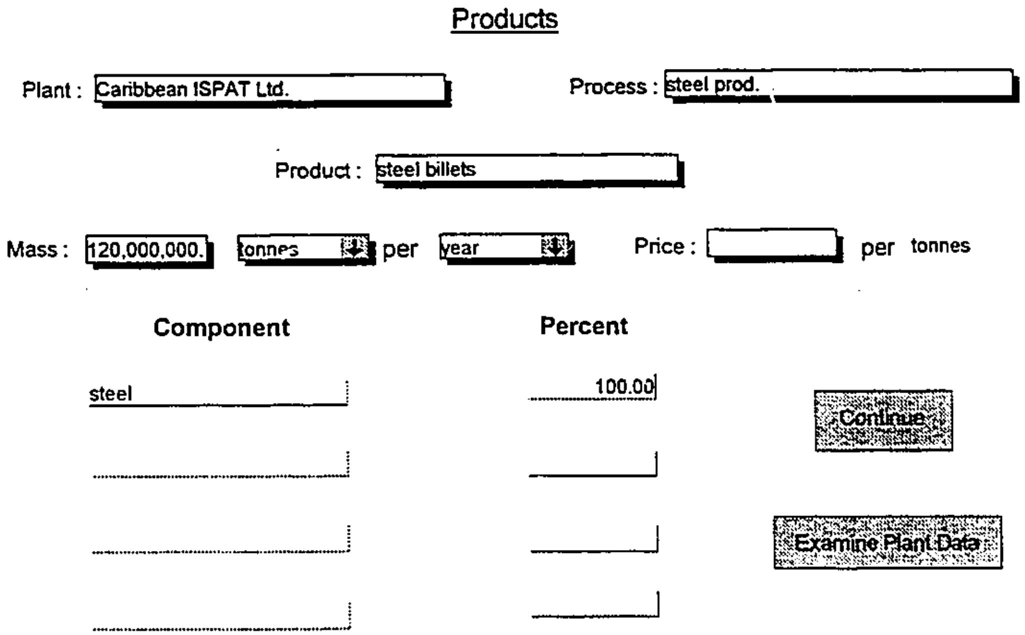
Plant Caribbean ISPAT Ltd.

Process DRI prod.

Input : iron ore

		Minimum	Maximum
PH :	7.00	7.00	8.00
COD :	0.00	0.00	0.00
Solvents :	0.00	0.00	0.00
Oil :	0.00	0.00	0.00
Soluble salts :	0.00	0.00	0.00
Heavy metals :	0.00	0.00	0.00
Iron :	673,500.00	650,000.00	700,000.00
Paper :	0.00	0.00	0.00
Organic Toxics :	4.00	1.00	5.00
Plastics :	0.00	0.00	0.00
Ash :	1,000,000.00	950,000.00	1,000,000.00
Other metals :	33,000.00	0.00	330,000.00

Figure A5.7 Data form for parameters of solid inputs.



Products

Plant : Caribbean ISPAT Ltd.

Process : steel prod.

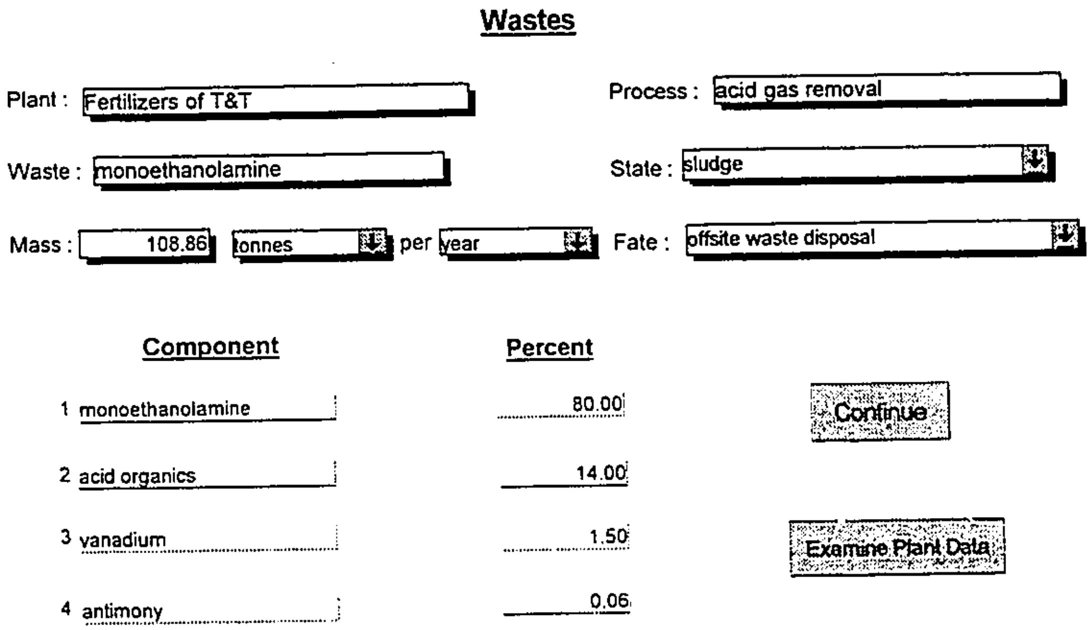
Product : steel billets

Mass : 120,000,000. tonnes per year

Price : per tonnes

Component	Percent
steel	100.00

Figure A5.8 Data input form for products



Wastes

Plant : Fertilizers of T&T

Process : acid gas removal

Waste : monoethanolamine

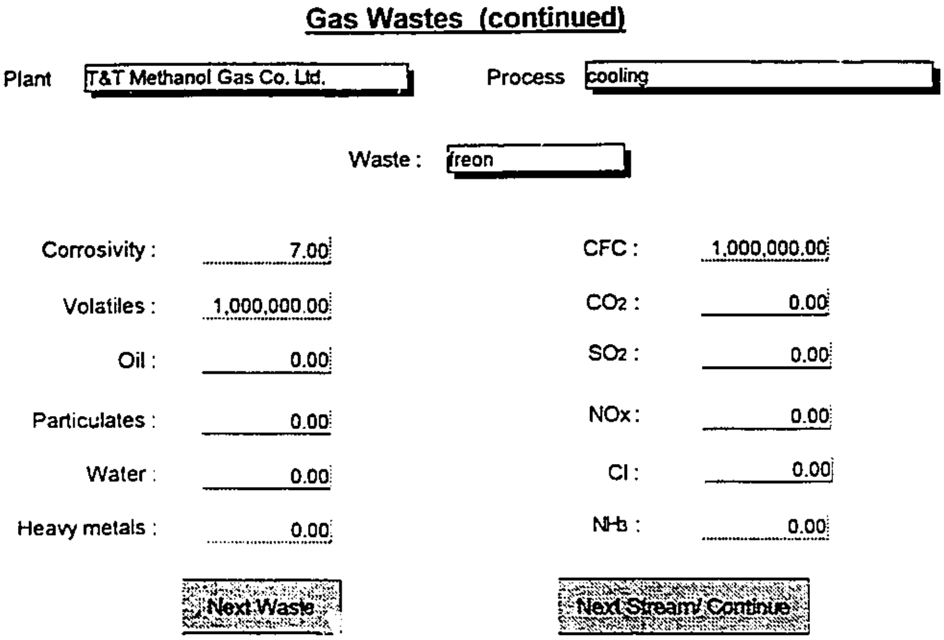
State : sludge

Mass : 108.86 tonnes per year

Fate : offsite waste disposal

	Component	Percent
1	monoethanolamine	80.00
2	acid organics	14.00
3	vanadium	1.50
4	antimony	0.06

Figure A5.9 General data input form for wastes.



Gas Wastes (continued)

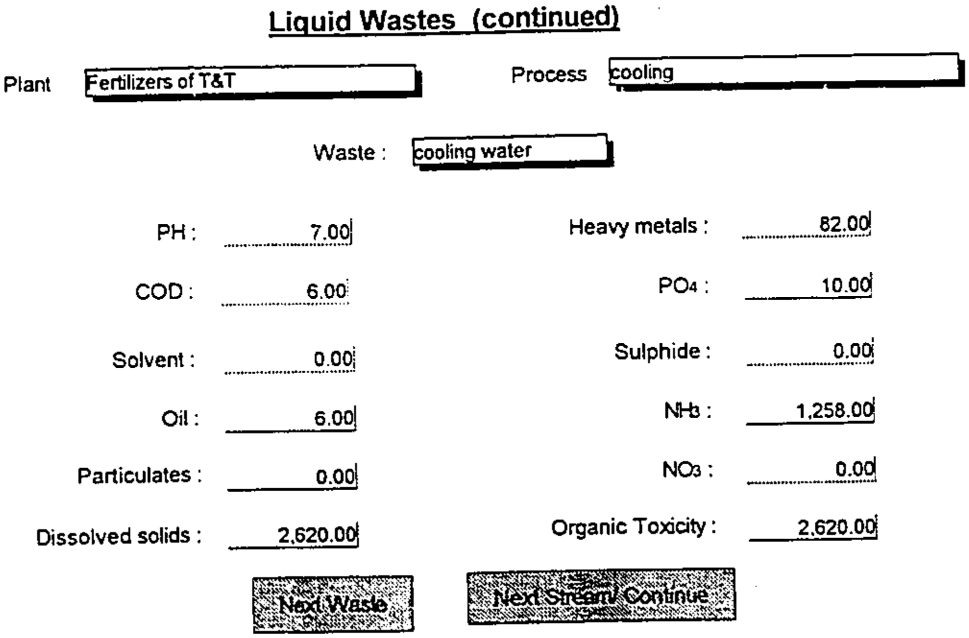
Plant: T&T Methanol Gas Co. Ltd.
Process: cooling

Waste : freon

Corrosivity : 7.00
Volatiles : 1,000,000.00
Oil : 0.00
Particulates : 0.00
Water : 0.00
Heavy metals : 0.00

CFC : 1,000,000.00
CO_2 : 0.00
SO_2 : 0.00
NOx : 0.00
Cl : 0.00
NH_3 : 0.00

Figure A5.10 Data input form for parameters of gas wastes



Liquid Wastes (continued)

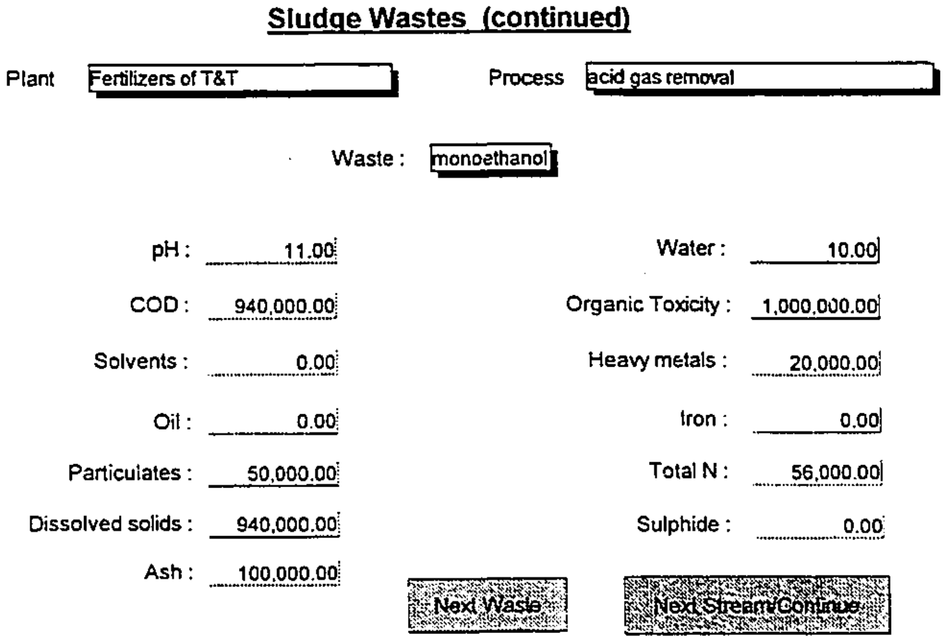
Plant: Fertilizers of T&T
Process: cooling

Waste : cooling water

PH : 7.00
COD : 6.00
Solvent : 0.00
Oil : 6.00
Particulates : 0.00
Dissolved solids : 2,620.00

Heavy metals : 82.00
PO_4 : 10.00
Sulphide : 0.00
NH_3 : 1,258.00
NO_3 : 0.00
Organic Toxicity : 2,620.00

Figure A5.11 Data input form for parameters of liquid wastes.



Sludge Wastes (continued)

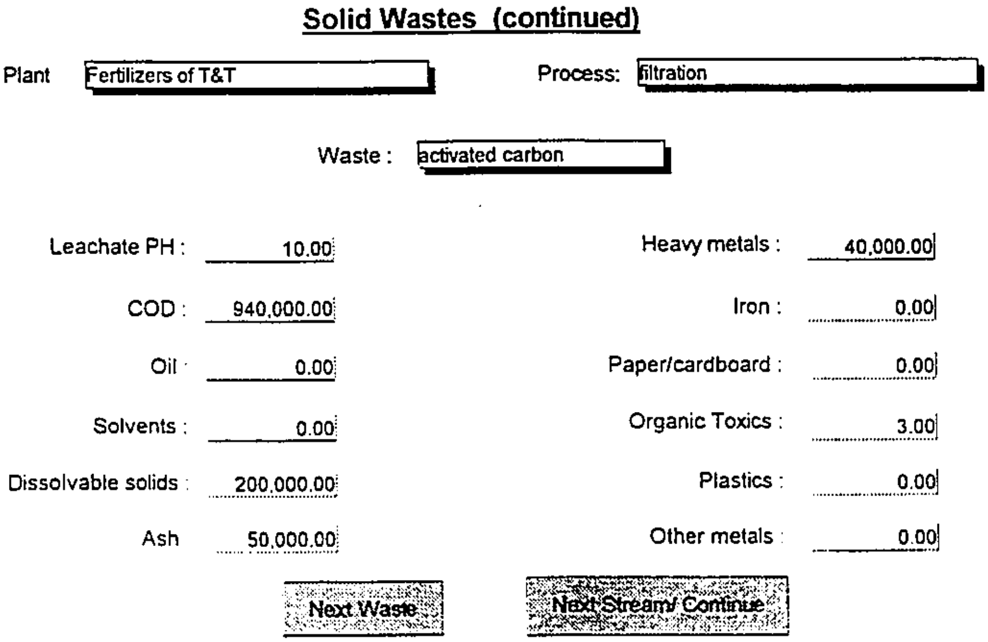
Plant Fertilizers of T&T

Process acid gas removal

Waste : monoethanol

pH :	11.00	Water :	10.00
COD :	940,000.00	Organic Toxicity :	1,000,000.00
Solvents :	0.00	Heavy metals :	20,000.00
Oil :	0.00	Iron :	0.00
Particulates :	50,000.00	Total N :	56,000.00
Dissolved solids :	940,000.00	Sulphide :	0.00
Ash :	100,000.00		

Figure A5.12 Data input form for parameters of sludge wastes



Solid Wastes (continued)

Plant Fertilizers of T&T

Process: filtration

Waste : activated carbon

Leachate PH :	10.00	Heavy metals :	40,000.00
COD :	940,000.00	Iron :	0.00
Oil	0.00	Paper/cardboard :	0.00
Solvents :	0.00	Organic Toxics :	3.00
Dissolvable solids :	200,000.00	Plastics :	0.00
Ash	50,000.00	Other metals :	0.00

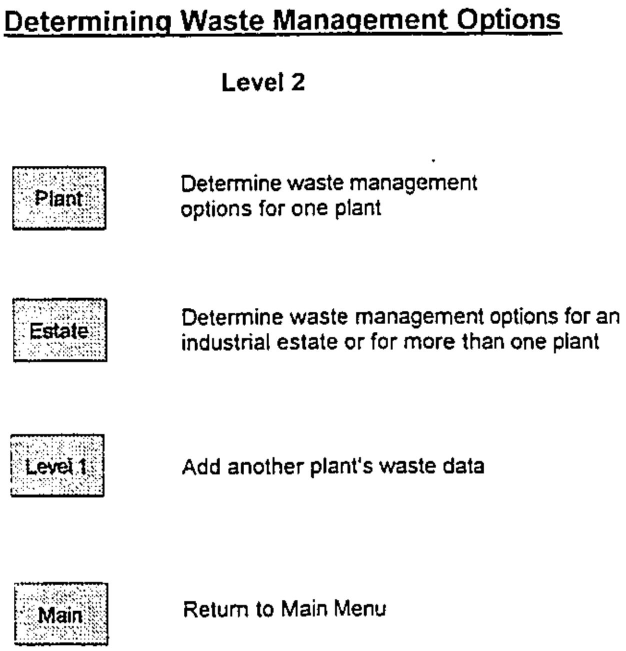
Figure A5.13 Form showing mass balance of inputs, products and wastes.

Please select a plant from the following list:

- T&T Methanol Gas Co. Ltd.
- Caribbean Safety Products Ltd.
- Central Trinidad Steel Ltd.
- Ceramic Designs Ltd.
- Cien Chemicals
- Steel Containers Ltd.
- Fertilizers of T&T
- Hydro Agri
- Caribbean ISPAT Ltd.
- Industrial Gases Ltd.
- National Agro Chemicals Ltd.
- Phoenix Park Gas Processors Ltd.
- Quesnel Scott Chlorine Plant
- Shell Lube Oil Blending Plant
- Shoruvi Industries
- Phoenix Plastics Ltd.
- Supermix Foods Ltd.
- T&T Electricity Company
- T&T Methanol Gas Co. Ltd.
- T&T Urea Company
- Trinidad Cement Ltd.
- Trintoc Urea Formaldehyde Plan
- United Engineering Services Ltd.
- Universal Foods Ltd.

Return to Main Menu

Figure A5.14 Form allowing user to select plant for updating data.



Determining Waste Management Options

Level 2

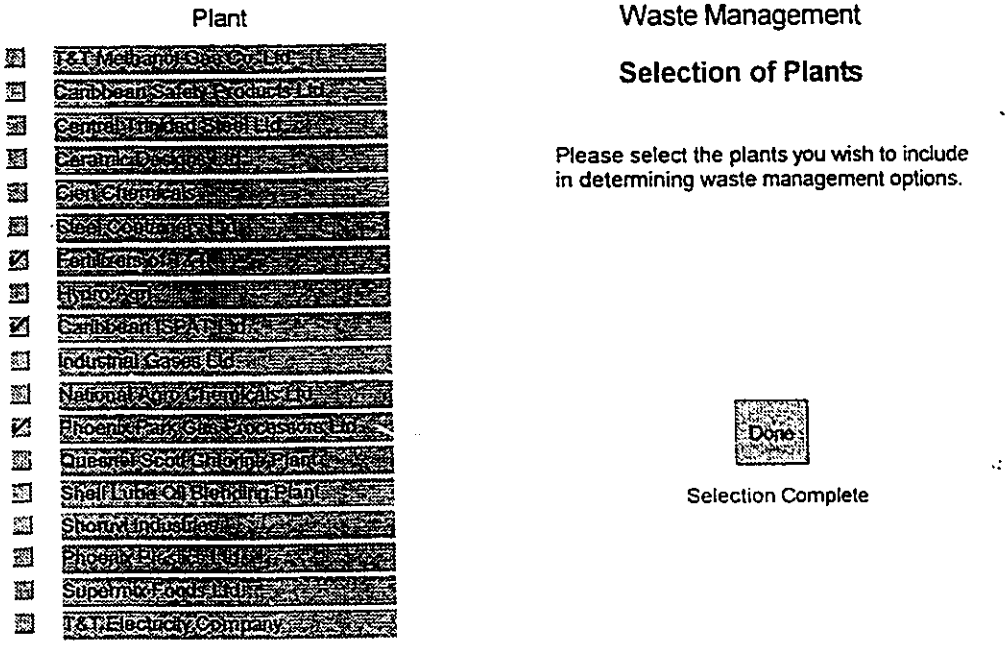
Determine waste management options for one plant

Determine waste management options for an industrial estate or for more than one plant

Add another plant's waste data

Return to Main Menu

Figure A5.15 Main menu - selecting evaluation of plant wastes.



Plant

☐ T&T Methanol Gas Co Ltd
☐ Caribbean Safety Products Ltd
☐ Central Trinidad Steel Ltd
☐ Ceramic Designs Ltd
☐ Glen Chemicals
☐ Steel Containers Ltd
☑ Fertilizers of T&T
☐ Hydro Agri
☑ Caribbean ISPAT Ltd
☐ Industrial Gases Ltd
☐ National Agro Chemicals Ltd
☑ Phoenix Park Gas Processors Ltd
☐ Questel Scott Chlorine Plant
☐ Shell Lube Oil Blending Plant
☐ Shorvil Industries
☐ Phoenix Plastics Ltd
☐ Supermix Foods Ltd
☐ T&T Electricity Company

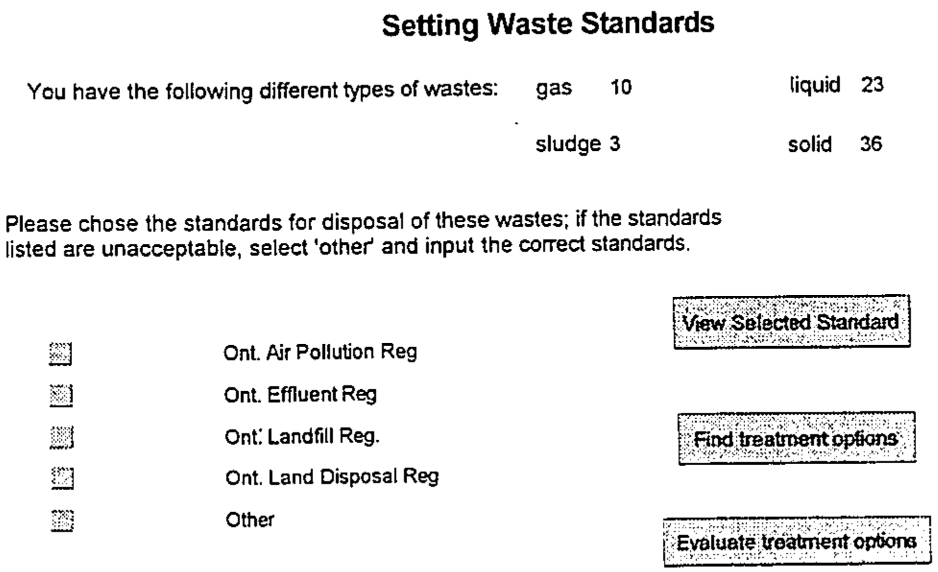
Waste Management

Selection of Plants

Please select the plants you wish to include in determining waste management options.

Selection Complete

Figure A5.16 Form allowing user to select plants to be included in the evaluation.



Setting Waste Standards

You have the following different types of wastes: gas 10 liquid 23
sludge 3 solid 36

Please chose the standards for disposal of these wastes; if the standards listed are unacceptable, select 'other' and input the correct standards.

☐ Ont. Air Pollution Reg
☐ Ont. Effluent Reg
☐ Ont. Landfill Reg.
☐ Ont. Land Disposal Reg
☐ Other

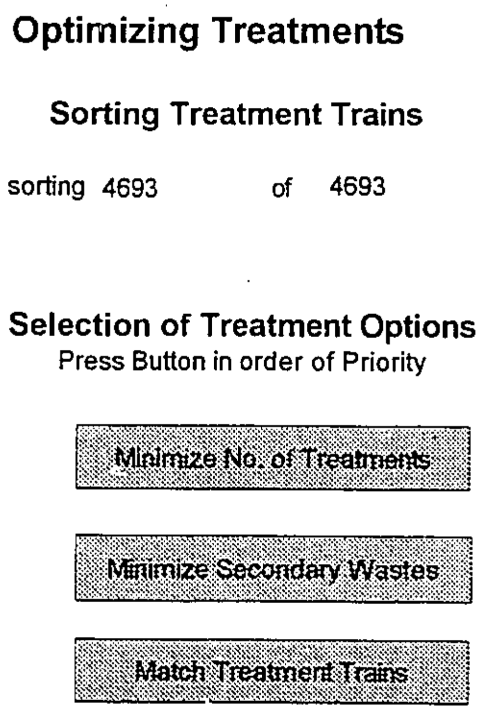
Figure A5.17 Form indicating the number of wastes from the selected plants, requesting user to select standards to be included in the evaluation and initiating the decision support system.

Final Results

Total Number of Wastes :	73	Number of Disposable Wastes	36
Number of Different Wastes	57	Number of Untreatable Wastes :	7
Number of Evaluated Wastes	44	Number of Recyclable Wastes	20
Number of Treatable Wastes	37	Number of Reusable Wastes	2

Number of Treatment Trains : 4693

Figure A5.18 Form showing results of evaluation



Optimizing Treatments

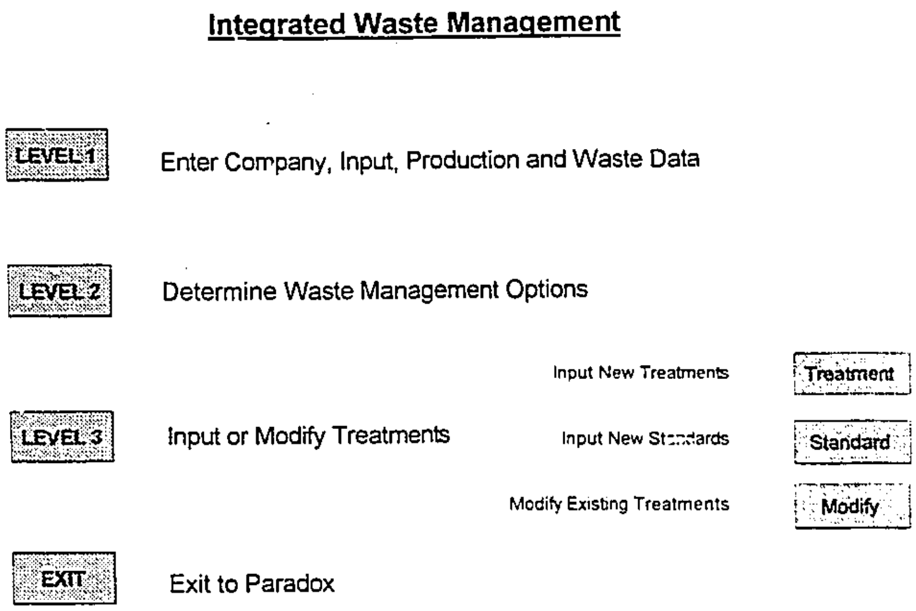
Sorting Treatment Trains

sorting 4693 of 4693

Selection of Treatment Options

Press Button in order of Priority

Figure A5.19 Form for selecting criteria for determining final options.



Integrated Waste Management

Enter Company, Input, Production and Waste Data

Determine Waste Management Options

Input or Modify Treatments

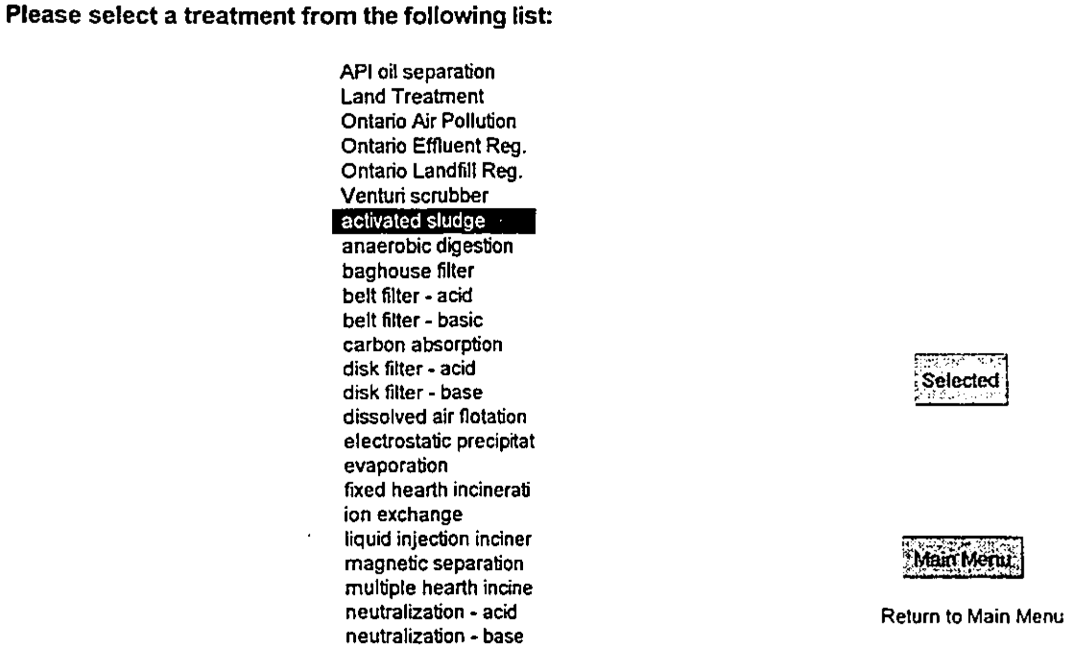
Input New Treatments

Input New Standards

Modify Existing Treatments

Exit to Paradox

Figure A5.20 Main menu - selecting treatment and standard input and upgrading

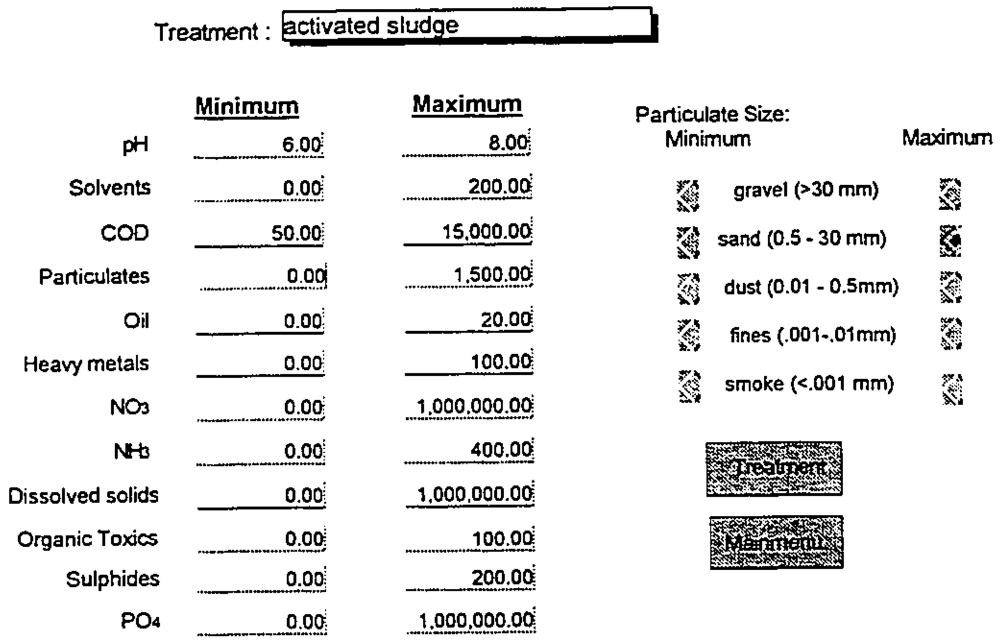


Please select a treatment from the following list:

- API oil separation
- Land Treatment
- Ontario Air Pollution
- Ontario Effluent Reg.
- Ontario Landfill Reg.
- Venturi scrubber
- activated sludge
- anaerobic digestion
- baghouse filter
- belt filter - acid
- belt filter - basic
- carbon absorption
- disk filter - acid
- disk filter - base
- dissolved air flotation
- electrostatic precipitat
- evaporation
- fixed hearth incinerati
- ion exchange
- liquid injection inciner
- magnetic separation
- multiple hearth incine
- neutralization - acid
- neutralization - base

Return to Main Menu

Figure A5.21 Selecting a treatment to upgrade.



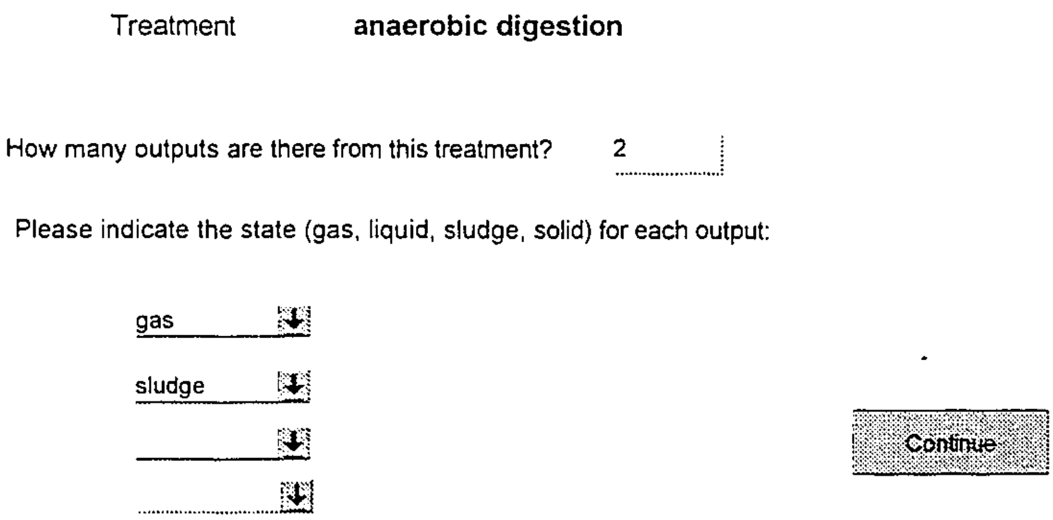
Treatment : activated sludge

	Minimum	Maximum
pH	6.00	8.00
Solvents	0.00	200.00
COD	50.00	15,000.00
Particulates	0.00	1,500.00
Oil	0.00	20.00
Heavy metals	0.00	100.00
NO_3	0.00	1,000,000.00
NH_3	0.00	400.00
Dissolved solids	0.00	1,000,000.00
Organic Toxics	0.00	100.00
Sulphides	0.00	200.00
PO_4	0.00	1,000,000.00

Particulate Size:

Minimum		Maximum
○	gravel (>30 mm)	○
○	sand (0.5 - 30 mm)	●
○	dust (0.01 - 0.5mm)	○
○	fines (.001-.01mm)	○
○	smoke (<.001 mm)	○

Figure A5.22 Form for inputting the determining parameters for the selected treatment.



Treatment anaerobic digestion

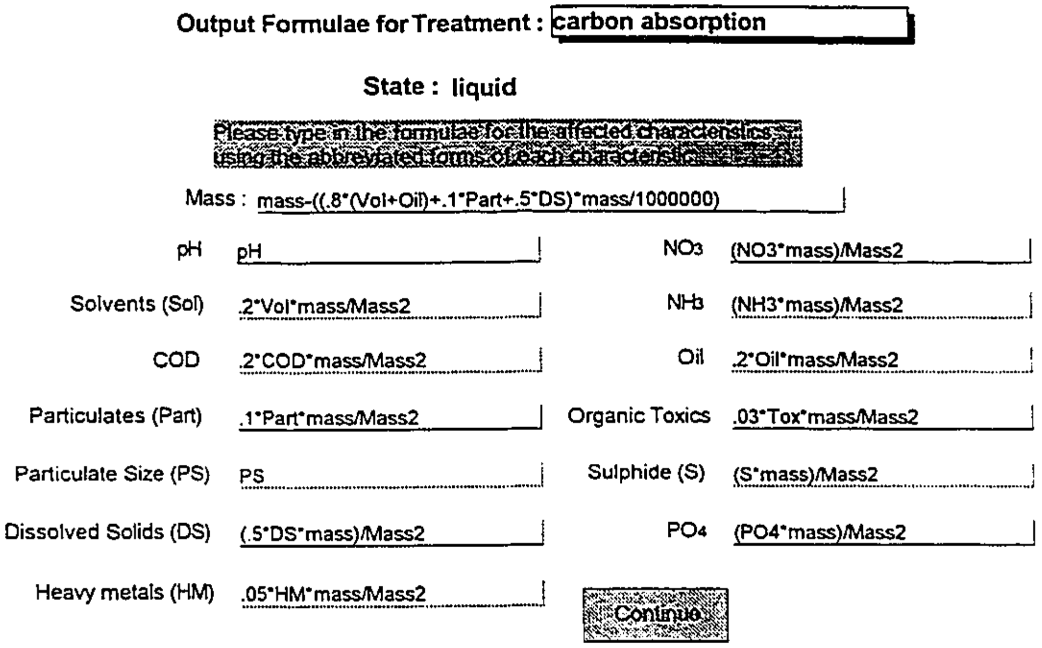
How many outputs are there from this treatment? 2

Please indicate the state (gas, liquid, sludge, solid) for each output:

gas

sludge

Figure A5.23 Form requesting the number and type of outputs from a treatment.



Output Formulae for Treatment : carbon absorption

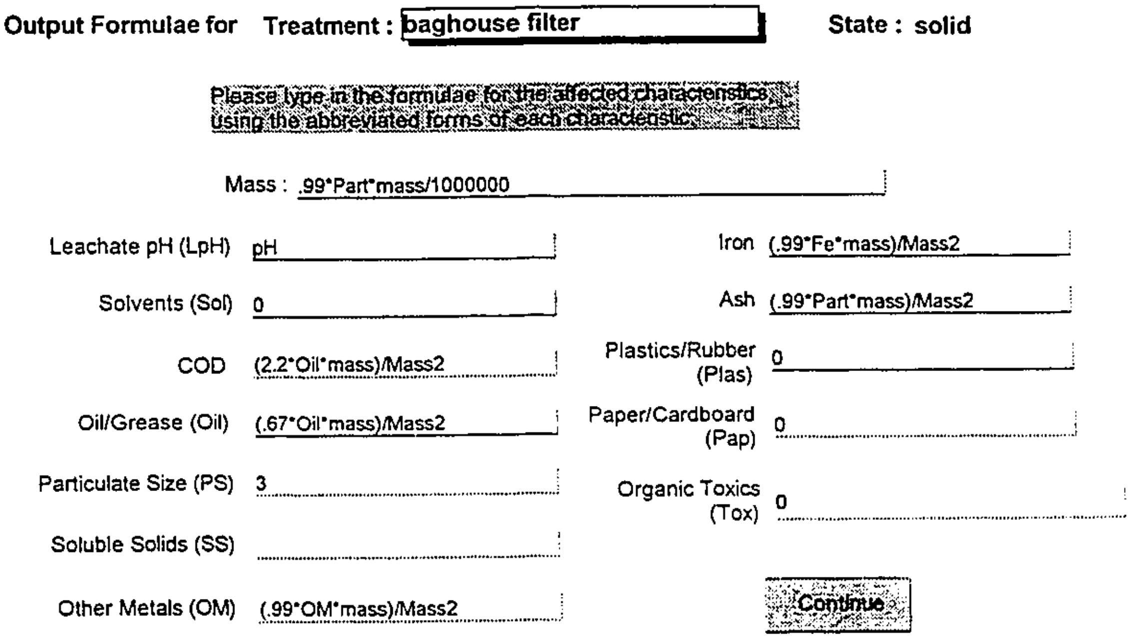
State : liquid

Please type in the formulae for the affected characteristics using the abbreviated forms of each characteristic

Mass : mass-((.8*(Vol+Oil)+.1*Part+.5*DS)*mass/1000000)

pH	pH	NO3	(NO3*mass)/Mass2
Solvents (Sol)	.2*Vol*mass/Mass2	NH3	(NH3*mass)/Mass2
COD	.2*COD*mass/Mass2	Oil	.2*Oil*mass/Mass2
Particulates (Part)	.1*Part*mass/Mass2	Organic Toxics	.03*Tox*mass/Mass2
Particulate Size (PS)	PS	Sulphide (S)	(S*mass)/Mass2
Dissolved Solids (DS)	(.5*DS*mass)/Mass2	PO4	(PO4*mass)/Mass2
Heavy metals (HM)	.05*HM*mass/Mass2		

Figure A5.24 Form for inputting liquid output formulae for the selected treatment.



Output Formulae for Treatment : baghouse filter **State : solid**

Please type in the formulae for the affected characteristics using the abbreviated forms of each characteristic

Mass : .99*Part*mass/1000000

Leachate pH (LpH)	pH	Iron	(.99*Fe*mass)/Mass2
Solvents (Sol)	0	Ash	(.99*Part*mass)/Mass2
COD	(2.2*Oil*mass)/Mass2	Plastics/Rubber (Plas)	0
Oil/Grease (Oil)	(.67*Oil*mass)/Mass2	Paper/Cardboard (Pap)	0
Particulate Size (PS)	3	Organic Toxics (Tox)	0
Soluble Solids (SS)			
Other Metals (OM)	(.99*OM*mass)/Mass2		

Figure A5.25 Form for inputting solid output formulae for the selected treatment.