AN ECONOMIC COMPARISON OF THE WASTE MANAGEMENT SCHEMES EMPLOYED IN CAPE TOWN & JOHANNESBURG

Submitted by:

Oliver Stotko

BSc(Eng) – Chemical

In partial fulfilment of the requirements of the Coursework MSc in Environmental Engineering

Date: 27/08/2006

Supervisor: Dr. C. Trois

ACKNOWLEDGEMENTS

Special thanks must be given to my supervisor, Dr. C. Trois, for assisting and guiding me in my research. I would also like to acknowledge the role of Mr. M. de Villiers (Pikitup) in providing me with the relevant reports required to analyse the Johannesburg waste management system.

Dedicated to my parents, Helen and Philip, grandparents, and my sister Emma for their continuous support and encouragement with regard to my research endeavours.

ABSTRACT

The disposal of waste into landfill sites is currently the most commonly employed method of dealing with waste in South Africa as well as internationally. However the global trend towards operating waste management systems in a more sustainable way has lead to the need to reverse this situation towards a waste management system that predominantly makes use of waste minimization schemes to deal with waste and relies minimally on waste disposal. The focus of this research was to determine which waste minimization schemes would be most effective in the Municipal Solid Waste Management Systems (MSWMS) of Cape Town and Johannesburg with regard to achieving this reversal in an economically sustainable manner.

The method used to achieve this objective was threefold, firstly requiring the development of a waste flow diagram for each respective city, followed by the development of a waste stream model based on the specific flow diagram and finally the extension of this material model into an economic model. The models were developed in Microsoft Excel and work on the premise that each particular stream (separate collected waste, transfer station waste, etc) of the MSWMS concerned has a particular associated cost (defined as cost per ton of waste processed). The model operates on the principle that under several pre-determined constraints the Excel *Solver* function calculates the optimal flow rates of the various waste streams which give the minimum overall MSWMS cost for future years.

The developed model has shown that the recovery of waste reduces the overall MSWMS costs until a threshold value (at which point under the proposed system all economically recoverable waste has been exhausted). Different waste minimization schemes were found to be appropriate for each respective city. However, the use of Material Recovery Facilities (MRFs) to recover recyclables has been shown to be a viable waste recovery scheme for both Cape Town and Johannesburg. Cape Town is in the process of implementing the development of MRFs in conjunction with existing transfer stations, while it is envisaged that MRFs will be developed on all of Johannesburg's Municipal landfill sites in the future.

Significant changes to the MSWMS of both cities are required for their respective landfilling waste streams to be substantially reduced in accordance with the Polokwane Declaration. Decreasing the landfilled waste stream is not only required by legislation, but the developed model has shown that the recovery of waste also reduces the overall MSWMS costs.

CONTENTS

PG.

PG.

LIST OF FIGURES

PG.

LIST OF TABLES

PG.

ACRONYMS

CBA:	Cost Benefit Analysis
CT:	Cape Town
DO:	Drop-Off Facility
IWMP:	Integrated Waste Management Plan
IWEX:	Integrated Waste Exchange
JHB:	Johannesburg
LCA:	Life Cycle Assessment
MCDA:	Multi-Criteria Decision Analysis
MRF:	Material Recovery Facility
MSWMS:	Municipal Solid Waste Management System
RCW:	Round collected waste
REL:	Rear-end loader
TS:	Transfer Station
VHWMF:	Vissershok Waste Management Facility
WSMB:	Waste stream mass balance

CHAPTER 1: INTRODUCTION

1.1 CONTEXT

The disposal of waste into landfill sites is currently the most commonly employed method of dealing with waste in South Africa as well as internationally. Ongoing research into the social and environmental impacts of disposing waste in landfill sites has however proved that the landfilling of waste is not a sustainable way of dealing with refuse. None-the-less landfilling remains the predominant waste management scheme due to the fact that it is firstly the oldest and most developed of the currently employed waste management schemes, and secondly due to its classification as being the most economical waste management scheme. The latter reason is proving to no longer always qualify as being accurate due to the "factoring in" of external costs into the analysis of different waste management schemes as well as through the discovery of alternative ways of dealing with waste (many of which are proving to be more economically sustainable than landfilling). These schemes predominantly involve the recovery of waste and are proving to be more economical due to the fact that they generate an income in the form of recovered material sales and also result in a direct cost saving in the form of minimising waste sent to landfill sites for disposal. The overall objectives of this dissertation are as follows:

- To develop an economic model of both Cape Town and Johannesburg's Solid Waste Management System in order to analyse the financial feasibility of various municipal waste minimization schemes that are either currently employed or proposed for future use by these respective Municipalities. This will in turn be utilized as a management tool for determining which waste minimization schemes can be most effectively employed in both the Cape Town and Johannesburg context (this type of management tool is often referred to as a Decision Support System).
- To determine the effect of both income and inflation increases on the economic feasibility of the various waste minimization operations through the use of sensitivity analyses.
- To compare the waste minimization schemes employed by the Cape Town and Johannesburg Municipal Solid Waste Divisions in order to facilitate the integration of ideas between these two respective municipalities.

In understanding the background to waste management in South Africa it is important to develop an awareness of the South African legislation that applies to waste management, and hence the following sub-chapter presents an overview of this legislation.

1.2 OVERVIEW OF RELEVANT LEGISLATION

Legislation relevant to waste management is divided into national/provincial legislation and local government legislation.

1.2.1 NATIONAL AND PROVINCIAL LEGISLATION

Currently there is no single national or provincial Act that brings together all aspects of waste management and defines what overall regulations apply when dealing with waste (a National Integrated Waste Management Bill is however currently being developed). The current national and provincial waste management legislation is specific to certain types of waste (eg: National Water Act; Nuclear Energy Act). As a result of this, South African legislation on waste is quite fragmented because each of these focussed waste legislations exhibit their own specific regulations. In the past, waste management legislation was also generally left to local authorities to formulate, and hence a large amount of municipal bylaws and local regulations exist which differ from one area to the next *(Mega-Tech Inc; 2004)*. The main national and provincial legislation that looks at the broad aspects of waste management are as follows:

- **National Waste Management Strategies and Action Plans - NWMS (1999):**
  This strategy is the foundation document for the development of a National Integrated Waste Management Bill (set to be drafted in the near future). It highlights numerous strategies and action plans for the management of waste, and more specifically for the minimisation/prevention of waste. It is important to note that this document deals with both hazardous and non-hazardous (general) waste, and for the purpose of this study only the latter will be considered. In terms of general waste, an objective of this document is to develop integrated waste management plans (IWMPs) at local government level with the aim of optimising waste management practices. The process of achieving this goal with regard to general waste is as follows:
  - Firstly, the Department of Environmental Affairs and Tourism (DEAT) was tasked with the drafting and circulation of regulations and guidelines outlining the method to be used by local government (municipalities) when compiling their particular IWMP.
  - Following this, the first generation plan of a particular municipality's IWMP was (according to the deadlines set) to be compiled during 2001, and to be submitted to provincial government by 2002.

- The IWMP must incorporate the views of the general public, and hence a public participation process is required to ensure involvement of all stakeholders.
- The final Integrated Waste Management Plans were scheduled to be submitted to the provincial government (under which a particular municipality served) by the end of 2003, and are expected to be implemented by 2006.
- A summary of the final Integrated Waste Management Plans is scheduled to be drawn up by each specific provincial government with the aim of incorporating this into their particular Provincial Environmental Management Plan. This plan would be reviewed by the Committee for Environmental Co-ordination (CEC) every 4 years.

(http://www.environment.gov.za/ProjProg/WasteMgmt/waste.html; accessed 18/09/2005)

This process should result in the waste management system exhibiting a greater efficiency, whereby associated impacts and financial costs associated with waste management are minimised.

- **White Paper on Integrated Pollution and Waste Management (2000):**

This paper was drawn up as a result of the NWMS and is a useful document that outlines certain legislation on waste management, which is used throughout the country. This legislation promotes the use of the waste hierarchy concept shown below.

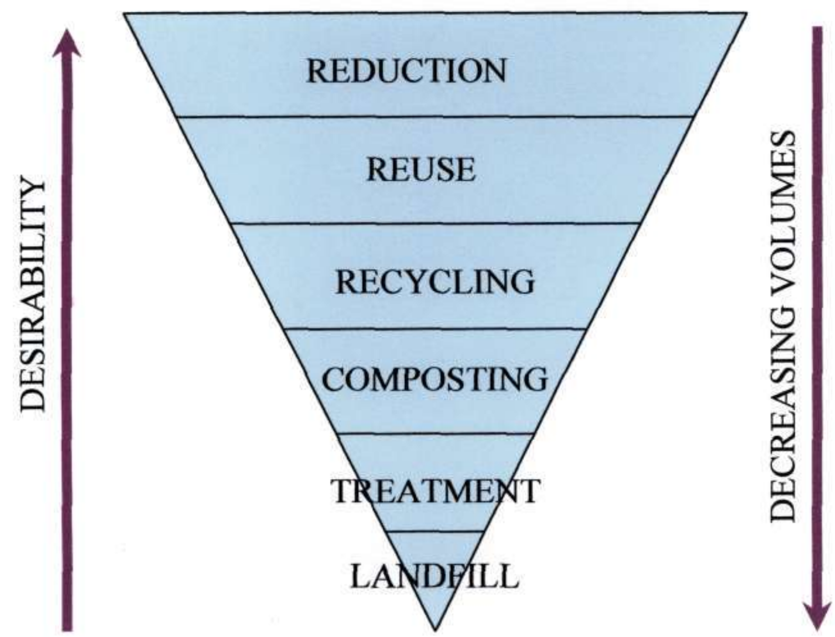

Figure 1.1: Waste hierarchy concept.

This concept outlines the different stages that must be followed to ultimately minimize the waste that must be disposed. The first stage is to encourage manufacturers and producers to minimize the amount of waste that they generate through the use of cleaner production technologies that result in more efficient usage of raw materials. The next stage (reuse of waste materials) is often possible as a result of the fact that many waste materials can be washed and repaired such that they can be reused to fulfil the same purpose that they originally served. Hence this waste material can be diverted from the waste stream and reused. Following this, recyclable materials in the waste stream can then be removed and used to produce new raw materials. Organic waste can also be recovered and used to make compost. After all these avenues have been used to minimize the waste stream then waste should be treated (physically, chemically and/or biologically) and then sent to a landfill site for disposal. *(Mega-Tech Inc; 2004)*

- **Polokwane Declaration on Waste Management (2001):**
  This declaration's aim was to reaffirm the need for implementing the waste hierarchy concept in the South African waste management industry. Industries were encouraged to make use of the waste hierarchy concept to minimize their waste. The goal of the declaration was that waste generation and waste disposal should be reduced by 50% and 25% respectively by the year 2012, with the overall goal of developing a "zero waste" strategy by the year 2022. "Zero waste" refers to the process whereby all waste produced is somehow reused or recovered so that no waste ends up going to landfill sites. *(Mega-Tech Inc; 2004)*

There is a large body of other legislation that is relevant to the theme of waste management, but only the important legislation is highlighted as follows. The **National Environmental Management Act (107 of 1998)** is the overriding legislation governing environmental matters, and thus all other relevant legislation is subject to its provisions. South Africa's Constitution also highlights the environmental rights of citizens and is thus also a relevant body of legislation. In terms of the operation of landfills and the development of landfills, the Department of Water Affairs and Forestry determines what procedures should be put in place to minimize the environmental impacts of leachate production on a particular landfill site, and these are highlighted in their guideline document termed **Minimum Requirements for Waste Disposal by Landfill (Draft 3rd Edition compiled in 2005)**. *(Mega-Tech Inc; 2004)*

1.2.2 LOCAL AND MUNICIPAL LEGISLATION

This basically outlines the responsibilities of all waste producers (industry, residents, etc) in terms of how they should deal with their waste. The following regulations are commonly applied:

- Solid waste must be placed in the provided municipal black bags or Wheeli-bins and placed outside of dwellings on the day of refuse collection.
- Industries that produce large amounts of waste must request the use of a skip or waste container from either their local Municipal Waste Services Department or else from a private Waste Management Company.
- Only the permitted solid waste may be disposed. Garden refuse and builders' rubble must be kept separate and transported to nearby municipal refuse/drop-off facilities.
- The dumping of waste in public spaces or anywhere other than at the designated refuse sites is a serious criminal offence.
- Any builder's rubble that is transported to a landfill site will be charged according to the waste tariff, unless the rubble is deemed to be appropriate landfill covering material.
- Every dwelling must provide easy access to their waste receptacles so that waste can be collected without hassle.
- The service of waste collection is provided under a particular tariff system decided upon by the local Municipal Waste Services Department. *(Mega-Tech Inc; 2004)*

CHAPTER 2: LITERATURE REVIEW

2.1 OVERVIEW OF WASTE MANAGEMENT MODELLING

It is inevitable that the progression of knowledge into the social and environmental impacts of the disposal of waste into landfill sites has created a need to develop a more sustainable method of managing waste in a society that no longer tolerates human activities that lead to its current and future detriment. Due to this increased awareness of human impact on the surrounding environment an acceptance of responsibility to maintain the surrounding environment has been developed. This has lead to the need to better manage human processes that impact on the environment. To this end comes the need to develop an effective waste management system that mitigates the resultant social and environmental impacts of this respective system as far as possible, while at the same time ensuring that the system is economically feasible. As a result of the fact that there is no single optimum waste management scheme that can fulfil these criteria it is necessary to manage waste according to a multi-disciplinary approach, termed an Integrated Waste Management Plan (IWMP). This approach involves the use of various waste management schemes, namely waste avoidance, waste recovery, waste incineration and finally waste disposal.

The operation of an Integrated Waste Management Plan requires careful planning due to its complex multi-disciplinary nature. The different schemes employed in a particular waste management system are inter-connected due to the fact that they influence the amount and nature of waste being sent to schemes further done the line. An example of this phenomenon is illustrated in the fact that a recycling scheme will reduce the amount of waste requiring final disposal, as well as decreasing the recyclables content within the waste, and thereby affecting the nature of the waste. It is thus evident that the planning of such a system requires the use of a management tool that allows for interactions between the different waste management schemes within a particular waste management system, and the tool generally used to achieve this objective is a model. At this stage it is important to define what is exactly meant by the term "model". A model is a schematic representation of a particular system, which allows one to simulate the operation of the particular system concerned. Hence a "waste management model" representing a particular waste management system allows one to simulate the operation of that particular waste management system. Waste management models are usually developed for particular regions or cities due to the fact that the geographical, environmental and socio-economic conditions of a particular region largely influence the efficiency of a particular waste management system. Hence these factors need to be considered in determining the most appropriate waste management system for that particular region. *(Abou Najm and El-Fadel, 2004)*

The following subchapters describe the three types of models that are utilized to simulate waste management systems and include models based on Cost Benefit Analyses, Life Cycle Assessments and Multi-criteria Decision Analyses.

2.1.1 MODEL TYPE 1: COST BENEFIT ANALYSIS

This model type evaluates the effectiveness of different waste management schemes in monetary terms. Generally it involves the optimisation of a particular waste management system by determining the combination of waste management schemes that result in the lowest operating cost. Two examples of the application of this waste management tool being applied to plan certain waste management systems are found in the following papers: *MCCK & Consultancy, 1998* and *Fiorucci et al, 2003*. The former of these two articles describes the use of a waste management model based on cost benefit analysis (CBA) that has aided in the planning of an effective waste management system in Dublin, Ireland, while the latter involves the development of a CBA model that has been applied to the Italian city of Genova. In order to assess the usefulness of this model type it is important to list its associated advantages and disadvantages, and these are presented in the following table.

Table 2.1: Advantages and disadvantages of using CBA type models.

ADVANTAGES	DISADVANTAGES
1) The model gives a single monetary figure as its output and is hence easily understood.	1) It is often difficult to express environmental and/or social impacts in monetary terms that allow these considerations to be incorporated into the model.
2) Allows management to analyse which waste management schemes are most effective.	2) Prices given to certain waste management schemes are assumed to increase at a constant rate, but operational changes to these schemes may change these prices from their original estimated value.

As is evident in Table 2.1 the advantages of CBA type models prove that this model type is a very useful management tool. The first disadvantage listed with regard to CBA type models is often rectifiable with the onset of increased knowledge into the environmental costs associated with mitigating certain impacts, for instance the costs of monitoring and treating leachate run-off from landfill sites to protect the surrounding environment. The social impacts are often difficult to quantify in monetary terms, however these are often inter-related to the environmental costs and in this way receive partial consideration. The second disadvantage of

CBA type models cannot easily be reconciled, but none-the-less this model type still remains a useful first step in the development of an effective Integrated Waste Management Plan. *(Morrissey and Browne, 2004)*

2.1.2 MODEL TYPE 2: LIFE CYCLE ASSESSMENT

This model type studies the potential impacts of certain activities (or schemes in the case of a waste management system) on the environment from the stage of raw material sourcing for the development of an activity to the operation and production stages to the final disposal of waste products formed as a result of that particular activity. This type of analysis is commonly referred to as a "cradle to grave" investigation. Several general life cycle assessment (LCA) packages exist which allow the usage of a large database of figures linked to the impacts of different activities. Some of these LCA programmes are specifically focussed on waste management, including the likes of ORWARE and WISARD. The former of these was developed by several research institutions in Sweden and is commonly used in this region, while the latter was developed by the Ecoliban Group and has been extensively used in the United Kingdom. An example of the usage of the ORWARE LCA software to model a waste management system is found in the paper by *Eriksson et al, 2002*, and involves the investigation of the waste management system employed in the Swedish city called Uppsala. The usefulness of this model type is investigated in the following table, which lists the advantages and disadvantages of LCA models. *(Morrissey and Browne, 2004)*

Table 2.2: Advantages and disadvantages of using LCA type models.

ADVANTAGES	DISADVANTAGES
1) Facilitates an analysis into which waste management schemes are most environmentally friendly.	1) The resultant environmental impact analysis often does not reflect exactly what will happen in reality, because the impacts are strongly determined by the place, time and method in which a particular scheme is operated (not incorporated into model).
2) Although these models focus on environmental impacts only it is possible to incorporate environmental costs into such models.	2) It is often difficult to define the boundaries which allow for only those associated impacts that have a significant effect to be considered. LCA's also generally neglect economic factors and never consider social impacts.

Out of the three model types, those models that are based on LCA's can potentially best determine the real impacts on the surrounding environment. As Table 2.2 above illustrates, LCA models have serious shortcomings, but they still serve as useful management tools.

2.1.3 MODEL TYPE 3: MULTI-CRITERIA DECISION ANALYSIS

This model type evaluates the effectiveness of different waste management schemes in a multi-dimensional way that allows for several variable criteria to be included in the model. The model operates on the principle that a series of unit weighting values are assigned to different criteria, which are based on practical experience, and these weightings are used to rank different schemes. For a particular waste management scheme to be analysed the resultant model weighting of that scheme for the different criteria (which may include social, environmental and economic impacts etc) is tallied and the overall value can then be compared with the overall weighting of other alternative waste management schemes. The most commonly used software used to develop models based on Multi-Criteria Decision Analyses (MCDA) include EXPERT CHOICE and ELECTRE TRI Assistant. The advantages and disadvantages of MCDA models are presented in the table below. *(Morrissey and Browne, 2004)*

Table 2.3: Advantages and disadvantages of using MCDA type models.

ADVANTAGES	DISADVANTAGES
1) Allows the input of both quantitative and qualitative information and hence facilitates the incorporation of non-economic criteria (eg: social and environmental criteria).	1) The resultant scheme ranking analysis produces a set of favourable schemes rather than an optimum combination of schemes that produce the best solution.
2) The preference of various stakeholder groups with differing needs can be incorporated into MCDA type models.	2) Criteria weight allocation is a subjective process and may lead to misconceptions of reality if values are poorly chosen.

Table 2.3 above indicates that out of the three model types MCDA type models are the most effective in incorporating all the different criterion that are important in an analysis that determines which waste management schemes are the most favourable. However it is evident that this model type is limited in its ability to analyse the influence of one scheme on another and hence cannot determine a combination of schemes that would complement each other.

2.2 WASTE MANAGEMENT SCHEME BACKGROUND

It was highlighted in Chapter 1 that the currently employed and recommended approach to dealing with waste is a broad Integrated Waste Management Plan in which several waste management schemes are employed in order to deal with waste in an appropriate way rather than using a single scheme to achieve this goal. The management of waste is developing into a very broad field which provides many different options to dealing with waste and these are highlighted in the following sub-chapter.

2.2.1 LANDFILLS AND LANDFILL CHARACTERISATION IN SOUTH AFRICA

Landfills are disposal sites onto which waste is deposited and isolated from the surrounding environment by encapsulation. The process of encapsulating waste in a landfill involves laying down lining material onto the land which will receive waste and then covering the waste with appropriate materials. The degree of encapsulation required varies as a function of various local factors and hence proposed landfill sites have to be classified in order to determine the extent of encapsulation that is deemed appropriate for that particular site. In classifying landfills three classification categories are examined, namely: type of waste to be disposed; the size of the waste stream; and the potential for leachate generation in the landfill site. Waste types are divided into two classes, which include general and hazardous waste. General waste exhibits characteristics and compositions that do not pose a significant hazard to public health or the environment if the waste is properly managed. Typical general waste includes domestic and commercial waste, certain industrial wastes, garden refuse and builders' rubble. It may also include small amounts of hazardous wastes including batteries, insecticide, medical waste, etc that is thrown into domestic and commercial waste. Hazardous waste is waste that may cause adverse effects to public health and/or the environment, and includes waste that may have any one or more of the following properties: toxic, ignitable, corrosive, carcinogenic, etc. (*http://www.dwaf.gov.za; accessed 11/11/2006*)

Hazardous wastes are categorised according to a hazard rating system, which is based on the toxicity, environmental fate and other criteria of the particular hazardous waste concerned. There are four hazard ratings, namely: Hazard Rating 1 (Extreme Hazard); Hazard Rating 2 (High Hazard); Hazard Rating 3 (Moderate Hazard); and Hazard Rating 4 (Low Hazard). Landfill sites that are to accept wastes of all hazard ratings (1-4) are classified as **H:H** sites, whereas sites classified as **H:h** sites can only accept waste with a hazard rating of 3 and 4 (i.e: moderate and low hazard waste). (*http://www.dwaf.gov.za; accessed 11/11/2006*)

With Regard to the classification of the size of the waste stream to be disposed of on a particular landfill site, the waste deposition is analysed by determining the maximum rate of deposition (MRD) for a particular site. The MRD is the projected maximum waste deposition expressed in tonnes per day for the entire expected life of a particular landfill site. It is calculated by the following formula:

$MRD = IRD*(1+d)^t$ ……….. *Where* IRD = *the initial determined rate of deposition for a particular landfill;* d = *estimated percentage increase in waste received per year based on annual population growth rate;* t = *expected lifetime of landfill site.*

Four size categories exist, including **C**ommunal, **S**mall, **M**edium, and **L**arge. Landfill sites are classed in these size categories according to the following table:

Table 2.4: Landfill size classification.

Disposal Site Size Class	Maximum Rate of Deposition – MRD (tonnes/day)
Communal (C)	<25
Small (S)	25-150
Medium (M)	150-500
Large (L)	>500

N.B: Values are based on a 5-day week operation.

Only general landfill sites are classified according to size. The classification of hazardous waste disposal sites does not take size into account, and is based solely on the hazard rating of waste. (*http://www.dwaf.gov.za; accessed 11/11/2006*)

The last classification category deals with the potential for significant leachate generation from the disposal site. All hazardous landfill sites are required to be designed with leachate collection systems, and hence this classification category is only used to determine whether general landfill sites require leachate collection systems. In order to determine whether significant leachate will be generated by a particular site, average annual rainfall data (R) and

A-pan evaporation data (E_a) for the area is gathered and compared in a climatic water balance. Essentially this balance states that if the data collected shows that $R > 0.4E_a$ for the bulk of the data gathered then the site requires leachate collection systems, and if $R < 0.4E_a$ for the majority of data gathered for the site then leachate generation for the site can be considered to not be significant. General landfills that require leachate collection systems are classified as B^+ sites, while disposal sites that do not require leachate collection are termed B^- sites. Hence, for example the full classification for a general disposal site that is classified as a large site, and requires leachate collection systems would be reported as G:L:B^+ (*http://www.dwaf.gov.za; accessed 11/11/2006*). The following figure is an illustration of the Shongweni Landfill Site in Durban.

Figure 2.1: The lining of the Shongweni Landfill Site.
(*http://www.engineered-linings.co.za; accessed 10/07/2006*)

Figure 2.1 illustrates the structure of landfill lining systems. The Shongweni site depicted in the diagram is a privately operated landfill site in Durban.

2.2.2 TRANSFER STATIONS

The function of a transfer station is to accept collected waste that is collected by municipal and private refuse trucks and to compact the received waste ready for transport by bulk haulage vehicles or railway to disposal facilities. The reason for operating transfer stations as an intermediate process between the collection and disposal of refuse is that these facilities help to minimise transport costs if the distance required to be travelled between the refuse collection and disposal point is very large. This situation occurs when landfill space within a city becomes of great shortage, resulting in the need to develop landfill sites outside of the city or else in non-centralised positions. Other advantages associated with operating transfer stations include the fact that refuse collection vehicles operate more productively (due to shorter travelling distances) and require less maintenance due to the fact that they only travel on tarred roads (which is not the case when they are required to travel on gravel roads in landfill sites), as well as the fact that landfill sites experience less traffic congestion due to decreased vehicle visits (*Chang et al, 1991)*. The general layout of a transfer station is shown in the diagram below.

Figure 2.2: Layout of a typical transfer station.
(*http://www.akura.co.za/compactors/transfer%20durban%20site2.jpg; accessed 10/07/2006*)

Figure 2.2 illustrates that typical transfer station infrastructure includes a raised platform from which refuse trucks can be emptied into a feed hopper that feeds the waste into waste compactors (shown as containers 2 and 7). The waste compactors compact the waste and are transported by road or rail once completely full to landfill sites, where they are emptied and then returned for re-use.

2.2.3 COMPOSTING

Composting is the process whereby organic material (garden refuse, food waste, etc) is converted into a stable soil-like product. The process involves a controlled biological degradation of organic material in the presence or absence of oxygen. The former of these two is termed aerobic degradation while the latter is called an anaerobic degradation process. Anaerobic degradation produces a number of odorous and potentially hazardous gases and hence this process requires careful control and gas treatment is an essential component of this process. Aerobic degradation is a much simpler process and is thus generally the preferred degradation method in composting processes. There are several ways to carry out aerobic degradation of organic material but the most commonly used method in South African Municipalities is the Open Windrow System, whereby shredded organic waste is placed in hill-like rows (windrows) as illustrated in the figure below, which are lifted and deposited again by a composting machine to re-aerate the windrows throughout the composting process. *(Mega-Tech Inc, 2004)*

Figure 2.3: Composting machine turning shredded garden waste for re-aeration.
(*http://www.pikitup.co.za/upload/images/Composting-Machine.gif; accessed 12/04/2006*)

Figure 2.3 above was taken at the Johannesburg Waste Management Services' first Garden Refuse Composting Plant situated in Panorama. The composting machine depicted is a Ritlee

Xecutech SP 4, and its function is to turn the shredded garden refuse to allow for the re-aeration of the windrows. In understanding why it is necessary to turn the windrows it must be taken into account that the micro-organisms carrying out the aerobic degradation of the garden refuse require oxygen to break down the waste and hence turning is required to bring a supply of oxygen into the centre of the windrow where oxygen has been depleted by the aerobic micro-organisms. During the degradation of waste gases are given off, and in the case of aerobic degradation carbon dioxide (CO_2) and water vapour (H_2O) is given off. This emission of gas results in a decrease in the mass of the organic material being composted, and this material decrease is quantified through the use of a Degradation Factor (D). The degradation factor represents the fraction of the initial organic mass that remains after degradation. The mass reduction of composted organic material is reported by *Renkow and Rubin (1998)* to be between 0.25 and 0.6, and since the degradation factor represents the mass that remains after degradation, the degradation factor ranges between 0.4 and 0.75.

2.2.4 DROP-OFFS

Drop-off facilities serve the function of providing a delivery point for bulky wastes, which typically include garden and garage refuse. Some drop-off facilities also accept builders rubble and recycling depots are also often incorporated into drop-off facilities. The figure below reveals the general layout of a drop-off facility

Figure 2.4: Gordon's Bay drop-off facility. (*Mega-Tech Inc, 2004*)

Refuse that is delivered to drop-off facilities is usually placed into skips – large open containers designed to store bulky waste. Drop-off facilities are an integral part of any effective Municipal waste management system and should ideally be positioned such that all of the inhabitants of a particular city have easy access to these facilities.

2.2.5 MATERIAL RECOVERY FACILITIES

A Material Recovery Facility (MRF) is a processing centre where recyclables are removed from mixed or partially sorted waste and differentiated into different recyclables. There are two main types of MRFs, namely "Clean" MRFs and "Dirty" MRFs. The former involves the processing of separately collected waste that is almost entirely composed of recyclables that need to be sorted into their various types, while the latter deals with the processing of mixed general waste and is thus a more complicated operation in terms of sorting due to the added separation process being required to separate recyclable waste from non-recyclable waste. This initial sorting stage required in "Dirty" MRFs is carried out by a series of mechanically operated separation processes, while the recyclables sorting stage common to both "Clean" and "Dirty" MRFs normally involves hand-sorting of recyclables across a slow-moving conveyor belt system by the facility personnel, as is illustrated in the figure below.

Figure 2.5: Hand-sorting of recyclables in an MRF.
(*www.godiversified.com/MRF.ht4.jpg; accessed 10/07/2006*)

The separation of recyclables into different recyclable types as illustrated in Figure 2.5 is a very labour-intensive process with a number of personnel being stationed at the same conveyor belt in order to ensure a good recovery of recyclables. The material that comes to the end of the sorting conveyor is stored ready for collection and disposal into a landfill site.

CHAPTER 3: METHODOLOGICAL APPROACH

3.1 MODELLING METHODOLOGY

The previous Chapter reveals that there are three types of models used to simulate waste management systems, and hence it is important to first explain how and why a particular model type was chosen to carry out the objectives of this research. The most important decision criterion in deciding which of the three model types (namely CBA, LCA or MCDA) was most appropriate for this research was the ability of a particular model type to facilitate the development of an effective Integrated Waste Management Plan (IWMP). As has already been mentioned in Chapter 2, an IWMP inevitably creates an inter-connected relationship between the different waste management schemes employed in that particular plan, and for this reason the development of an effective IWMP can only be carried out through the use of a model type that is able to take into account the influence of one scheme on another. Models based on either Cost Benefit Analyses, or Life Cycle Assessment are designed to accommodate the inter-connected nature of the schemes employed in an IWMP, while models based on Multi-Criteria Decision Analyses are unfortunately only able to rate the effectiveness of specific waste management schemes on an individual basis and are thus not able to easily analyse the effect of one scheme on another. For this reason the latter model type was not employed in conducting this research. In deciding between the use of CBA or LCA type models, the former was chosen due to the fact that unlike LCA type models, which more readily require expensive software packages, CBA type models can easily be developed from the inception stage and thus do not require expensive software packages for their development. The development of a model from the inception stage rather than from building a model on the foundation of an already existing modelling software package results in a greater incorporation of local conditions and waste management system requirements, and for this reason CBA type models were found to be favoured over LCA type models.

The disadvantages of using CBA models have been described in Chapter 2, and the most pertinent of these involves the fact that CBA models often neglect the social and environmental impacts of modelled processes. In order to rectify this CBA modelling flaw, the philosophy of the waste hierarchy was incorporated into the model through the provision of landfill airspace cost saving values to the various waste minimization schemes (which ultimately reduced the amount of waste being sent to landfill sites). In understanding this rationale it is important to note that the waste hierarchy was developed from an environmental and social perspective and states that the disposal of waste is the least appropriate waste management scheme, and hence those schemes that help to reduce the quantity of waste going to landfill are environmentally and socially favoured.

3.2 COMPUTATIONAL METHODOLOGY

The development of an economic model of a Municipal Solid Waste Management System (MSWMS) requires three steps, which include:

i. The development of a flow diagram of the MSWMS.
ii. The development of a waste stream mass balance with the aid of the MSWMS flow diagram.
iii. The development of a model that links the waste stream mass balance to financial indicators in order to provide a tool for determining the best waste minimization strategies.

3.2.1 DEVELOPMENT OF THE FLOW DIAGRAM

The flow diagrams were developed through the collection of data on the structure and characteristics of both Cape Town and Johannesburg's MSWMS, and collated to formulate a flow diagram for each respective city. Each waste management scheme (eg: landfilling, recycling, etc) was assigned to a particular box, and the streams that were discerned to be inputs and outputs of a particular scheme were indicated as arrows into or out of that particular box. The various streams were then assigned different numbers, and streams that were facilitated by the Municipal Council were marked in bold.

The reasoning for this was that the model is designed to only focus on those streams that represent a cost to the City Council, and hence streams that represent private company involvement are not considered as a result of the fact that these respective companies would cover the cost of the associated stream. The input stream to recycling centres/depots is also included in the analysis as a result of the fact that this sector has been subsidised by both City Council's for the reason that many of the organisations that are involved in this sector are not financially viable and thus depend on funding to cover their revenue shortfall in relation to their expenses. It is evident that the City Council derives a direct benefit from financially aiding recycling centres/depots as a result of the fact that this sector helps to minimise the amount of waste that would have otherwise represented a collection and disposal cost to the City Council. The sectors of the waste flow diagram facilitated by private companies are profitable and hence are self-sustaining without the assistance of outside funding.

3.2.2 DEVELOPMENT OF THE WASTE STREAM MASS BALANCE

In order to develop the waste stream mass balance (WSMB) in Excel a workbook was sub-divided into two sheets, the first (termed the Data Sheet) containing all the data required for the waste stream analysis and the second (termed Stream Sheet) comprising of a series of columns that represent the various streams present in the particular Waste Management System concerned. The Data Sheet is presented in the figure below, and contains both fixed and input data.

Table A1: Cape Town Waste Characterisation *(Mega-Tech, May 2004)*

Recyclables Fractions	**Household**	**Commercial/Industrial**	**2-Bag stream**
Builder's Rubble	-	-	-
Green Waste	-	-	-
Organics	0.47	0.31	-
Metal	0.05	0.01	0.05
Glass	0.08	0.02	0.32
Paper & Cardboard	0.19	0.18	0.54
Plastic	0.13	0.02	0.09
Other	0.08	0.47	-
TOTAL	1.00	1.00	1.00

Table A4: Analysis of Overall Waste Generated (*Mega-Tech, May 2004*)

Source	**Amount (t/yr)**	**Mass Fraction**
Household	935835	0.38
Commercial and Industrial	1034344	0.42
Green	123136	0.05
Builder's Rubble	369408	0.15
TOTAL	2462723	1

Parameters:

Total Generated Waste	2462723
Transfer Station(s) Capacity	606724
Cost to Landfill ton of waste	44.20
Landfill/TS Splitting Ratio (F1):	0.29
MRF/Landfill Split Ratio (F2):	0.00
Vissershok Waste (Private)	320000
Baseline Year (2003/2004)	2003
Year Analysed	2005
Inflation Rate	**0.05**
Overheads/Admin. For SWC	0.26
End-of-Life Deposit Bottles (t/yr)	6000
Income Increase Rate	0.07
Number of MRFs	0

Figure 3.1: Waste stream mass balance Data Sheet developed in Excel for Cape Town.

Figure 3.1 indicates the format of the Data Sheet and includes data labelled as "Parameters", which incorporates all data input into the sheet at the start of a WSMB, as well as tabulated data that represents all fixed data that was assumed to be constant in the model and is data that is required to determine the immediate post-generation stream compositions. The immediate post-generation streams are those streams that involve the collection of waste directly from the generation source. Data required for only some of these streams is presented in the figure as an example of the data format. In order to calculate the immediate post-generation stream flow rates each stream was assigned a mass fraction, that when multiplied by the Total Generated Waste value (which is input as a parameter in the Data Sheet as illustrated in Figure 3.1) for a particular year would give the flow rate of that particular stream, as indicated below:

$\mathbf{Y_i \times M^{total} = M_i}$ .... *where Y_i is the mass fraction of the total generated waste sent to a particular waste management scheme(i), M^{total} is the total annual mass flow rate of generated waste, and M_i is the annual mass flow rate of waste sent to a particular waste management scheme(i).*

The mass fraction Y_i is a changeable variable, and it will later be explained how this fraction for the various streams is changed by the economic model to yield a MSWMS of minimal net cost (see Section 3.2.3). The initial values of the mass fraction Y_i for the various waste streams were calculated using information taken from the Solid Waste Status Quo Reports for Cape Town and Johannesburg respectively *(Mega-Tech Inc, 2004-1*; *Jarrod Ball & Associates, 2003)*, and these acted as the baseline mass fraction values for the various streams sent to specific waste management schemes. This baseline data is of the year 2002/2003 in the case of Cape Town, while the baseline data for Johannesburg is from 2001/2002. It was important to gather all the data from one particular year to ensure consistency in the data, and the data chosen was the most recent comprehensive compilation of data of the entire Cape Town and Johannesburg waste management systems. An example of how these mass fraction values are used to calculate the immediate post-generation stream flow rates in the above-mentioned Stream Sheet is presented in the figure below, and includes an illustration of the method used to determine the composition of specific streams using the data from the Data Sheet.

Table A3: Stream Mass Fractions

Stream	Mass Fraction
Waste Landfilled (excl. DO)	0.84
Recovered Landfill Waste	6E-04
MRF Recovery	0.00
Waste Recycled (2 Bag)	4E-05
Separate Organics Collection	0.00
Waste Recycled (Centres)	0.09
Council Composted Waste	0.01
Drop-off Waste	0.05
TOTAL	1.0000

STREAM NO:	**2A**
STREAM NAME:	Recycling (2 Bag)
COLLECTOR:	Enviroglass
FLOWS:	
Total (t/yr):	102
Components:	
Builder's Rubble (t/yr)	
Disposed	-
Recycled	-
Landfill Cover (t/yr)	
Soil	-
Organics (t/yr):	
Agricultural waste	-
Green Waste	-
Household Organics	-
Compost Product	-
Recyclables (t/yr):	
Metal	5
Glass	33
Paper & Cardboard	55
Plastic	9
Other	-
Balance Check:	102

Figure 3.2: Portion of the waste stream mass balance Stream Sheet for Cape Town.

Figure 3.2 highlights the format of the Stream Sheet in Excel, and is intended to illustrate how the total and component flow rates of a specific stream are calculated in the waste stream analysis. The example stream chosen to illustrate the method used in the WSMB is the 2-Bag Recycling Scheme (which is a stream for the separate collection of recyclables from households). The data set labelled Table A3 in Figure 3.2 is a table of the baseline mass fractions described above for the various immediate post-generation waste streams, and includes the baseline mass fraction for the Waste Recycled (2-Bag) stream, namely 4E-05. This value is multiplied by the Total Generated Waste value of 2,462,723 tonnes/year (which is the input parameter of the Data Sheet shown in Figure 3.1) to yield a waste flow rate of 102 tonnes/year. This flow rate value is calculated in the Recycling (2-Bag) column under the row labelled total as is indicated in Figure 3.2.

In order to determine the component flow rates of the 2-Bag Recycling stream the calculated total stream flow rate is multiplied by the respective component composition values tabulated in the Data Sheet (as shown in Figure 3.1 under the 2-Bag Stream column of Table A1). For example the component mass fraction of metal recyclables for the 2-Bag Recycling stream is 0.05 (see Figure 3.1) and when this value is multiplied by the total flow rate of this stream the resultant metal recyclables component flow rate is calculated to be 5 tonnes/year (as is shown in figure 3.2). The components analysed include builder's rubble, organic and recyclable material. Organic material was further split into green waste and food waste, while recyclables were split into metal, glass, paper and cardboard, plastic and other material (which includes all unclassified material). This same procedure is used to calculate the stream flow rates for several of the variable streams that are listed in Figure 3.2 in the table labelled as Table A3. The complete Excel Data and Stream Sheets for both cities can be found in **Appendix A** and **Appendix B** respectively.

All of the streams that follow the immediate post-generation waste streams are calculated through the accounting of mass flow rates going from one scheme to another, and are thus calculated through mass balancing techniques. Only recovery and splitting schemes change the flow rate of waste moving from one scheme to another, and special mass balancing techniques are required to account for these changes.

In the case of the recovery streams, those recovery stream component characteristics that include non-recoverable material in their composition were re-calculated excluding the non-recoverable component (which was included in the Combined Collected Waste stream) as a result of the fact that all non-recoverable material would ultimately be collected and disposed in a landfill. The Combined Collected Waste stream includes all waste that is collected by the Waste Management Department concerned and is destined for disposal (except in the case where MRFs are employed to recover useful materials from this waste stream).

There are only two splitting schemes in the WSMB, and the first of these is the Combined Collected Waste stream, which was modelled to split into two streams, namely the Direct Feed to Landfill and the Feed to Transfer Stations. A split fraction (F1) was used to determine the respective flow rates for each particular stream by multiplying this fraction with the total and component values of the Combined Collected Waste. A second split fraction (F2) is employed in order to determine what portion of waste sent to Transfer Stations in the case of Cape Town or Landfill Sites in the case of Johannesburg is initially sent through an MRF. Examples of the stream equations used in the mass balance are highlighted in **Appendix C**.

3.2.3 DEVELOPMENT OF THE COST MINIMIZATION MODEL

As mentioned earlier the cost minimization model operates through changing the stream fractions that determine the flow rates of the immediate post-generation streams in the MSWMS. Each stream is assigned an income and airspace credit value (for recovery schemes) from which the corresponding economic operational cost (with some streams also including a capital cost element) is subtracted and then multiplied by the calculated stream flow rate to determine the net cost of that specific stream, and hence its effect on the overall MSWMS net cost. An example of the procedure used in this model type is shown below.

Table A3: Stream Mass Fractions

Stream	Mass Fraction
Collected Waste	0.65
Waste Landfilled (excl. DO)	0.59
Recovered Landfill Waste	4E-04
MRF Recovery	0.05
Waste Recycled (2 Bag)	0.06
Separate Organics Collection	0.15
Waste Recycled (Centres)	0.09
Council Composted Waste	0.00
Drop-off Waste	0.05
TOTAL	1.00
Objective Function:	514.6

STREAM NO:	**24**
STREAM NAME:	Organics Recovery
COLLECTOR:	SWM
FLOWS:	
Total (t/yr):	544247
Components:	
Builder's Rubble (t/yr)	
Disposed	-
Recycled	-
Landfill Cover (t/yr)	
Soil	-
Organics (t/yr):	
Agricultural waste	-
Green Waste	54425
Household Organics	489822
Compost Product	
Recyclables (t/yr):	
Metal	0
Glass	-
Paper & Cardboard	-
Plastic	-
Other	-
Balance Check	544247
ECONOMIC ANALYSIS	*
Variable Cost (R/t)	588.6
Operational Costs	320366347.7
Income-based Benefit	202912675.4
Airspace Cost Benefit	187788715.4
Capital Cost	24306165.4
Total Profit/Loss	46.0

Figure 3.3: Portion of the Cost Minimization Model for Cape Town.

The stream example illustrated in Figure 3.3 is the Organics Recovery stream, which encompasses all of the Council-based organics recovery schemes that produce compost product. The economic data for the stream is shown at the bottom of the stream column under the title "Economic Analysis". The first value displayed in this section is the variable operational cost, which is multiplied by the total flow rate of the stream to give the Operational Cost displayed in the row that follows. The same method is used to determine the income generated from the scheme whereby the sales price of compost is multiplied by the amount of compost product produced to give the total income for this scheme. The airspace credit income refers to the recovery streams which are credited with an unseen income of the cost that would have been associated with these materials had they been sent through a transfer station and then to a landfill. The airspace credit income value is calculated as the cost of landfilling plus the product of the transfer station split fraction and the cost of processing transfer station waste, and the resultant value is multiplied by the total amount of waste diverted from being disposed to give the airspace credit income. The last economic variable displayed in the Organics Recovery stream column illustrated in Figure 3.3 is the Capital Cost, which is an annualised calculation of the capital required to develop the infrastructure necessary for this scheme.

The stream costs (Capital Costs; Operational Costs) are then added and subtracted from the addition of the income values (Income; Airspace Credit Income) to yield a net stream cost that is labelled "Total Profit/Loss". This value is reported in millions of Rands and hence is reported differently to the other economic variables. The net stream cost/profit of all of the modelled streams are then added together to obtain the Overall MSWMS Cost/Profit value which is reported as the Objective Function in Figure 3.3. The Overall MSWMS Cost reported is that of Cape Town for the modelled year 2030/2031. It is important to note that positive values of the Objective Function indicate a profit, while negative values indicate a net cost. The model was set up using Excel's Solver function to change the stream mass fractions reported in Figure 3.3 with the aim of maximizing the abovementioned Objective Function (the target cell in Solver). The way Solver operates is that it changes the values of the variable stream mass fractions until the resultant values of the different stream mass fractions give the maximum possible Objective Function value. The format of the Solver tool in Excel is illustrated in the following figure:

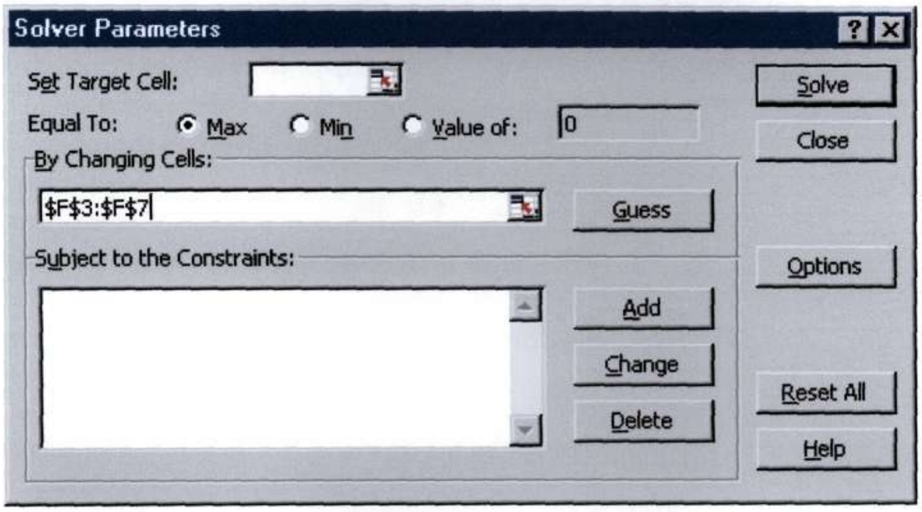

Figure 3.4: Solver function format in Excel. (*http://www.dslimited.biz; accessed 10/07/2006*)

Figure 3.4 is displayed to illustrate how the economic model calculations are facilitated by the Solver function in Excel. Firstly, the "Set Target Cell" was input as the Objective Function, which is the Overall MSWMS Cost/Profit value. The "Max" function was checked so that Solver would calculate the maximum value for the set target cell. The variables to be changed by Solver to achieve the objective of obtaining the maximum Objective Function are the stream mass fractions and are input into the "By Changing Cells" field. A number of constraints were input into the Solver Function to ensure that the model operated from a perspective that is logical to real life scenarios, and these are listed in **Appendix C**.

The specific data required to carry out the development of both the Cape Town and Johannesburg models is given in the respective Chapters that cover these two case studies.

CHAPTER 4: CASE STUDY OF CAPE TOWN'S WASTE STREAM

4.1 INTRODUCTION

4.1.1 BACKGROUND

Cape Town is situated in the Western Cape and is South Africa's third most populous city. Cape Town also has the second largest city economy in South Africa, and currently produces approximately 2.45 million tonnes of solid waste per year. Cape Town currently makes use of six different landfills to dispose of waste generated in the city. The Vissershok Waste Management Facility (VHWMF) is the only operational landfill that is privately owned by the waste management company Enviroserv, with the rest of the landfills being owned and operated by the Cape Town Municipal Council. The Municipal landfills include Bellville South (GLB^+), Coastal Park (GLB^+), Faure (GLB^+), Swartklip (GLB^+) and Vissershok (GLB^+; H:h), which is adjacent to VHWMF. *(Coetzee and Botes, 2005)*

The Bellville South and Faure landfills are expected to be closed during the second half of 2006. The former of these contains enough land to be able to accept waste until approximately 2010, but is being closed prematurely due to the health and environmental risks associated with this site. These risks include the fact that the Bellville landfill site is situated very close to residential areas, as well as the fact that the landfill lies directly over the Cape Flats aquifer, and hence has the potential to pollute this sensitive groundwater source. Resistance towards the operation of landfills close to residential areas has already resulted in the closure of one of Cape Town's former landfill sites, namely the Brackenfell landfill, which was closed in 2005. The Swartklip landfill site was officially closed in 2004, but continues to accept builder's rubble, with a maximum disposal capacity of 30,000 tonnes per year. Similar to the Swartklip landfill, the Faure landfill site will also continue to accept builder's rubble (maximum of 30,000 tonnes per year) after its closure in 2006. Both sites will serve this purpose for at least the next five years. *(Coetzee and Botes, 2005)*

The Coastal Park landfill site is scheduled to be closed in 2016, but proposed extensions to the landfill site would extend its lifespan to 2025. The VHWMF (private) and Vissershok (Municipal) landfills are expected to reach capacity by 2014 and 2015 respectively. As a result of the rapid closure of Cape Town's existing landfills, as well as the scarcity of suitable land for landfill development within the city, the Municipal Council has decided to develop a regional landfill site that serves the entire city. This regional landfill site will ultimately be served by seven transfer stations situated in different areas of the city. As Cape Town's existing landfill sites reach their capacity they will be substituted by transfer stations that will take over the role of these respective landfills as collection points for the waste generated in the different areas of the city. The existing landfills as well as the placement of the proposed transfer stations is highlighted in the figure below. *(Mega-Tech Inc, 2004-1)*

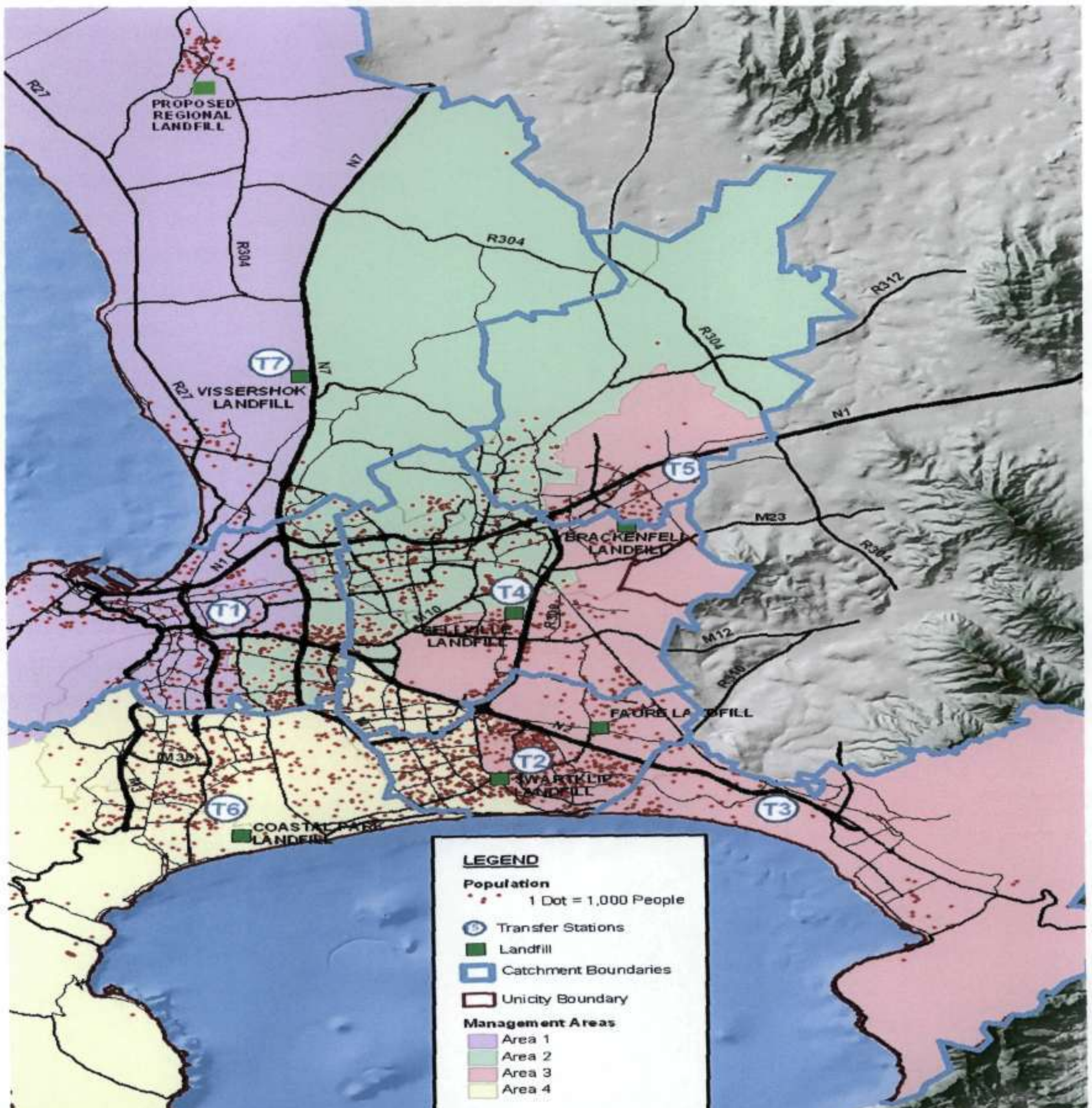

Figure 4.1: Cape Town's existing landfill sites and proposed transfer stations.

(Coetzee and Botes, 2005)

The above figure, Figure 4.1, assigns numbers to the transfer stations according to the chronology of their development. The Athlone Refuse Transfer Station (T1 in Figure 4.1) and the Swartklip Refuse Transfer Station (T2 in Figure 4.1) have already been developed, with the former being built in 1978 and recently upgraded, while the Swartklip Refuse Transfer Station has only been in operation since 2003. Both sites are designed to process a maximum waste capacity of 250,000 tonnes/year. The waste that is sent to these transfer stations is compacted into sealed containers that are sent to the Vissershok landfill site by rail. It is envisaged that all of the compacted waste coming from the existing and proposed transfer stations will be transported to the operating landfills by rail. *(Coetzee and Botes, 2005)*

Figure 4.1 above also reveals the positioning of the proposed regional landfill site, and the reasons for this choice are described as follows: Development in Cape Town is restricted by two natural barriers, which include the Atlantic/Indian Oceans and the mountains that surround the city. The former barrier restricts development on the southern and western sides of the city, while mountainous regions on the eastern side of the city as well as mountain ranges within the south-western section of the city also restrict development. Hence due to Cape Town's urban expansion, the only area containing sufficient land space (that is suitably separated from residential areas) for the development of the proposed regional landfill site lies in the north-western section of the city. Two suitable sites have been identified near Atlantis and Kalbaskraal respectively, with both sites being situated close to Cape Town's municipal boundary. The proposed site near Atlantis is shown in the above figure, Figure 4.1.

4.1.2 OBJECTIVES OF STUDY

- To develop a waste flow diagram of the MSWMS in Cape Town.
- To develop an economic model of Cape Town's Solid Waste Management System in order to analyse the financial feasibility of various municipal waste minimization schemes that are either currently employed or proposed for future use by the Cape Town Municipal Council.
- To determine the effect of inflation and income increase changes on the financial feasibility of the various waste minimization schemes through the use of sensitivity analyses.

4.1.3 CONTEXT

Waste Reduction Schemes

- *Waste Minimisation Clubs:* A Dutch environmental management company called Beco facilitates the formation of these clubs in Cape Town. Waste Minimisation Clubs in Cape Town exist in several industries, namely the plastics, meat products, retail motor and textile industries, among others. *(Mega-Tech Inc, 2004-1)*

Waste Reuse Schemes

- *Integrated Waste Exchange (IWEX) Programme:* The City of Cape Town launched their IWEX website in May 2000, with the aim of listing wastes that companies either produce or require as a raw material and then trying to link the companies that require a particular waste as a raw material with a company that may produce that particular waste material. In so doing, waste materials can be diverted and reused as raw materials. The main focus of this programme is based on reducing the amount of hazardous wastes that are sent to landfills, as well as trying to expand the recycling market in Cape Town. In this sense this programme not only facilitates the reuse of wastes, but it also deals with the recycling of wastes. Most of the non-hazardous (general) solid waste that is minimised through this programme is as a result of these wastes being sent to recycling companies and as such only a limited amount of wastes that are relevant to this study are being reused as a result of this programme. *(Mega-Tech Inc, 2004-1)*
- *Reuse of Deposit Bottles:* Deposit bottles in excess of 6000 tonnes per year are being reused to package beverages. Returnable deposit bottles are used by several beverage companies in Cape Town including Coca-Cola, South African Breweries as well as a few other liquor manufacturers.
- *Reuse of Second-hand Materials by Charities:* Empty yoghurt containers and other used food packaging are reused by several soup kitchens to serve meals. Another programme that involves the reuse of waste materials is the programme run by the charity organisations Shawco and Haven Shelter Organisation that empowers poor communities by aiding them in the production of artwork from waste materials. *(Mega-Tech Inc, 2004-1)*

Waste Recovery Schemes

Recycling Schemes

- *2 Bag Programme:* This programme was first implemented in the Marina da Gama complex in Muizenburg with the issuing of yellow bags for recyclables, and black bags for non-recyclable waste. The Marina da Gama complex has 1000 households, and of these 50-60% participate in the programme on a weekly basis, while 75-80% of the households place a yellow bag outside their homes at least once a month. The programme has thus exhibited a high participation rate from the community concerned, but it still remains economically unviable due to high collection costs. The yellow bags (recyclables) are collected by a contractor, namely Enviroglass, and the black bags are collected by the City Council. A further proposed collection plan is to use a single Council truck with a separate compartment for recyclables to collect both the black and yellow bags. The yellow bags would be placed in the recyclables compartment while the black bags would be placed in the truck compactor. The implementation of this phase should improve the economic feasibility of this programme. A similar 2-bag system is proposed for the Cape Town suburb of Sea Point, but this programme has not yet been implemented. Sea Point is comprised predominantly of flat complexes and restaurants, so the potential for recyclables recovery in the area is quite high, because there is a high waste generation rate per square metre of land. *(Mega-Tech Inc, 2004-1)*
- *Recycling Centres/Depots:* Many of the schools in Cape Town operate recycling depots, some of which also collect recyclables from restaurants. A large number of buy-back centres also exist in Cape Town, with the majority accepting only paper and cardboard. *(Mega-Tech Inc, 2004-1)*
- *Landfill Scavenging for Recyclables:* The Bellville South, Coastal Park and Vissershok Waste Disposal facilities allow landfill recyclers to collect recyclables from the landfill during the operating times of the landfill. The recyclables collected are sold to a contractor, Interwaste, that manages the landfill scavenging operations. *(Mega-Tech Inc, 2004-1)*

Composting

- *Mixed Waste Composting Plants:* The City Council operates two composting facilities, namely Radnor and Sacks Circle Composting Plants, that mainly process mixed household waste with the aim of recovering organic waste to produce compost. Both facilities were initially equipped with a magnetic separator (that separates out metal from the mixed waste) but only the one present at the Sacks Circle Composting Plant is currently operational. The waste is split into two fractions, namely compostable and non-compostable materials. The non-compostable materials are sent to landfills, and the compostable material is further processed. The Radnor Composting Plant makes use of an aerated rotating drum fermenter followed by windrows (that are turned every 10 days) to biologically degrade the organic fraction of the waste received at the plant. Sacks Circle Composting Plant only makes use of windrows, with the waste being turned and wetted every month. Approximately 50% of the waste received at these facilities is sent to landfills. *(Mega-Tech Inc, 2004-1)*

- *Drop-off Facilities:* The City Council's aim is to have a drop-off facility within 5-7 km away from every business/household/industry. Some of the current drop-offs are managed by private contractors, including Interwaste. The contractor managed drop-offs have pre-processing facilities that include garden waste chipping facilities used to decrease the bulking factor of the garden waste and hence decreasing transportation costs. Garden waste is sold to one of three private composting companies, namely Biocircle, Master Organics or Reliance Compost Trust. *(Mega-Tech Inc, 2004-1)*

Builder's Rubble Recovery

- *Landfill Cover Material:* Builders' rubble up to 1 ton that is suitable as landfill cover can be delivered free of charge to landfills. This offers building firms an incentive to deliver their building rubble for use as the daily landfill cover material which is required by each landfill to cover the disposed waste at the end of each day of operation. The City Council has a shortage of landfill cover material and hence relies quite heavily on builders' bringing their rubble to the various landfills as landfill cover material *(Mega-Tech Inc, 2004-1)*. Considering this as well as the fact that the daily landfill cover requirement is 150mm (*www.dwaf.gov.za; accessed 11/11/2006*), the scope for increase in builders' rubble recovery is fairly limited.
- *Clean Builders' Rubble Recycling:* There are a few companies involved in the gathering, processing (crushing and grading) and reselling of building materials. The largest of these companies is Malan's Quarry. *(Mega-Tech Inc, 2004-1)*

4.2 REQUIRED METHODOLOGICAL DATA

The specific information required for the development of Cape Town's Municipal Solid Waste Management System (MSWMS) economic model is grouped into the different stages of the model formation as follows:

i. Flow diagram data.
ii. Waste stream mass balance data.
iii. Economic model data.

4.2.1 FLOW DIAGRAM DATA

The data used to develop Cape Town's Waste Flow Diagram was captured from the City of Cape Town's Solid Waste Management Status Quo Report *(Mega-Tech Inc, 2004-1)*. The proposed use of material recovery facilities (MRFs) to recover recyclables from general waste was included in the model and information on the possible characteristics of this scheme was gathered from *Novella (2002)*. The proposed scheme works on the premise that in the future the majority of Cape Town's collected waste will first go through a transfer station before being disposed on operating landfill sites. Hence, an effective waste recovery scheme would be to combine the transfer stations with MRFs and Composting Facilities. Recyclables and organic waste would be recovered from the general waste at each of these respective facilities before the waste stream is sent to the transfer station, and then ultimately to a landfill. The separate collection schemes for recyclables and organic waste (proposed) were designed to be sent to the MRFs and Composting Facilities respectively. *(Novella, 2002)*

The developed flow diagram for Cape Town is shown on the following page (note that the streams marked in bold are those streams that are facilitated or assisted by the Municipal Council and represent the streams that are considered in the model).

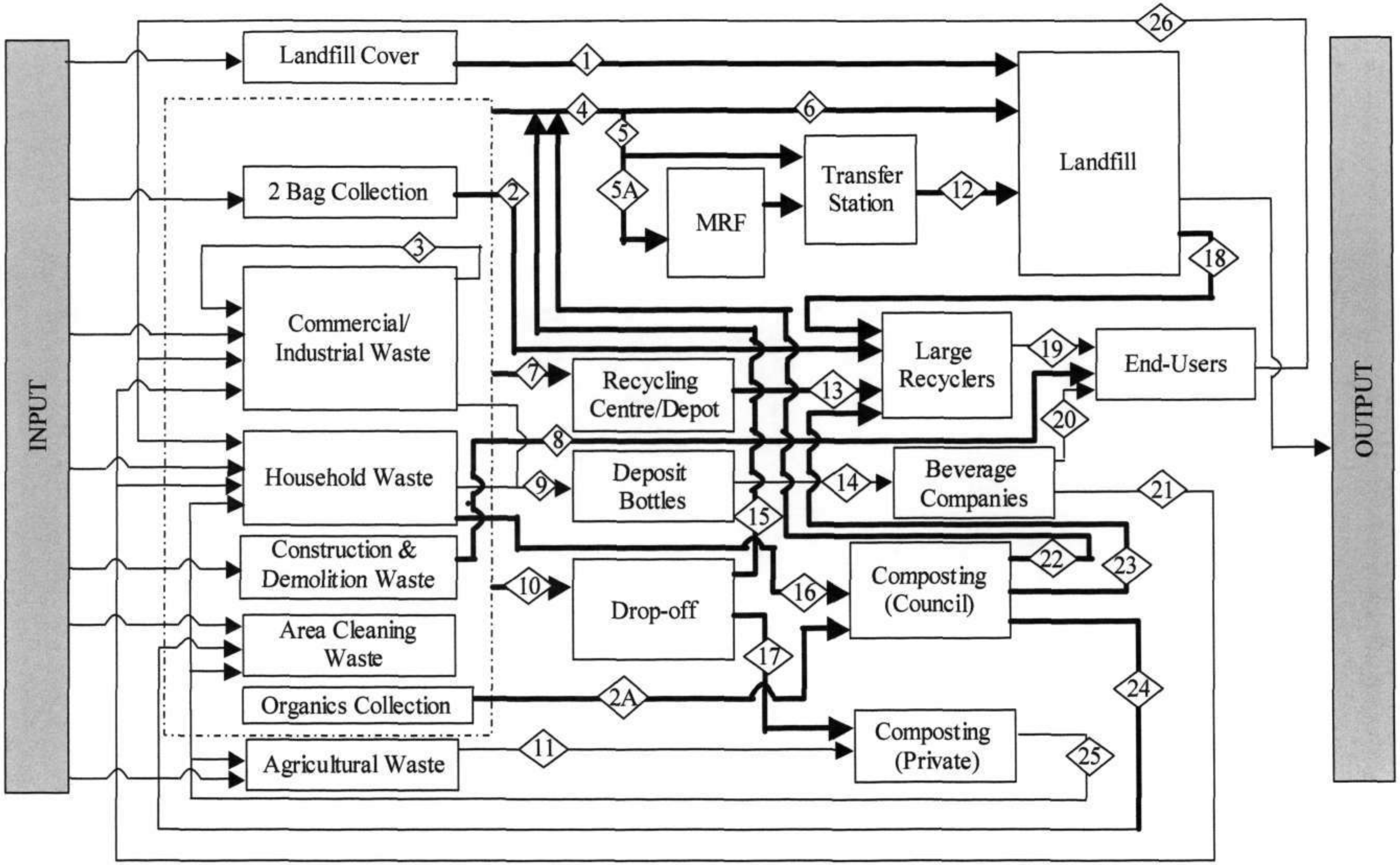

Figure 4.2: Flow diagram of the waste stream in the city of Cape Town

4.2.2 WASTE STREAM MASS BALANCE DATA

The waste composition of Household and Commercial/Industrial waste is presented in the table below.

Table 4.1: Composition of household and commercial/industrial waste.

Component	**Household (%)**	**Commercial/Industrial (%)**
Organics	47%	31%
Metal	5%	1%
Glass	8%	2%
Paper & Cardboard	19%	18%
Plastic	13%	1%
Other	8%	47%
TOTAL	*100%*	*100%*

The data presented in Table 4.1 was extracted from the City of Cape Town's Solid Waste Management Draft Assessment Report *(Mega-Tech Inc, 2004-2)*. The household waste composition data was calculated through the compilation of the data from two separate reports *(Ingerop Africa, 1999; Wright-Pierce et al, 1999)* that investigated the composition of household waste from three different income groups, namely low, middle and high income. The data from both studies was collected through the characterisation of waste collected from specific areas in Cape Town, including all three economic groups. The overall household waste component characteristics were calculated by multiplying a specific components composition for each income group by the respective fraction of the total amount of household waste each economic group produces and then summing these values to give each overall component composition. The composition of commercial/industrial waste was not referenced and thus the source of this data is unknown. Since no other information on the commercial/industrial waste composition could be obtained this reported data was used as an estimate. Only the recyclable fractions were reported in this waste composition characterisation and hence the unclassified composition of 78% was assumed to be 40% organics and 60% other material, which gave the respective component composition reported in the Commercial/Industrial composition column of Table 4.1.

Data on the characterisation of the total generated waste stream into four components, namely household, commercial/industrial, green and builder's rubble waste was gathered from the City of Cape Town's Solid Waste Management Status Quo Report *(Mega-Tech Inc, 2004-1)*, and is presented in the figure below:

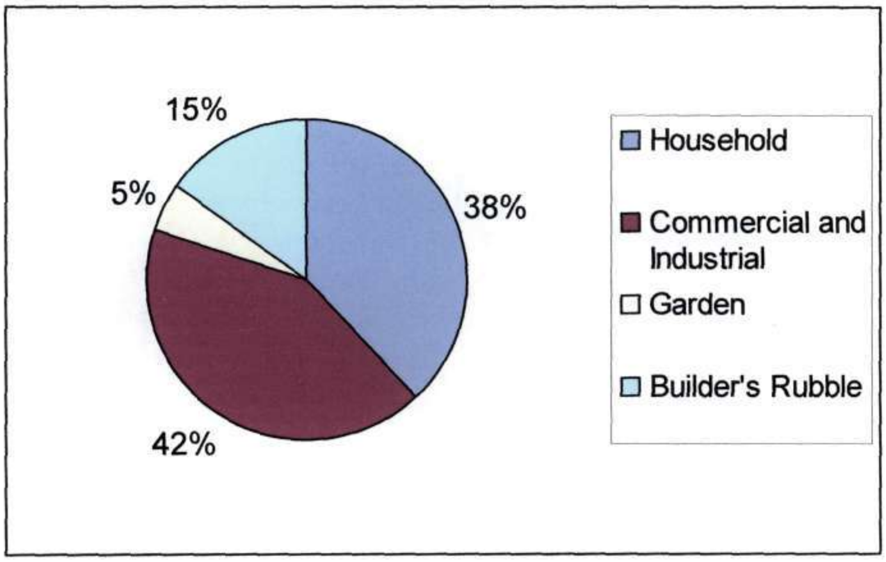

Figure 4.3: Overall composition of generated waste.

Garden waste is further classified as having three sources in the City of Cape Town's Solid Waste Management Draft Assessment Report *(Mega-Tech Inc, 2004-2)*, which include garden services (44%), topping up of bin (32%) and parks authority (24%). The parks authority and garden services garden waste was assumed to all be transported to drop-off facilities and hence knowing that garden refuse comprises 65% of drop-off waste the total drop-off waste stream flow rate can be determined with the rest of the waste being builder's rubble. The recovery of garden refuse from drop-offs was reported as 64% in City of Cape Town's Solid Waste Management Draft Assessment Report *(Mega-Tech Inc, 2004-2)*, and this was used to determine the amount of recovered material from drop-offs, with all of the builder's rubble received at drop-offs taken as being sent to landfill.

The component characterisations of all of the recycling streams (including 2-Bag Collection, Recycling Centres/Depots and Landfill Recycling) were determined through the use of the baseline data (2002/2003), and these compositions were assumed to remain constant for the purpose of the model. The Separate Organics Collection stream was assumed to be comprised of 90% recoverable material and the rest being non-recoverable, with the waste source being household waste (as the Council does not collect any commercial waste). This assumption is in line with the Marina da Gama 2-Bag Collection data that revealed that 10% of the materials in the recyclable bags collected were non-recoverable. The 90% recoverable fraction of the Separate Organics Collection stream was further split into one tenth garden waste and nine tenths food waste. The Sacks Circle Composting plant was contacted to determine the amount of metal recovered from the plant, and this yielded that 2% of the recovered waste is metal, with the rest being organics.

As is highlighted in the Methodological Approach chapter (Chapter 3), two split fractions are used to determine the flow rate of two scheme split procedures whereby firstly the Combined Collected Waste stream is split into waste sent directly to Landfill Sites and into waste that is sent to Transfer Stations, and secondly the split fraction that splits the resultant Transfer Station waste into waste sent to MRFs prior to transfer and waste sent directly to the Transfer Station. The first split fraction (F1) values were manually changed according to the year modelled, using data from *Coetzee and Botes (2005)*, which forecasts the fraction of waste that will be sent to transfer stations for several future years. Values for the total amount of generated waste for future years were also extracted from the presentation by *Coetzee and Botes (2005)*. The second split fraction used in the waste stream analysis is used to split waste sent to transfer stations into waste that is first processed in Material Recovery Facilities (MRFs) and waste that is not processed in the MRFs, and the values of this fraction are determined from the MRF Recovery stream mass fraction that is determined by the model.

4.2.3 COST MINIMIZATION MODEL DATA

The various streams that are changed in the model, as well as the variables associated with them, are shown in Table 4.2.

Table 4.2: The stream fractions that are changed in the model and their associated variables.

Stream	Operational Cost for 2003/2004 (R/tonne)	Stream Income Values for 2003/2004 (R/tonne)
Landfill Waste [1]	40.1	74.3 (bulk waste only)
Recovered Landfill Waste	-	-
MRF Recovery [2,3]	38.9*(M)+5753727*n	$413*m_m+155*m_g+525*m_{pc}+800*m_p$
Recycling (Co-Collection) [4]	$108.3*M_{co}+5753727*n$	-
Organics Collection [1,5]	560.6	$D*100*m_o$
Recycling (Centres)	-	-
Mixed Waste Composting [6,7]	240.1	$D*100*m_o+413*m_m$
Drop-Off (DO) Waste	-	-

Table 4.2 summarises the cost and income values for the various streams that are changed by the model to give the minimal overall net MSWMS cost. It is important to note that the reported cost of landfilling waste includes the cost of operating Drop-Off Sites due the fact that these sites serve as Intermediate Disposal sites for Garden and Builders' Rubble refuse. The disposal cost was determined by dividing the non-administrative Landfill and Drop-Off Site operational cost of R68.9 million (2003/2004) by the amount of landfilled waste for the year 2003/2004, namely 1,719,000 tonnes, yielding the resultant value of R40.1/tonne *(Mega-Tech Inc, 2004-1)*. In terms of the income gained from bulk landfill waste it is important to note that this is only a small fraction of the waste that is disposed in the landfills. Bulk waste represents all commercial waste that is collected by private Waste Management Companies (or delivered by individual companies) and is brought to one of the Municipal landfills for disposal. The Recovered Landfill Waste stream is operated by a private company, and hence exhibits no costs or income for the Municipal Council. The flow rate of this stream was kept constant at 1469

[1] **Mega-Tech Inc, 2004-1**
[2] **Chang et al, 2005**; Glossary: M=input flow rate to MRFs, n=number of MRFs in operation.
[3] **Beningfield, 2002**; Glossary: $m_{(i)}$=mass of material (i) recovered (m=metal, g=glass, pc=paper & cardboard, p=plastic).
[4] **DSM Environmental, 2004**
[5] **Jarrod Ball & Associates, 2003**
[6] **Renkow and Rubin, 1998**; Glossary: m_h=household waste sent to compost plant, m_s=separate organics collection.
[7] http://www.defra.gov.uk/corporate/consult/animalbyprod/purpose.htm; Glossary: D=degradation factor.

tonnes/year for all years modelled as a result of the fact that landfill picking is not a favourable recovery scheme from a social perspective.

The MRF operational costs were obtained from *Chang et al (2005)* in which a plot of the operation costs of various existing MRFs in the United States of America versus the input flow rate (design capacity) yielded a linear regression for the MRFs with high input rates. The R^2 value for the regression was 0.99, which is testimony of the linear nature of the data. Processing plants normally exhibit an economy of scale in terms of the design capacity of the particular plant, and this was also shown by *Chang et al (2005)*. This design capacity economy of scale translates into the fact that the bigger the plant the lower the operational cost per tonne of processed material, which is not a linear function. However, the reason that the MRF data plotted in the *Chang et al (2005)* article is linear is that the data plotted was of high input flow rates and hence at these design capacities the operational cost exhibits the best economy of scale and becomes a linear function. The reason the y-intercept of the linear equation is multiplied by the number of MRFs in operation is that this initial cost is required for each individual MRF to be shifted from the region of cost per design capacity that exhibits an increasing design capacity scale economy to the linear region in which the operational cost per tonne is a constant. The original equation was converted from US$ to Rand through the use of engineering techniques (see **Appendix D1**). An important constraint in the design of MRFs is the requirement that the organics feed to the plant must be fairly low for hygienic reasons. The chosen specification of the MRF feed was <25% organics. This constraint is the driving force behind operating expensive composting plants and influences the material recovery rates in the MRFs. The recovery rate at this specification was taken as 50%, which is the approximate value reported in a recent Pikitup Material Reclamation study (*DSM Environmental, 2004*). Material collected in the 2-Bag recycling scheme which is sent to the MRFs was given a recovery rate of 80%, which is the middle value reported for clean MRFs in a report written for the European Commission on the costs of various waste management techniques employed in Europe (http://europa.eu.int/comm/environment/waste/studies/pdf/euwastemanagement_annexes.pdf.; accessed 23/03/2006).

The 2-Bag Recycling stream economic variables in Table 4.2 were also taken from Piktup's recent Material Reclamation study *(DSM Environmental, 2004)*. The values of the economic variables given in Chapter 8 of the City of Cape Town's Solid Waste Management Status Quo Report *(Mega-Tech Inc, 2004-1)* were only used for the year 2005/2006, as these values correspond to the current separate collection method of having a private contractor collecting the recyclables and the Council collecting the rest of the waste. The economic variables reported in Piktup's Material Reclamation study *(DSM Environmental, 2004)*, however, are valid for the proposed future collection system whereby recyclables and the remaining household waste are collected by the same collection vehicle. Hence, with the exception of the year 2005/2006, all of the modelled years make use of the latter economic variables.

The separate Organics Collection stream operational cost reported in Table 4.2 is comprised of the separate organics collection cost as well as the cost of operating Composting Plants that convert this raw material into compost product. The collection cost was assumed to be equal to the product of the Separate Organics Collection Cost for Johannesburg (reported in Chapter 5) and the Collection Cost Location Factor calculated for Cape Town relative to Johannesburg. The Collection Cost Location Factor was determined by dividing the refuse collection cost of Cape Town by the respective cost for Johannesburg, yielding a value of 1.3. The resultant collection cost is R400.4/tonne of organics collected. The cost involved in operating a Composting Plant with input streams of high organics purity was reported in http://www.defra.gov.uk/corporate/consult/animalbyprod/purpose.htm (accessed 05/01/2006) to be R160.2/tonne of input (converted cost from pounds to rands).

The Recycling Centres stream is operated independently of the Municipal Council, however as mentioned earlier recycling subsidies are often given to the organisations that run these schemes. The subsidies given are calculated through the use of airspace credits where the organisations that run recycling schemes are credited with the money that the Council would have had to pay if the recovered waste had to be processed. The airspace credit is taken to include the cost of processing waste through transfer stations as well as the disposal cost to landfill the waste, and along with each individual stream income is subtracted from the operational and capital costs of all of the respective recovery streams to yield the net cost for each specific stream. The airspace credit value is calculated by adding the landfill disposal costs to the product of the fraction of waste sent to transfer stations with the transfer station operational cost per tonne. The fraction of collected waste that is sent through transfer stations will increase from its current 2005/2006 value of 0.2 to approximately 1 by 2016 as reported by *Coetzee and Botes (2005)*. The 2003/2004 operational cost of the Athlone Refuse Transfer Station was reported as being R13.34 million in Chapter 7 (pg. 7-8) of the City of Cape Town's Solid Waste Management Status Quo Report *(Mega-Tech Inc, 2004-1)*. Hence taking into account that this transfer station has a design capacity of approximately 250,000 tonnes/year the operational cost for this facility was R53.3/tonne for 2003/2004.

The operational cost for the Mixed Waste Composting Plants reported in Table 4.2 was extracted from *Renkow and Rubin (1998)*. This source was a study of the operational and capital costs of a number of existing Mixed Waste Composting Facilities in the USA, and reported an average operating cost of US$28/tonne of waste processed in these facilities. This was also converted through the use of engineering techniques to a cost in South African Rand terms (see **Appendix D1**). The resultant cost of R240.1/tonne is similar to the cost reported for the existing Sacks Circle Composting Plant of R288/tonne (from Chapter 7 of the Status Quo Report by *Mega-Tech Inc, 2004-1*). The former of these two costs was used in the model as a result of the fact that the Composting Plants are to be upgraded to current technologies that are represented by the former cost. The cost of processing general household waste in Composting Facilities was thus calculated by multiplying the reported Mixed Waste Composting operational cost by the amount of household waste sent to the Composting Plants. The reason that the Mixed Waste operational cost is significantly higher than the operational cost of the separate Organics Collection Composting Plants is that the waste from the separate Organics Collection stream requires little or no pre-sorting and processing before it is composted in windrows. Hence the cost reported for processing the separate Organics Collection waste stream is the operational cost of producing compost from a relatively pure organic feedstock, while the Mixed Waste Composting operational cost incorporates this function as well as the function of separating out the organic fraction of the general waste. The income generated from producing the compost comes from the recovery of ferrous metals and the sale of compost product. The compost was assumed to be sold at the lowest value of bagged compost product, namely R100/tonne (which is the price reported in Chapter 7 of the Status Quo Report by *Mega-Tech Inc, 2004-1*). The degradation factor used in determining the compost product income is the fraction of the initial organic mass that remains after degradation. The composting degradation factor is reported by *Renkow and Rubin (1998)* to be between 0.4 and 0.75, and hence the value of 0.6 was chosen.

As mentioned earlier the Drop-Off facility costs are incorporated in the Waste Disposal costs, and it is important to note that this waste management scheme is a pre-requisite of a good MSWMS and hence is mandatory. If the general public is not given the opportunity to deliver garden and builders' rubble waste to facilities close to where they live then waste dumping would become more prevalent. The Drop-Off flow rate fraction of the total generated waste stream was thus taken as being constant, with a value of 0.053 (the value calculated for 2002/2003 is 0.035, however since the number of operating landfills is decreasing all the time the Parks Authority waste was assumed to be sent to Drop-Offs for future years).

In terms of the Combined Collected Waste stream the cost of collection was determined by dividing the operational cost for collection services by the total amount of waste collected by the Municipal Council (which encompasses Drop-Off waste and all of the unrecovered generated household waste). The collection services operational cost for 2003/2004 was reported as R379.18 million in Chapter 6 of the City of Cape Town's Solid Waste Management Status Quo Report *(Mega-Tech Inc, 2004-1)*. It was assumed that the administration/overhead costs encompassed in this cost were 25.9% (which is the administrative portion of the Waste Disposal cost reported for 2003/2004 in Chapter 7 of the Status Quo Report by *Mega-Tech Inc, 2004-1*). As a result of the fact that the administrative/overhead costs would be in place regardless of the quantity collected this portion of the cost was subtracted from the collection services operational cost and the resultant value is divided by the quantity to waste collected by the Municipality to yield the collection cost/tonne operational cost of R313.6/tonne.

The capital costs required to develop the infrastructure needed to operate several of the waste management schemes are highlighted in Table 4.3 below:

Table 4.3: The capital costs considered in the cost minimization model for 2003/2004.

Scheme	Capital Cost (Rand)	Source
Transfer Stations	$(51500*(M_{TS}/260)+48000000*n)/y$	*Coetzee and Botes, 2005*
MRFs	$(48876.7*(M_{MRF}/260)+14172062*n)/y$	*Chang et al, 2005*
Composting Facilities	$222.9*m_h+$ $(276.2*m_s+4269027.7*n)/y$	*Renkow and Rubin, 1998; http://www.defra.gov.za*
Co-Collection	$(9.5*S)/5+49.2*M_{CO}$	*Jarrod Ball & Associates, 2003*
Organics Collection	$(643246*(m_s/2772))/y$	*DSM Environmental, 2004*

Glossary: *M_{TS}=combined transfer station input flow rate; n=number of transfer stations, MRFs or Composting Facilities in operation; y=number of years over which capital was paid; M_{MRF}=combined MRF input flow rate; m_h=household waste sent to compost plant; m_s=separate organics collection; S=number of collection service points; M_{CO}=co-collection recyclables flow rate.*

The capital costs are included in the cost functions for each stream by calculating the total capital cost required to develop the various facilities and then dividing this value by the number of years over which these capital costs are paid. The number of years of payment is determined by subtracting the model year from the year 2005/2006, which is the year that capital spending on all of these proposed plants is expected to commence - as reported in Chapter 7 of the Status Quo Report by *Mega-Tech Inc, 2004-1* (as indicated on pg. 7.7). As reported earlier the costs to process General Household Waste as compared to separate Organics Collection Waste are very different, hence the inclusion of two separate terms in the capital cost of Composting Facilities. As is seen in Table 3.3 the first term of the capital cost reported for composting facilities (which represents General Household Waste composting) is reported as an annual dept service value (annual repayment value), and hence this term is not divided by the number of years of capital payment. Another important fact to note regarding the format of the data presented in Table 4.3 is that all of the capital costs were reported using the cost basis year 2003/2004.

The capital cost equations shown in Table 4.3 for both the Transfer Stations and MRFs are reported on a tonnes per day capacity basis, and hence the formula involves the division of the annual input flow rates to these respective units by 260 – which is the number of working days in a year. In terms of the capital cost equation reported for Co-Collection in Table 4.3, the cost is broken up into two components, with the first being the cost of providing bins for recyclables to all of the city's households and the second representing the cost of converting the current collection vehicle to include a recyclables compartment. The former of these two component costs is broken down into a R9.50 cost per bin, and is divided by 5 due to the fact that the average reported lifespan of Council bins is five years (*DSM Environmental, 2004*). The Organics Collection capital cost is made up of the cost of purchasing new REL refuse trucks for the purpose of separate organics collection, with each REL refuse truck costing R643,246 as determined from a newspaper article written in the Dispatch newspaper on 18/11/1997 *(http://www.dispatch.co.za/1997/11/18/page%203.htm; accessed on 31/03/2006)*. The refuse truck is multiplied by the quotient of the total separate organics collection flow rate and the value 2772. The value 2772 (units: tonnes/year/truck) represents the average annual collection capacity of a refuse truck in Cape Town, as calculated in **Appendix D1**.

In forecasting both capital and operation costs an inflation rate of 5% was assumed, while income was modelled to increase at 7% per year.

4.3 RESULTS AND DISCUSSION

The results are split into two sections, namely material flow rate results and economic results.

4.3.1 MATERIAL FLOW RATE RESULTS

The table below illustrates the stream compositions calculated by the model for several years.

Table 4.4: Modelled stream compositions of the total generated waste stream for several years.

Stream Percentage	2005/2006 (%)	2015/2016 (%)	2030/2031 (%)
Landfill Waste (Excl. DO)	84.34	70.21	59.49
Recovered Landfill Waste	0.06	0.05	0.04
MRF Recovery (Dirty)	0.00	1.42	5.51
Recycling (2-Bag)	4E-03	5.88	5.88
Recycling (Centres)	9.18	9.18	9.18
Organics Collection	0.00	8.03	14.67
Mixed Waste Composting	1.19	0.00	0.00
Drop-Off (DO) Waste	5.23	5.23	5.23
TOTAL	*100.00*	*100.00*	*100.00*

The first trend observed in Table 4.4 is that the amount of material sent to landfills decreases as time progresses, which is indicative of the fact that by decreasing the amount of material sent to landfills the Overall MSWMS net cost decreases. Hence, contrary to popular belief, it makes economic sense to divert material from landfills until a certain threshold value (which represents the point at which, under the proposed management system, all of the available material that is economically feasible to recover is depleted). The second trend is the increased amount of waste sent through MRFs as time progresses, which shows that the MRF scheme is a favoured waste recovery option in terms of its economic feasibility. It is important to note that the material sent through the MRFs is the sum of both the Dirty MRF Recovery and the 2-Bag Recycling streams. Table 4.4 reveals that the 2-Bag Recycling scheme is the favoured method of material recovery for materials sent to MRFs. This is as a result of the fact that clean recyclables yield higher recovery rates when passed through MRFs. The Recycling (Centres) stream is initially the favoured recovery mechanism, with the MRFs substituting this role once they are sufficiently developed and hence the model later attempts to minimise the flow rate of the Recycling (Centres) stream – as this stream ultimately diverts recoverable material away from the income-generating MRFs. The Recycling (Centres) stream was given the constraint that the mass fraction of this stream cannot go below the initial value reported for 2005/2006 as a result of the fact that this sector represents private recycling operations that will not likely fall away. This is the reason that the mass fraction for this stream remains constant. It is interesting to note that the Recycling (Centres) stream was the favoured recovery mechanism for the early modelled years despite the airspace credit subsidies paid out to private recyclers being kept at 100%. This illustrates that for the current years of operation it is better to fully subsidise the Recycling (Centres) stream than to send this waste to the landfill. Another interesting trend shown in Table 4.4 is that the stream mass fraction of Household Composted Material is immediately given a zero value after the current year as a result of the fact that the costs associated with this stream are enormous. The Organics Collection stream, however, increases with time due to the fact that this stream helps to minimise the amount of putrescible waste in the commingled waste sent to MRFs, and hence ensures that a greater amount of commingled waste can be fed into the MRFs while still obeying the constraint of keeping the feed organics composition less than 25%. The Cape Town Municipal Council has developed several future landfill targets , which are highlighted in the following figure along with the model values.

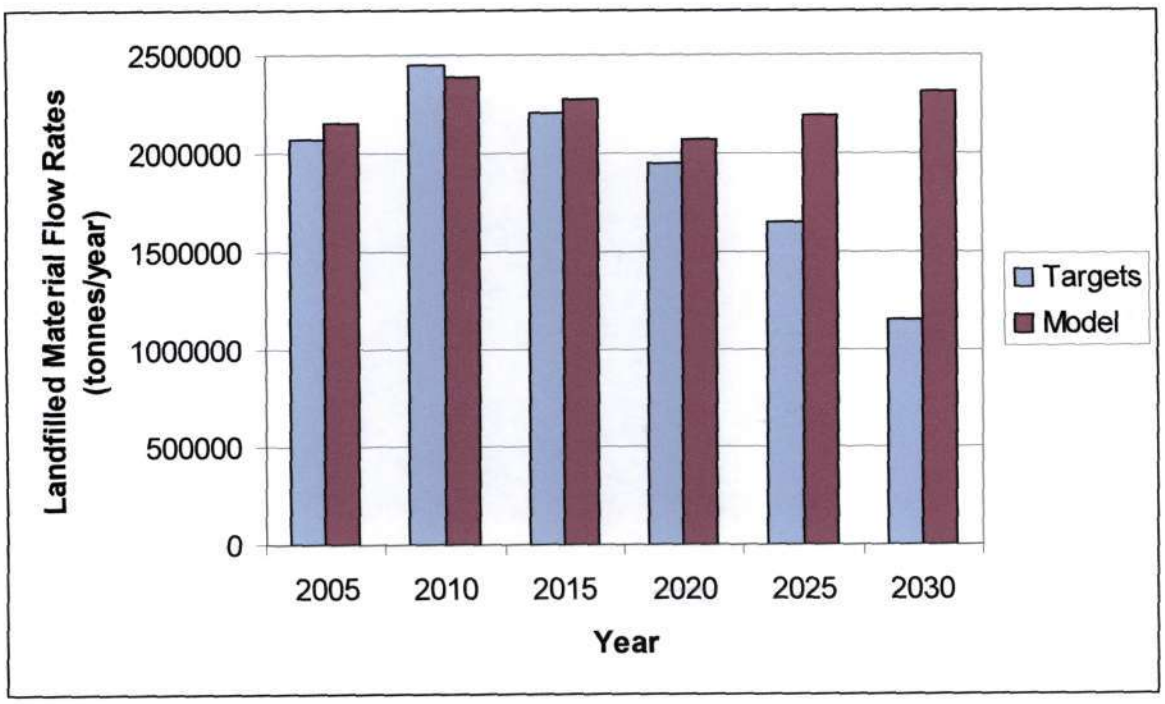

Figure 4.4: Model and target waste disposal flow rates for several future years.

Figure 4.4 above reveals that the target and model values are initially very similar, indicating that the targets set by the Cape Town City Council (reported in *Mega-Tech Inc, 2004-1*) can certainly be achieved at minimal cost to the Council. The targeted landfill waste becomes lower than the model values after 2020, which reveals that if the targets are to be met for the years following 2020, then the MSWMS has to be operated at a Overall Cost/Profit value lower than the maximum (at which the model values are set), or else alternative recovery schemes need to also be developed. The figure below plots the model and target generated waste recovery rates.

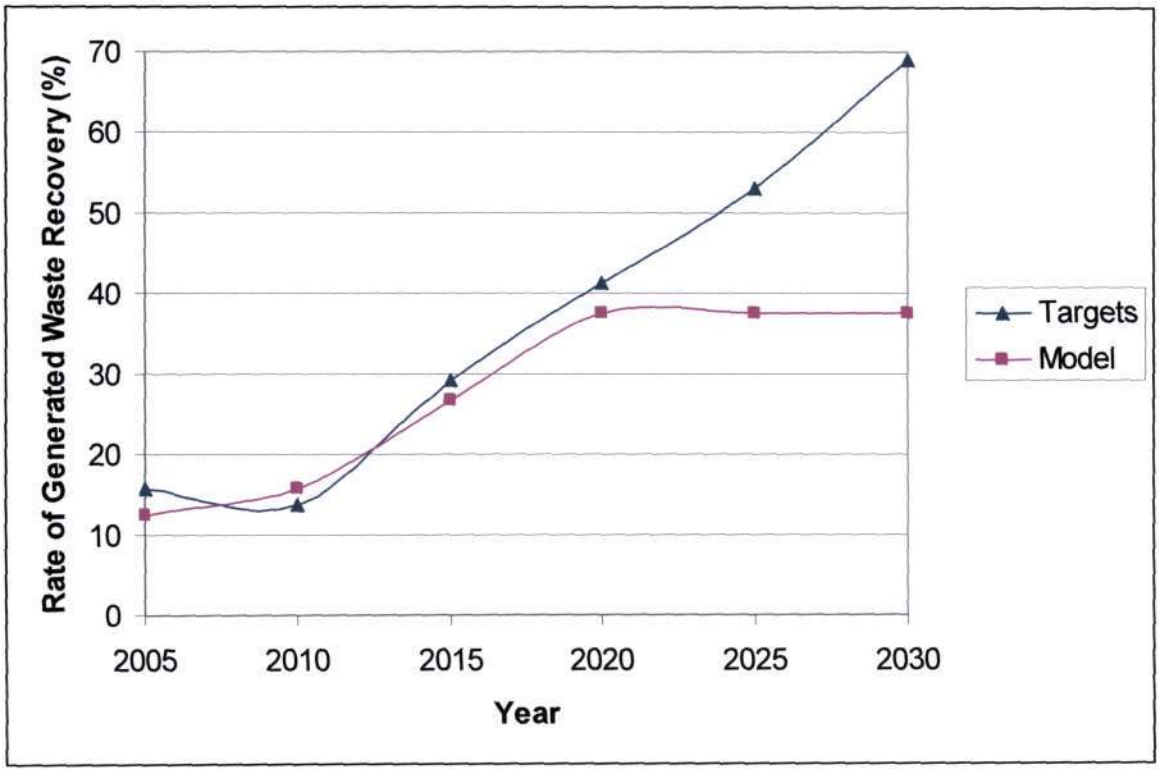

Figure 4.5: Model and target generated waste recovery rates for several future years.

As shown in Figure 4.5 the increases in the generated waste recovery rates for both the model and the target values are fairly parallel from 2005-2020. The plotted waste recovery target values exhibit a small initial five year lapse period, where the recovery rate remains fairly constant. According to the model it is favourable to start the commencement on recovery rate increases immediately, and the initial targets exhibit an unnecessary delay of the inevitable. The reason the model recovery rate starts to level off to the value of approximately 37.5% after 2015 is that this point represents the stage at which all of the economically recoverable material has been exploited and the remaining waste is either unrecoverable or too expensive to recover. To inform the decisions on how to properly increase the recovery rates of generated waste in line with the target values it is imperative that the composition of the waste modelled to be sent to landfills be analysed. As a result the composition of landfilled material as well as the composition of recovered material for the model year 2030/2031 are displayed below.

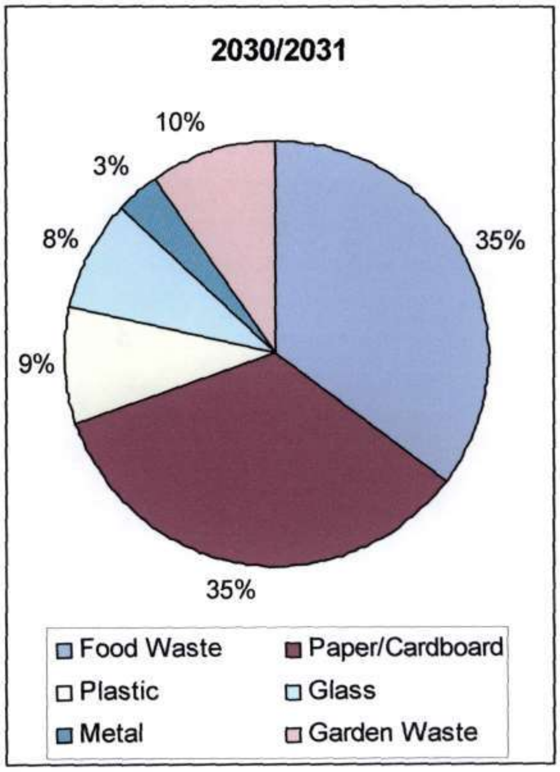

Figure 4.6: Recovered material composition.

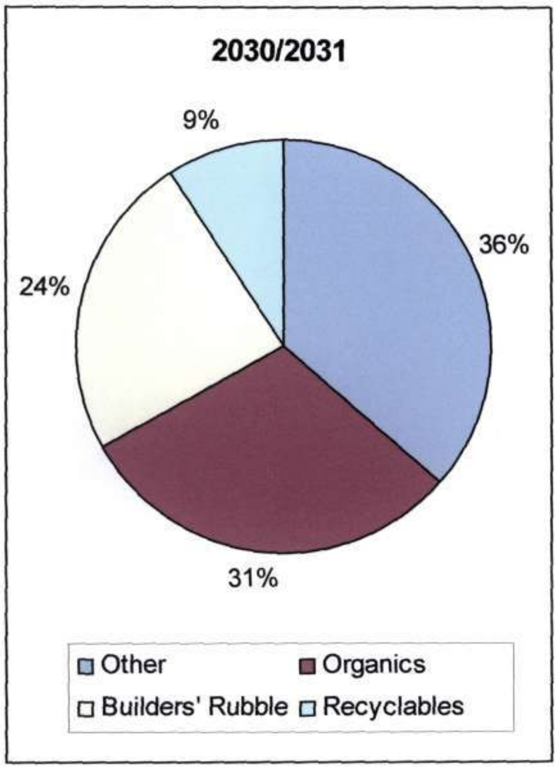

Figure 4.7: Landfill material composition.

Figure 4.6 reveals that 45% of the recovered material is organic (food waste and garden waste), indicating the importance of organic material recovery from the perspective of ensuring a feed to the MRFs with an organic composition of <25%. Due to the fact that the composting facilities operating costs are higher than the generated income from them, the model only favours these recovery schemes because they allow for greater inputs of material to the income-generating MRFs. Aside from the above-mentioned reason it is also vital to recover organic waste if a significant amount of the generated waste stream is to be diverted from being sent to landfills. As is to be expected the recyclable material that exhibits the greatest recovery in Figure 4.6 is paper and cardboard. Figure 4.7 above shows that 36% of the material sent to landfills is material that is not readily recyclable (classed as Other). In order to reduce the amount of other material and hence the amount of waste sent to landfills the government has to develop laws that ensure manufacturers only use readily recyclable material to produce products as well as in packaging materials.

4.3.2 ECONOMIC RESULTS

The net cost/profit values for the various years modelled are plotted below. These values are the resultant objective function values determined by Solver to be the maximum Overall MSWMS Cost/Profit values for the particular year concerned, under the programmed constraints.

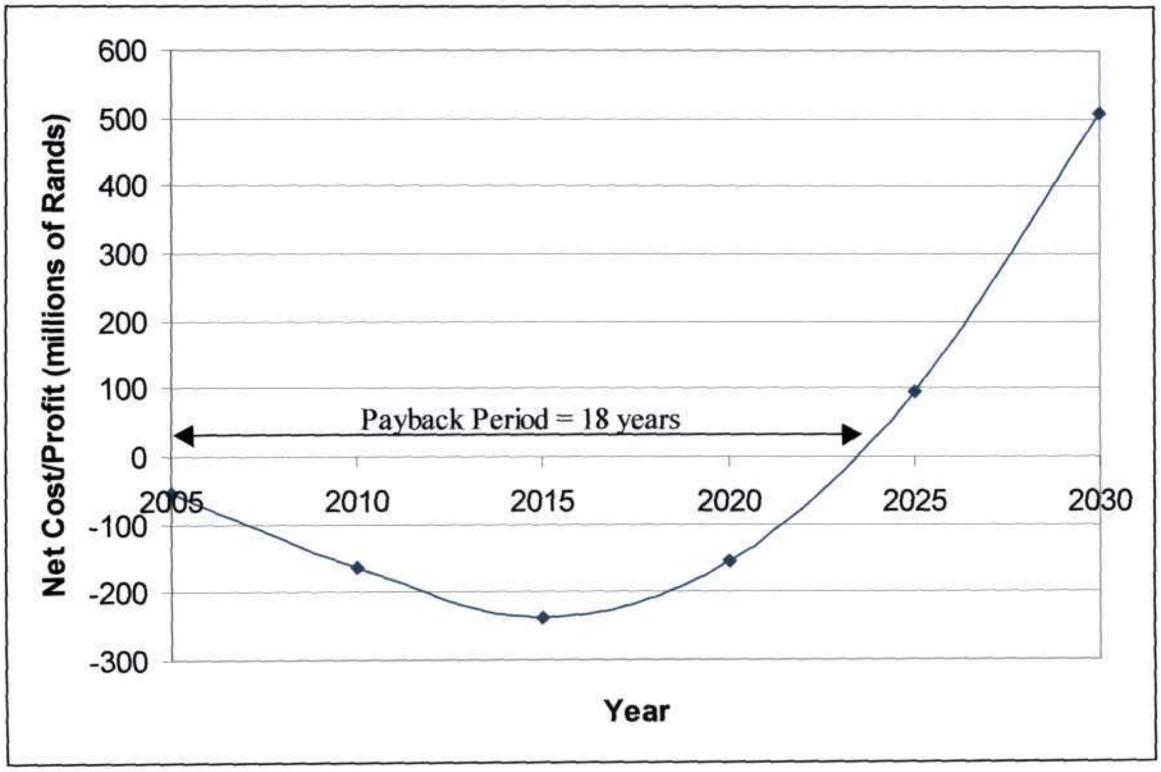

Figure 4.8: Plot of modelled net cost/profit (objective function values) for various years.

Figure 4.8 reveals that the payback period for the development of the proposed MSWMS is 18 years, meaning that if the MRF type MSWMS is chosen to be implemented in Cape Town then it will take 18 years for the income generated from the system to pay back the capital required for this MSWMS to be developed. The total calculated capital costs for the MRFs, Composting Facilities, Transfer Stations and Separate Collection Capital until 2030 are R2.36 billion, R0.61 billion, R0.76 billion, and R1.32 billion respectively. This indicates that the Cape Town Municipal Council requires a large amount of capital to start up this MSWMS, but when it is fully operational it will generate a large amount of income. After 2024, the Council will start to generate a net profit from the MSWMS, which will continue to increase. This profit could be used to implement further projects to increase the recovery of waste materials, and thereby decreasing the amount of waste sent to landfills.

4.4 SENSITIVITY ANALYSIS

The effects of annual income and inflation rate changes on the net cost/profit values exhibited by the model are highlighted in the figure below.

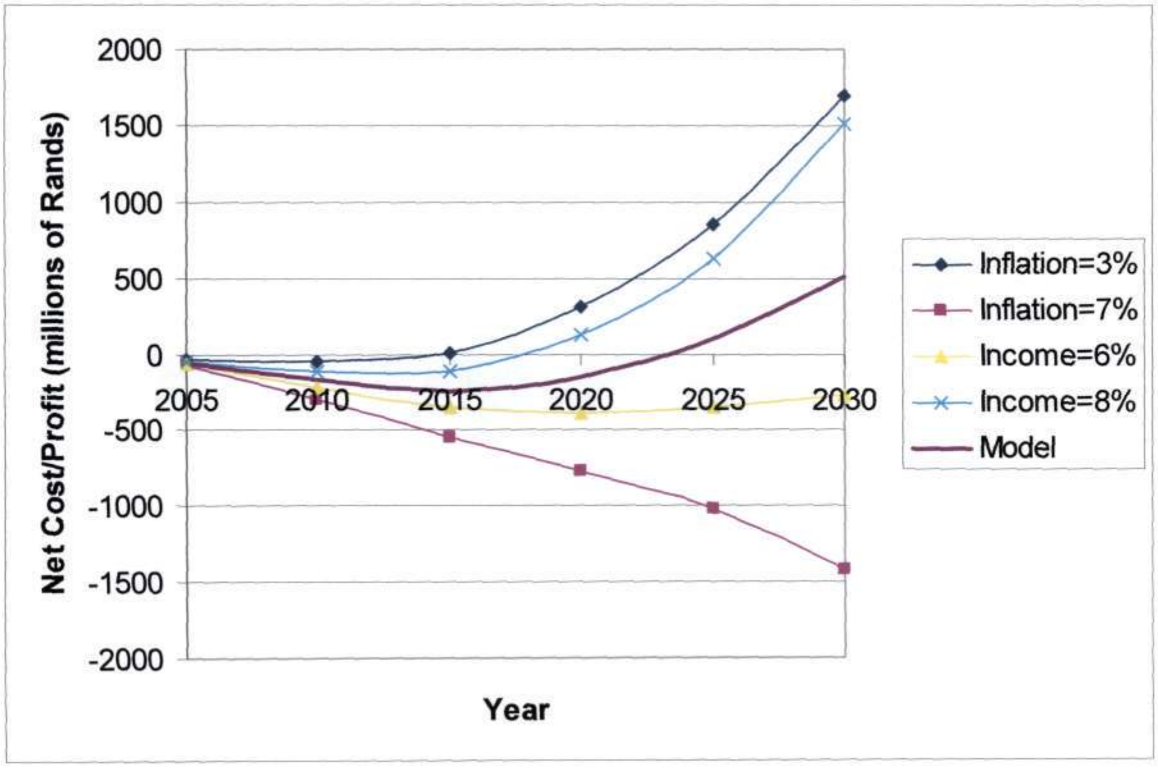

Figure 4.9: Sensitivity analyses of the income increase and inflation rates used in the model.

The model values used for the annual income increase and inflation rates are 7% and 5% respectively. Sensitivity analyses on these two important model parameters yielded the graphs shown in Figure 4.9. When carrying out the analyses only one parameter was changed at a time with the other being kept at its original model value. The inflation rate analyses at 3% and 7% revealed that the payback periods changed from the original model value of 18 years to 9 and infinite years respectively. An infinite payback period means that the MSWMS costs will always exceed the income generated from the MSWMS, as demonstrated in the 7% inflation rate graph. On the other hand when keeping the inflation rate at the original value of 5% and changing the annual income increase rate to 6% and 8% the payback period determined was 35 and 13 years respectively. These analyses have shown that changes in both the inflation rate and annual income increase rate have a major influence on the economic feasibility of the modelled MSWMS.

CHAPTER 5: CASE STUDY OF JOHANNESBURG'S WASTE STREAM

5.1 INTRODUCTION

5.1.1 BACKGROUND

Situated in the Gauteng Province, Johannesburg is South Africa's most populous city. Johannesburg is also South Africa's largest metropolitan economy, and presently generates approximately 2.47 million tonnes of general waste per annum. The majority of generated waste is disposed in the city's five Council-owned landfill sites, which are operated by the Council appointed waste management company Pikitup. Pikitup carries out the solid waste management function of the Johannesburg Municipal Council. Approximately 600,000 tonnes/annum of waste that is collected by private waste management companies is disposed into landfills outside of the Johannesburg Municipal boundaries, including the privately owned landfill site called Chloorkop, which is operated by the waste management company Enviroserv. The five operational Council landfill sites include Ennerdale (GMB$^-$), Goudkoppies (GLB$^+$), Linbro Park (GLB$^-$), Marie Louise (GLB$^-$) and Robinson Deep (GLB$^-$). *(Jarrod Ball & Associates, 2003)*

The Johannesburg waste management scheme makes use of a depot system, whereby waste collection is facilitated by depots set up in the various administrative areas of Johannesburg. The various waste management functions for the different areas of Johannesburg are hence co-ordinated by the depot within a particular area. These waste collection functions include Round Collected Waste (RCW), Dailies (daily organics collection from commercial enterprises), Illegal dumping, Street Cleaning and Bulk Services. There are currently 11 depots in operation within the Johannesburg Municipality. The collection of garden refuse is facilitated through the operation of Garden Refuse Sites throughout Johannesburg. These sites operate on the basis that garden waste is delivered and tipped into skips on these sites. Johannesburg currently makes use of 48 Garden Refuse Sites, some of which also have containers for recyclable material, but all of these sites do not accept builders' rubble. Builders' rubble has to thus be transported directly to the city's general landfill sites, or else contracted to be collected in skips by one of the city's waste management facilities. *(Jarrod Ball & Associates, 2003)*

Pikitup also currently operates an incinerator for medical wastes that is situated on the premises of the Robinson Deep Landfill Site. The following figure illustrates the positioning of the various landfill sites within the Johannesburg Municipality, as well as highlighting the waste loadings of these disposal facilities.

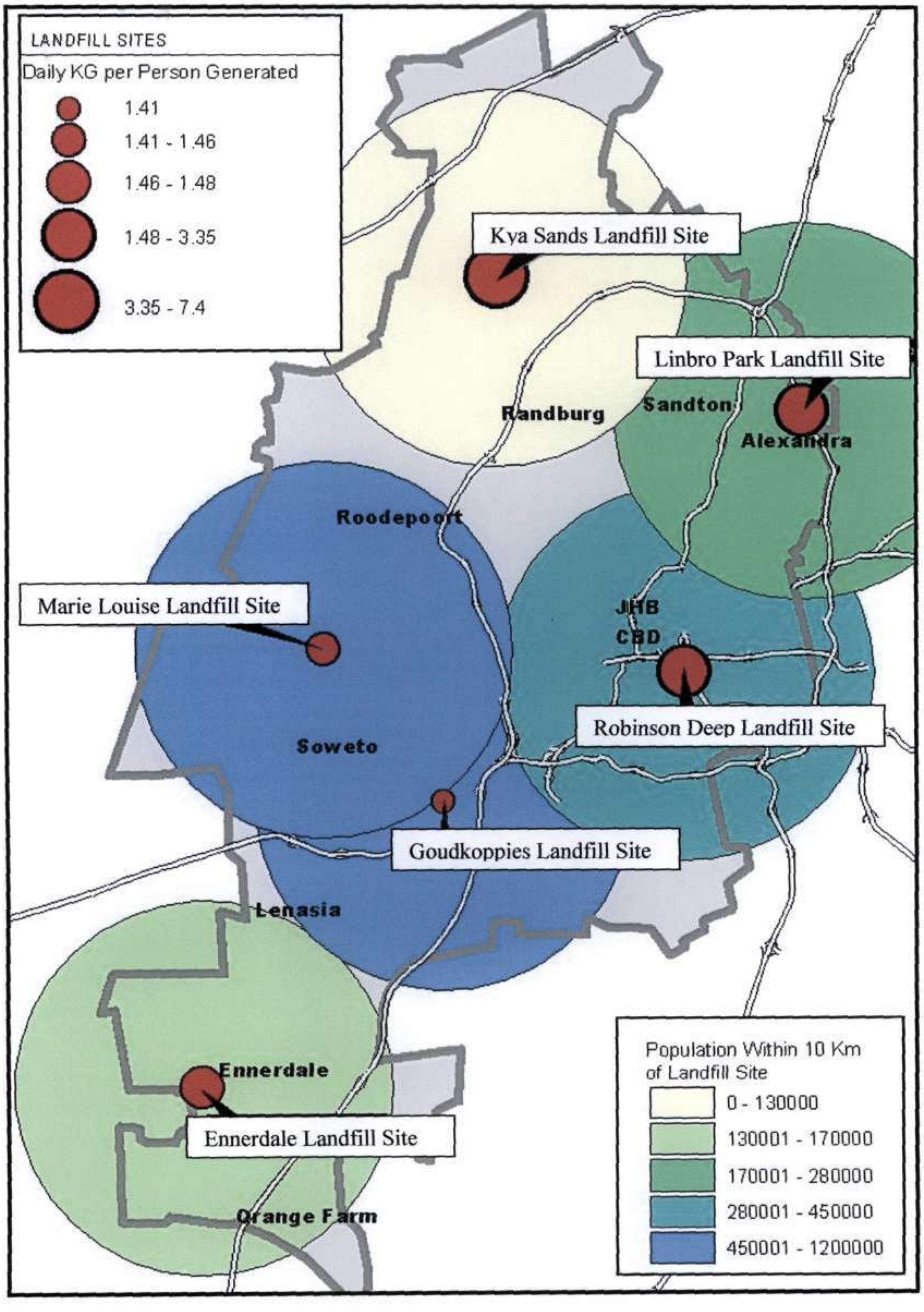

Figure 5.1: Johannesburg's operational and recently closed landfill sites.

(http://ceroi.net , accessed 16/03/2006)

Figure 5.1 above illustrates the location of Johannesburg's five operational Council landfill sites as well as the recently closed Kya Sands Landfill Site. Kya Sands Landfill Site was closed in 2002 after reaching final capacity. The proposed replacement for the closed Kya Sands landfill is the planned Northern Works Landfill Site, which is still being investigated under the Environmental Impact Assessment and DWAF Permit procedures. *(Jarrod Ball & Associates, 2003)*

Currently waste that was previously disposed of on the Kya Sands Landfill Site is being transported to the Linbro Park Landfill Site, or else is sent via transfer station to the private Chloorkop Landfill Site. Johannesburg's only transfer stations are the Dale Road and Olifantsfontein Transfer Stations that are situated in the Midrand/Ivory Park district. Chloorkop Landfill Site is situated in the Kempton Park area, which lies outside the north-eastern border of the Johannesburg Municipality. Hence the Chloorkop Landfill Site is not shown in Figure 5.1, which only illustrates the area covered by the Johannesburg Municipality. *(Jarrod Ball & Associates, 2003)*

The Linbro Park Landfill Site is expected to be closed by the end of 2006, which will result in increased amounts of waste from the northern areas of the Johannesburg Municipality being sent to the Chloorkop Landfill Site. This situation exacerbates the need for the Northern Works Landfill site to come into operation as soon as possible. Waste generated in the immediate surroundings of the Linbro Park Landfill will be sent to the Marie Louise Landfill Site once the former landfill is closed. The closure of the Marie Louise Landfill Site is expected to only take place in the year 2024, however the lifespan of this landfill is dependant on the extra waste loading that will be placed on the site once neighbouring landfill sites are closed. *(Jarrod Ball & Associates, 2003)*

With regard to the other three landfill sites the Robinson Deep, Ennerdale and Goudkoppies Landfills are expected to be closed in 2009, 2014 and 2040 respectively. *(Jarrod Ball & Associates, 2003)*

5.1.2 OBJECTIVES OF STUDY

- To develop a waste flow diagram of the Solid Waste Management System in Johannesburg.
- To develop an economic model of Johannesburg's Solid Waste Management System in order to analyse the financial feasibility of various municipal waste minimization schemes that are either currently employed or proposed for future use by Pikitup.
- To determine the effect of inflation and income increase changes on the financial feasibility of the various waste minimization schemes through the use of sensitivity analyses.

5.1.3 CONTEXT

Waste Reduction Schemes

- *Waste Minimisation Clubs:* Johannesburg has a number of Waste Minimisation Clubs in several different industries, namely the plastics, meat products, retail motor and metal finishing industries, among others. The Dutch company Beco is involved in facilitating these clubs. *(Jarrod Ball & Associates, 2003)*

Waste Reuse Schemes

- *Reuse of Deposit Bottles:* The Gauteng Province operates a deposit bottle recovery scheme called *Ecowash,* which aims at recovering liquor deposit bottles used to package alcoholic beverages produced by the Distell Group. It is estimated that the *Ecowash* programme results in the recovery of 1.5 million Distell deposit bottles from Johannesburg. Some of the beverage brands which make use of the deposit bottle system are the Distell Group, Coca-Cola and South African Breweries (SAB). *(Jarrod Ball & Associates, 2003)*

Waste Recovery Schemes

Recycling Schemes

- *Recycling Centres/Depots:* Many of the schools in Johannesburg operate recycling depots. Five Pikitup-supported buy-back centres also exist in Johannesburg, with the majority accepting paper, cardboard, glass bottles and jars, tins and expanded styrene. Several of the

Garden Refuse Sites contain receptacles for recyclables that are serviced by the various recycling companies in the city. *(Jarrod Ball & Associates, 2003)*

- *Landfill Scavenging for Recyclables:* Waste scavenging by Landfill Recyclers occurs on all five Pikitup operated landfill sites during the operating times of the landfill. Several empowerment companies, including Tshabala Waste and Vuma Waste manage the landfill scavenging operations, ensuring that the Landfill Recyclers collect recyclables under safe conditions. *(Jarrod Ball & Associates, 2003)*
- *Dirty Landfill MRFs:* MBB Consulting constructed a landfill MRF close to the Robinson Deep Landfill Site in 1988. This plant is operated by the waste management company Skip Waste, and incorporates a rotary drum screen that sorts the waste into low (organics) and high value (recyclables) waste, with the latter fraction being sent onto a conveyor for further hand sorting. The low value waste as well as the unrecoverable high value waste is then transported to the landfill. *(http://www.mbb.co.za , accessed 21/03/2006)*
- *Mondi's Ronnie Bag Scheme:* Roughly 3% of the waste paper collected for recycling in Johannesburg comes from the operation of this scheme that involves the provision of separate bags to households for the kerbside collection of paper. *(Jarrod Ball & Associates, 2003)*

Composting

- *Municipal Composting Plants:* The City Council operates two Sewage Sludge Composting Plants, one in the southern part of Johannesburg (Olifantsvlei Works) and another in the northern part of Johannesburg (Northern Works). Both these plants make use of chipped recovered garden waste as an additive to the waste sewage sludge in order to improve the quality of the resultant compost product. The garden waste is sourced from the Garden Refuse Drop-off Facilities. *(Jarrod Ball & Associates, 2003)*
- *Drop-off Facilities:* Pikitup operates 48 Drop-off Facilities (termed Garden Sites by Pikitup) in the city of Johannesburg, which accept garden refuse, but not builders' rubble. A number of these facilities also provide containers for the deposit of recyclable materials. *(http://www.pikitup.co.za/default.asp?id=686 , accessed 21/03/2006)*
- *Garden Refuse Composting Facility:* Recovered garden waste from several Drop-Off Facilities, including Ballyclare, Fairlands, Victory Park, Waterval and Woodmead, is sent to the Panorama Garden Refuse Composting Facility to be converted into compost product. *(http://www.pikitup.co.za/default.asp?id=629 , accessed 21/03/2006)*. The produced compost is sold to the surrounding community, and is registered by the Department of

Agriculture as a Type 2 fertiliser. The Panorama Composting Plant was constructed to process a maximum garden refuse capacity of 60,000 tons per annum. *(http://www.pikitup.co.za/default.asp?id=763 , accessed 21/03/2006)*

Builder's Rubble Recovery

- *Landfill Cover Material:* Soil material or builders' rubble that is suitable as landfill cover can be delivered free of charge to landfills. Cover material is used daily to encapsulate waste disposed, and this material needs to be sourced from outside if the landfill does not contain stockpiles of this material. Considering this as well as the fact that the daily landfill cover requirement is 150mm (*www.dwaf.gov.za; accessed 11/11/2006*), the scope for increase in builders' rubble recovery is fairly limited. *(Jarrod Ball & Associates, 2003)*
- *Builders' Rubble Usage as Fill Material:* There are a few construction companies that make use of builders' rubble as a fill material when constructing buildings. *(Jarrod Ball & Associates, 2003)*

5.2 REQUIRED METHODOLOGICAL DATA

The specific information required for the development of Johannesburg's Municipal Solid Waste Management System (MSWMS) economic model is grouped into the different stages of the model formation as follows:

i. Flow diagram data.
ii. Waste stream mass balance data.
iii. Economic model data.

5.2.1 FLOW DIAGRAM DATA

The data used to develop Johannesburg's Waste Flow Diagram was captured from the City of Johannesburg's Solid Waste Management Status Quo Report *(Jarrod Ball & Associates, 2003)*. Several waste minimization schemes were proposed for use as part of the Johannesburg Waste Management System in *DSM Environmental Services (2004)*. The most cost-effective of these schemes were added to the flow diagram, and include:

- The use of a separate collection system whereby recyclables and remaining refuse are collected by the same Refuse Truck, but in separate compartments. The recyclables would then be sent to Clean MRFs for sorting and recovery.
- Developing Dirty MRFs similar to the Skip Waste MRF, mentioned earlier, at all of the Pikitup landfill sites in Johannesburg. For this scheme, Waste Inspectors would be stationed at the weighbridge of a particular landfill with the role of diverting incoming refuse loads with high recyclables compositions to the particular landfill MRF concerned.

Another proposed waste minimization scheme included in the flow diagram was a separate organics collection scheme whereby putrescible waste would be collected from commercial enterprises and sent to food waste composting plants. Pikitup already runs a collection programme for the daily collection of putrescible waste (termed Dailies), however the programme involves the collection of only a small portion of available food waste.

The developed flow diagram for Johannesburg is shown on the following page (note that the streams marked in bold are those streams that are facilitated or assisted by Pikitup and represent the streams that are considered in the model).

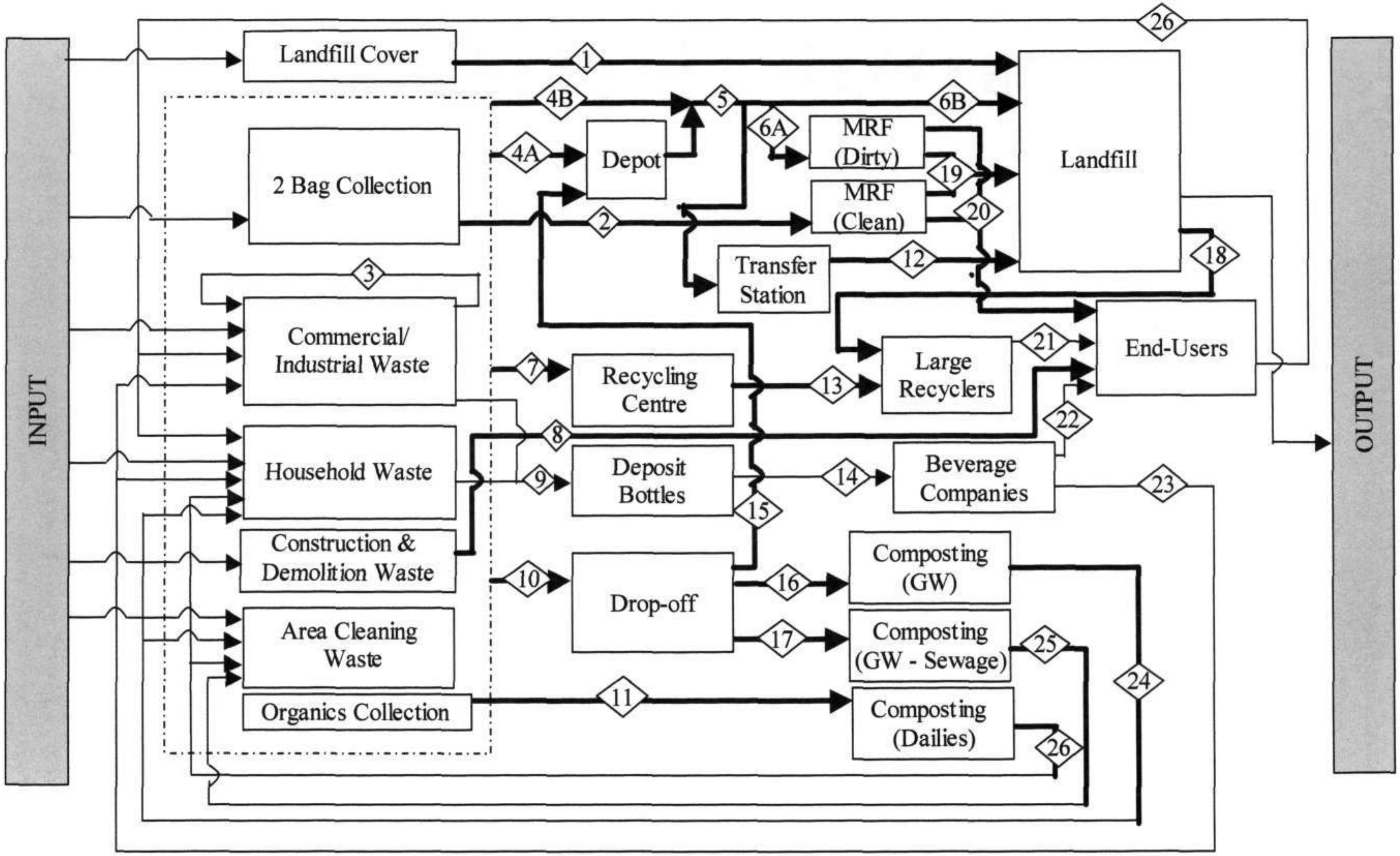

Figure 5.2: Flow diagram of the waste stream in the city of Johannesburg

5.2.2 WASTE STREAM MASS BALANCE DATA

The waste composition of Household and Commercial/Industrial waste is presented in the table below.

Table 5.1: Composition of household and commercial/industrial waste.

Component	Household (%)	Commercial/Industrial (%)
Builders' Rubble	2%	-
Green Waste	23%	-
Organics	12%	31%
Metal	3%	2%
Glass	4%	4%
Paper & Cardboard	17%	10%
Plastic	10%	7%
Other	29%	46%
TOTAL	*100%*	*100%*

The household waste composition data in Table 5.1 was calculated through the compilation of data gathered from landfill sampling of waste at three different landfill sites in Johannesburg, namely Linbro Park, Marie Louise and Robinson Deep. The data gathered from these studies was reported by *Jarrod Ball & Associates (2001)*. The waste sampling was carried out randomly choosing refuse loads brought in by truck from a particular area which was to be analysed, and the waste load was then emptied onto the landfill and a sample of this waste was taken by a Front-End-Loader. The sample was then analysed by a task team, and this same procedure was used to determine the composition of waste from other areas as well. Different areas were classed according to different socio-economic categories, and the categories included areas of low, medium and high income as well as the CBD classification for business waste *(Jarrod Ball & Associates, 2001)*. The overall household waste component characteristics were calculated by multiplying a specific component's composition for each income group by the respective fraction of the total amount of household waste each economic group produces and then summing these values to give each overall component composition. Data on the composition of commercial/industrial waste was taken from *van der Walt and Liebenberg (2004)*. Only the recyclable fractions were reported in this waste composition characterisation and hence the unclassified composition of 77% was assumed to be

40% organics and 60% other material, which gave the respective component composition for these components as reported in the Commercial/Industrial composition column of Table 5.1.

Data on the characterisation of the total generated waste stream into four components, namely household, commercial/industrial, area cleaning and green refuse was gathered from the City of Johannesburg's Solid Waste Management Status Quo Report *(Jarrod Ball & Associates, 2003)*, and is presented in the figure below:

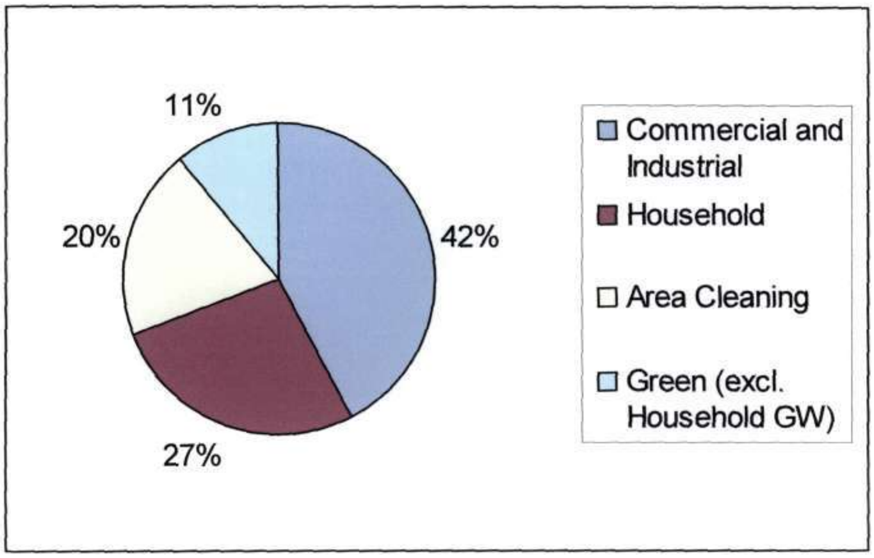

Figure 5.3: Overall composition of generated waste.

Garden waste is further classified as having three sources in the City of Johannesburg's Solid Waste Management Status Quo Report *(Jarrod Ball & Associates, 2003)*, which include garden services/drop-offs (61%), topping up of bin (35%) and street cleaning (4%). The garden services and street cleaning waste is transported to drop-off facilities and hence as a result of the fact that only garden refuse is accepted at Drop-Offs the total flow rate of waste going to the Drop-Offs can be calculated. The 2005/2006 recovery of garden refuse from drop-offs was reported as 12% *(http://www.pikitup.co.za/jit_default_763.html, accessed 23/03/2006)*, and this was used to determine the amount of recovered material from drop-offs for the model year 2005/2006.

The component characterisations of the Recycling Centres/Depots and Landfill Recycling schemes were determined through the use of the baseline data (2001/2002), and these compositions were assumed to remain constant for the purpose of the model. The Co-

Collections (2-Bag) recycling scheme component characterisations was determined by summing the products of the specific Household and Commercial/Industrial component characterisations and their respective collection factors. The collection factors are the mass fractions of the total refuse collection that represent the amount of Household and Commercial/Industrial waste collected respectively, and are as follows: Household Collection represents 69.9% of the total collected waste, while Commercial/Industrial waste collection represents 30.1% *(Jarrod Ball & Associates, 2003)*. Pikitup currently runs a Separate Organics Collection scheme (termed Dailies collection), whereby putrescible waste is collected from businesses on a daily basis.. The Separate Organics Collection stream is modelled to be sent to Food Waste Composting Facilities developed after the year 2015/2016, before which the waste was assumed to be sent to landfill.

The Combined Collected Waste stream was modelled to split into two streams, namely the MRF/Landfill Feed and the Feed to Transfer Stations. The split fraction for each of these respective streams was multiplied by the total and component values of the Combined Collected Waste stream to determine the respective flows for that particular stream. The split fraction was kept constant as a result of the fact that it is not likely that the amount of waste sent to Transfer Stations will increase in the modelled timeframe, due to the fact that Johannesburg has a large amount of space still available for Landfills in the various areas of the city. Values for the total amount of generated waste for future years were extracted from Appendix 18 of the City of Johannesburg's Solid Waste Management Status Quo Report. *(Jarrod Ball & Associates, 2003)*

The second split fraction used in the waste stream mass balance divides the waste sent to Landfills into waste that is first processed in Material Recovery Facilities (MRFs) and waste that is not processed in the MRFs.

5.2.3 COST MINIMIZATION MODEL DATA

The various streams that are changed in the model, as well as the variables associated with them, are shown in the following table.

Table 5.2: The stream fractions that are changed in the model and their associated variables.

Stream	Operational Cost for 2004/2005 (R/tonne)	Stream Income Values for 2004/2005 (R/tonne)
Landfill Waste [8]	26.7	85.22 (bulk waste only)
Landfill Waste Recovery	-	-
Dirty MRF Recovery [9]	$40.3*M_d+164{,}365*N_{dmrf}+35*(M_d-M_r)+130*m_{dm}+90*m_{dg}+150*m_{dpc}+200*m_{dp}$	$400*m_{dm}+250*m_{dg}+315*m_{dpc}+755*m_{dp}$
Co-Collection (2-Bag)[1, 2]	$110.6*M_c+31{,}719*N_{cmrf}+35*(1-R)*M_c+130*m_{cm}+90*m_{cg}+150*m_{cpc}+200*m_{cp}$	$400*m_{cm}+250*m_{cg}+315*m_{cpc}+755*m_{cp}$
Organics Collection [1, 10]	644.5	(565.5+100*D)
Recycling (Centres)	-	-
DO Waste Composted [11]	$69.9*M_{rgw}+491{,}273*N_{gwcf}$	D*100
DO Waste Landfilled	-	-

Table 5.2 summarises the cost and income values for the various streams that are changed by the model to give the minimal overall net MSWMS cost. In terms of the income gained from bulk landfill waste it is important to note that this is only a small fraction of the waste that is disposed in the landfills, with much of the privately collected waste being transported to privately operated landfill sites outside of the City of Johannesburg. It is important to note that the reported cost of landfilling waste includes the cost of operating Drop-Off Sites due the fact that these sites serve as Intermediate Disposal sites for garden and garage refuse. The disposal cost was determined by dividing the non-administrative Landfill and Drop-Off Site operational cost of R43.1 million (2004/2005) by the amount of landfilled waste for the year 2004/2005, namely 1,612,469 tonnes, yielding the resultant value of R26.7/tonne. Bulk waste represents all commercial waste that is collected by private Waste Management Companies (or

[8] **Jarrod Ball & Associates, 2003**

[9] **DSM Environmental Services, 2004**; Glossary: M_d= dirty MRF input, M_r=recovered material, N_{dmrf}=no. of dirty MRFs, m_{di}=flow rate of recovered material *i* for dirty MRFs; M_c=Co-Collection material, R=stream recyclables fraction, N_{cmrf}=no. of clean MRFs, m_{ci}=flow rate of recovered material *i* for clean MRFs.

[10] **Renkow and Rubin, 1998**; Glossary: D=degradation factor

[11] http://europa.eu.int%00/comm/environment/waste/studies/pdf/euwastemanagement_annexes.pdf; Glossary: M_{rgw}=flow rate of recovered Green Waste, N_{gwcf}=no. of GW Composting Facilities ,D=degradation factor.

delivered by individual companies) and is brought to one of the Pikitup landfills for disposal. The Recovered Landfill Waste stream is operated by a private company, and hence exhibits no costs or income for Pikitup. The flow rate of this stream was kept constant at 12,350 tonnes/year for all years modelled as a result of the fact that landfill scavenging is not a favourable recovery scheme from a social perspective. *(Jarrod Ball & Associates, 2003)*

The Dirty Landfill MRF operational costs were obtained from *DSM Environmental Services (2004)* in which several waste recovery schemes were analysed in terms of their economic feasibility. The Dirty Landfill MRF operational cost included a variable cost of R40.3/tonne, a fixed cost of R164,365 per plant, a waste tipping charge of R35/tonne of waste disposed and the MRF Recyclists Revenue Costs for recovering various amounts of different recyclables. The variable cost was assumed to be constant for all plant sizes. The Clean Landfill MRF operational costs reported in Table 5.2 are also taken from the *DSM Environmental Services (2004)* material recovery study. It is important to note that the reported variable operational cost for Clean Landfill MRFs of R110.6/tonne is made up of a Recyclables Collection Cost of R72.9/tonne and the MRF plant operational cost of R37.7/tonne. The fixed operational cost of the Clean Landfill MRFs is R31,719 per plant, which is considerably lower than the respective Dirty Landfill MRF fixed operational cost as a result of the fact that a Dirty Landfill MRF is much more complex in operation than a Clean Landfill MRF (which only requires limited pre-sorting of the material sent into the plant). An important constraint in the design of MRFs is the requirement that the organics feed to the plant must be fairly low for hygienic reasons, and this constraint is well accommodated by the modelled system due to the separate organics collection scheme. The stream recyclables fraction for the Clean Landfill MRFs was taken as 0.9, which is equivalent to the resultant recyclables fraction of the recycling bags collected in the 2-Bag Marina da Gama programme in Cape Town *(Mega-Tech Inc, 2004)*. Hence 10% of the feed to the Clean Landfill MRFs is disposed due to its non-recyclable nature and this amount is multiplied by the waste tipping cost of R35/tonne to determine the disposal costs of this particular scheme. The Clean Landfill MRF also exhibits Recyclists Revenue Costs for the recovery of recyclables. The revenue generated from the different materials recovered is the same for both the Dirty and Clean Landfill MRFs as the materials are taken as being of the same quality, however it is important to note that only 90% of the recyclable material sent to the Dirty Landfill MRFs is recovered, while 100% of the recyclable material sent to the Clean Landfill MRFs is assumed to be recovered. The material revenue data was also taken from *DSM Environmental Services (2004)*.

The separate Organics Collection stream operational cost reported in Table 5.2 was calculated by dividing the annual Dailies Collection Operational Cost of R5,703,397 (which excludes the administrative/overhead cost) by the annual amount of waste collected by the Dailies Collection scheme, namely 16,046 tonnes/year, yielding a value of R355.4/tonne *(Jarrod Ball & Associates, 2003)*. The composition of the Dailies collection was assumed to be the same as the Commercial Waste composition reported in section 5.2.2 of this report, and is thus a general (mixed) waste stream. The reason that the reported value for the Organics Collection operational cost in Table 4.2 is R644.5/tonne is as a result of the fact that this cost includes the operational cost of the Food Waste Composting Facilities to which this stream is sent for processing into compost product. Data on the operational costs of General Waste Composting Facilities was taken from an article written by Renkow and Rubin (1998). This reference reported the average General Waste Composting Facilities operating cost as US$28/tonne of waste processed in these facilities for the year 1995. This value was converted into the baseline and South African Rand terms through the use of engineering techniques. Hence the resultant Food Waste Compost Facilities operational cost for the baseline year 2004/2005 came to R289.1/tonne (which makes up the difference of the total Organics Collection operational cost of R644.5/tonne reported in Table 5.2 and the Dailies Collection cost of R355.4/tonne).

The Recycling Centres stream is operated independently of Pikitup, however, as mentioned earlier recycling subsidies are often given to the organisations that run these schemes to aid them in making these schemes financially feasible. The subsidies given are calculated through the use of airspace credits where the organisations that run recycling schemes are credited with the money that the Council would have had to pay if the recovered waste had to be processed. The airspace credit is taken to include the cost of processing waste through transfer stations as well as the disposal cost to landfill the waste. The airspace credit value is calculated by adding the landfill disposal costs to the product of the fraction of waste sent to transfer stations with the transfer station operational cost per tonne (taken as R53.4/tonne - *Mega-Tech Inc, 2004-1*). As stated earlier, the fraction of collected waste that is sent through transfer stations was assumed to remain constant for the years modelled. The operational cost of the Waste Collection Services for Johannesburg for the year 2004/2005 was calculated using data reported in the City of Johannesburg's Solid Waste Management Status Quo Report *(Jarrod Ball & Associates,2003)*, and yielded a value of R271.29 million (see **Appendix D2**). The fraction of this cost that makes up the administrative/overhead cost was assumed to be the same as that of the Waste Disposal Services, which exhibits a 24.72% cost fraction for administrative/overhead costs (http://www.gautengleg.gov.za; accessed 20/03/2006). The administrative/overhead costs were subtracted from the collection services operational cost and the resultant value was divided by the quantity to waste collected by Pikitup in 2004/2005, namely 698,621 tonnes, to yield the collection cost/tonne operational cost of R292.3/tonne. *(Jarrod Ball & Associates, 2003)*

The operational cost for the Drop-Off Garden Refuse Composting Plants reported in Table 5.2 was determined through the use of the following website, accessed on the 04/04/2006: http://europa.eu.int%00/comm/environment/waste/studies/pdf/euwastemanagement_annexes.pdf. The reference contains a study of the operational and capital costs for Garden Waste Composting Facilities as reported on page A224 of this Acrobat file. The reported costs were converted through the substitution of local utility (electricity, water, etc) costs for those reported in the report to determine the costs in South African Rand terms (see **Appendix D2**). The resultant cost is comprised of a variable cost that is a function of the design capacity of the Composting Facility concerned, namely R69.9/tonne, as well as a fixed cost per Composting Facility of R491,273. The income generated from producing the compost comes from the recovery of ferrous metals and the sale of compost product. The compost was assumed to be sold at R100/tonne (which is the price reported in Chapter 7 of the Status Quo Report by *Mega-Tech Inc, 2004-1*). The degradation factor (D) is the fraction of the initial organic mass that remains after degradation. The degradation factor reported by *Renkow and Rubin (1998)* was indicated to be between 0.4 and 0.75 (a value of 0.6 was thus chosen).

As mentioned earlier the Drop-Off facility costs are incorporated in the Waste Disposal costs, and it is important to note that this waste management scheme is a pre-requisite of a good MSWMS and hence is mandatory. If the general public is not given the opportunity to deliver garden and garage waste to facilities close to where they live then waste dumping would become more prevalent. The Drop-Off flow rate fraction of the total generated waste stream was thus taken as being constant, with a value of 0.100. The portion of Drop-Off garden refuse sent to either Landfill Sites or Garden Waste Composting Facilities were, however, allowed to vary.

The capital costs required to develop the infrastructure needed to operate several of the waste management schemes, namely the Transfer Stations, MRFs and the Composting Plants are highlighted in the following table.

Table 5.3: The capital costs considered in the cost minimization model for 2004/2005.

Scheme	Capital Cost (Rand)	Source
Transfer Stations	$(51500*(M_{TS}/260)+48000000*n)/y$	*Coetzee and Botes, 2005*
MRFs	$(251.9*M_d)/y+\{(202.5*M_c)/y+(10*S)/5\}$	*DSM Environmental, 2004*
Composting Facilities	$234.1*m_{com}+(675408*(m_{com}/4015))/y + (65.8*M_{rgw})/y$	*Renkow and Rubin, 1998; http://europa.eu.int*

Glossary: *M_{TS}=combined transfer station input flow rate; n=number of transfer stations in operation; y=number of years over which capital was paid; M_d=dirty MRF input flow rate; M_c=clean MRF input flow rate; S=number of collection service points; m_{com}=mixed commercial waste sent to compost plant; m_{rgw}=recovered garden waste sent to garden waste composting plants.*

The capital costs are included in the cost functions for each stream by calculating the total capital cost required to develop the various facilities and then dividing this value by the number of years over which these capital costs are paid. The number of years of payment is determined by subtracting the model year from the year 2005/2006, which is the year that capital spending on all of these proposed plants is expected to commence. Dirty MRFs require greater amounts of capital than clean MRFs as a result of the fact that the former requires a greater amount of pre-sorting equipment. However the clean MRFs rely on the effective operation of a separate collection scheme which operates on the premise that refuse is placed in two separate bins: the existing bins being used to dispose of non-recyclable and putrescible waste, while the second bin is to be used for the storage of recyclables. The latter bins need to be purchased and distributed for the commencement of this programme, and since the bins have a lifespan of five years the capital costs incurred from the purchase of these bins is divided by this figure. The recyclables bins are provided free-of-charge as an incentive to encourage recycling.

Table 5.3 illustrates the capital costs of both the Mixed Commercial Waste Composting Facilities and the Garden Waste Composting Facilities. The former capital cost is made up of two components, with the first being the capital required to develop the Composting Facilities and the second being the cost of purchasing extra REL Collection Vehicles for the collection of the refuse to be processed in these facilities. Each REL Collection Vehicle costs approximately R675,408 as determined from a newspaper article written in the Dispatch newspaper on

18/11/1997 (http://www.dispatch.co.za/1997/11/18/page%203.htm; accessed on 31/03/2006). The refuse truck is multiplied by the quotient of the total commercial organics collection flow rate and the value 4015. The value 4015 (units: tonnes/year/truck) represents the average annual collection capacity of a refuse truck in Johannesburg, as reported in *Jarrod Ball & Associates (2003)*.

In forecasting both capital and operation costs an inflation rate of 5% was assumed, while income was modelled to increase at 6% per year.

5.3 RESULTS AND DISCUSSION

The results are split into two sections, namely material flow rate results and economic results.

5.3.1 MATERIAL FLOW RATE RESULTS

The table below illustrates the stream compositions calculated by the model for several years.

Table 5.4: Modelled stream compositions of the total generated waste stream for several years.

Stream Percentage	2005/2006 (%)	2015/2016 (%)	2030/2031 (%)
Landfill Waste (Excl. DO)	77.58	71.37	67.33
Recovered Landfill Waste	0.66	0.56	0.43
Dirty MRF Recovery	0.00	0.00	0.00
Recycling (2-Bag)	0.00	3.60	4.92
Recycling (Centres)	10.85	10.85	10.85
Organics Collection (Dailies)	0.88	3.60	6.45
DO Waste Recovered	2.28	10.02	10.02
DO Waste Disposed	7.74	0.00	0.00
TOTAL	*100.00*	*100.00*	*100.00*

Table 5.4 highlights the stream compositions that give the maximum Overall MSWMS Cost/Profit value for several modelled years. The first trend observed is that the amount of material sent to landfills decreases as time progresses, which is indicative of the fact that by decreasing the amount of material sent to landfills the overall MSWMS net cost decreases. Hence it makes economic sense to divert material from landfills until a certain threshold value (which represents the point at which, under the proposed management system, all of the available material that is economically feasible to recover is depleted). The second trend is the stable zero input assigned to the Dirty MRFs as time progresses, indicating that this recovery scheme is not a favoured option in terms of economic feasibility. However, Table 5.4 also reveals that the 2-Bag Recycling scheme increases with time (indicating that it is a favoured method of material recovery) and since this material is also sent to MRFs, the use of this recovery scheme in conjunction with a separate recyclables collection operation is indeed a viable option. This is as a result of the fact that clean recyclables yield higher recovery rates and require very little pre-sorting when passed through MRFs, unlike the processing of mixed general wastes in MRFs, which require greater pre-sorting operations and yield lower recovery

rates due to a greater contamination of the recyclables. The model attempts to minimise the flow rate of the Recycling (Centres) stream throughout the modelled period due to the fact that this stream ultimately diverts recoverable material away from the income-generating MRFs. The Recycling (Centres) stream was given the constraint that the mass fraction of this stream cannot go below the initial value reported for 2005/2006 as a result of the fact that this sector represents private recycling operations that will not likely fall away. This is the reason that the mass fraction for this stream remains constant.

Another interesting trend shown in Table 5.4 is that the stream mass fraction of the Organics Collection stream increases with time, and this trend is attributed to the fact that the Organics Collection stream is sourced from the commercial sector and thus the tariffs charged for the collection of this waste stream are high enough to cover the collection and Compost Plant expenses. The Garden Waste Composting scheme, termed as DO Waste Recovery in Table 5.4, is favoured to such a great degree that the model already brought the value of this stream to its highest possible value by the year 2015/2016. Pikitup has developed a single landfill target for the year 2020, and as a result this target was extrapolated for future years. The resultant target values are highlighted in the following figure along with the values received from the model.

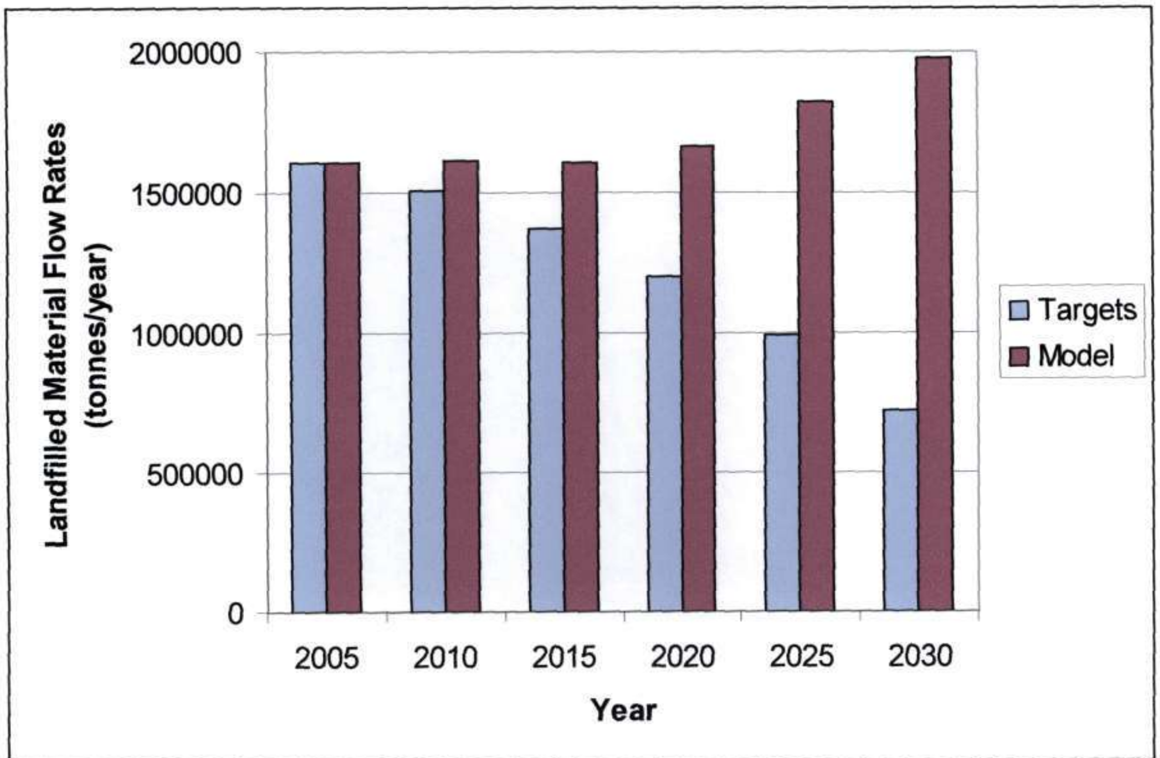

Figure 5.4: Model and target waste disposal flow rates for several future years.

Figure 5.4 above reveals that the targets stipulate that waste disposal should immediately be reduced in a fairly linear way. The model, however suggests that it is best to keep the amount of waste sent to landfills fairly constant until 2020, after which there is a slight rise in the amount of waste sent to landfill sites. The targeted landfill waste values become significantly lower than the model values after 2015, which reveals that if the targets are to be met for the years following 2015, then the MSWMS has to be operated at a Overall Cost/Profit value lower than the maximum (at which the model values are set), or else alternative recovery schemes need to also be developed. The figure below plots the corresponding model and target generated waste recovery rates.

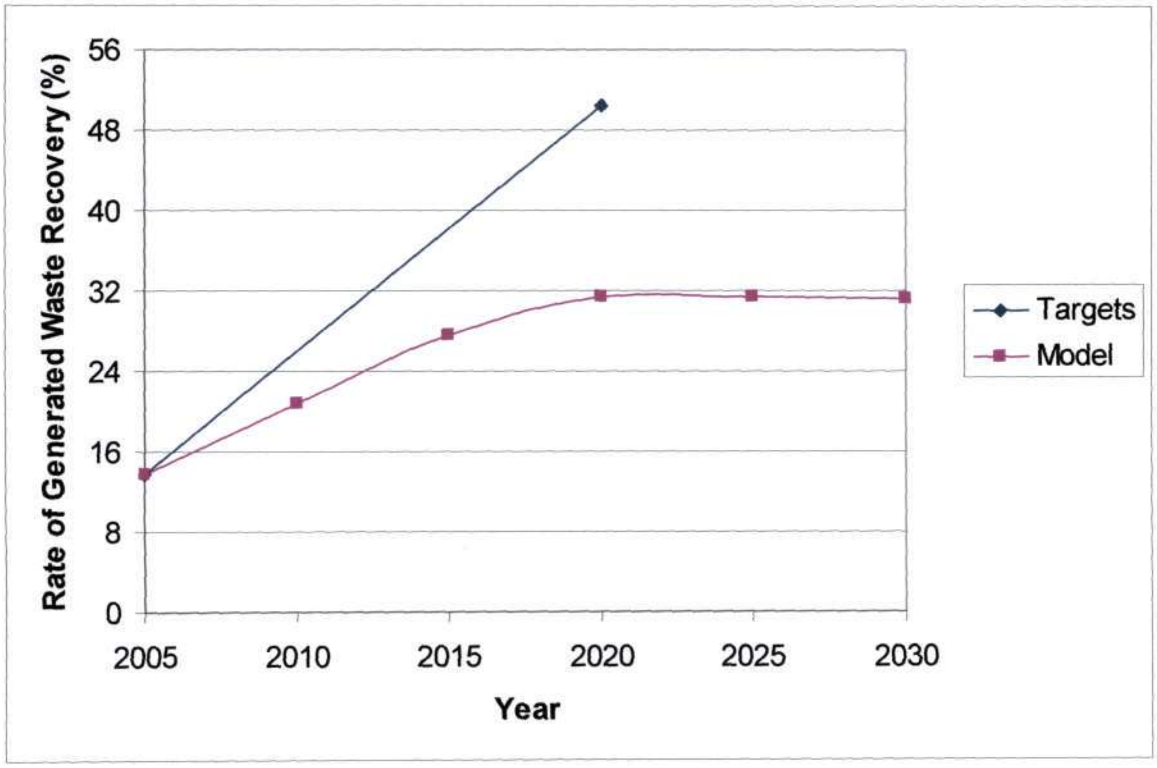

Figure 5.5: Model and target generated waste recovery rates for several future years.

As shown in Figure 5.5 the recovery rates determined by the model increase until the year 2020, at which point the recovery rate reaches a maximum threshold value and remains constant at this value of 31.3% for future years. The only target value that is reported for Johannesburg in *Mega-Tech Inc (2004-1)* is that for the year 2020, and hence extrapolated target estimates were used for earlier years. The waste recovery target for 2020 is significantly higher than the recovery rate produced by the model for this year, and as a result if this target is to be met then the MSWMS of Johannesburg either needs to be operated at an Overall Cost/Profit value lower than the maximum or else several other recovery schemes need to be implemented into the system along side those proposed in the model. To inform the decisions on how to properly increase the recovery rates of generated waste in line with the target values it is imperative that the composition of the waste modelled to be sent to landfills be analysed. As a result the disposed and recovered material compositions for the model year 2030/2031 are displayed in the following two figures.

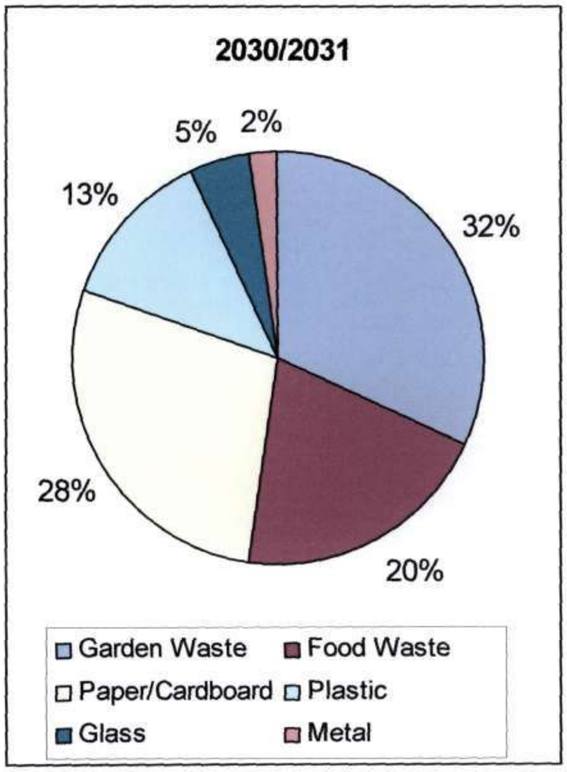

Figure 5.6: Recovered material composition.

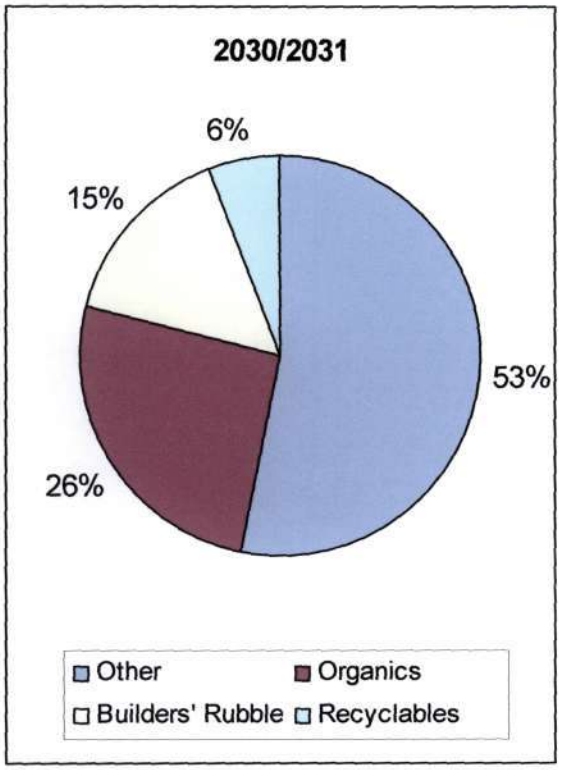

Figure 5.7: Landfill material composition.

Figure 5.6 reveals that 52% of the recovered material is organic (food waste and garden waste), indicating that organics composting can indeed be a viable waste recovery scheme. The recovery of organic waste is imperative if a significant amount of the generated waste stream is to be diverted from being sent to landfills. As is to be expected the recyclable material that exhibits the greatest recovery in Figure 5.6 is paper and cardboard. Figure 5.7 above shows that 53% of the material sent to landfills is material that is not readily recyclable (classed as Other). In order to reduce the amount of other material and hence the amount of waste sent to landfills the government has to develop laws that ensure manufacturers only use readily recyclable material to produce products as well as in packaging materials.

5.3.2 ECONOMIC RESULTS

The net cost/profit values for the various years modelled are plotted below. These values are the resultant objective function values determined by Solver to be the maximum Overall MSWMS Cost/Profit values for the particular year concerned, under the programmed constraints.

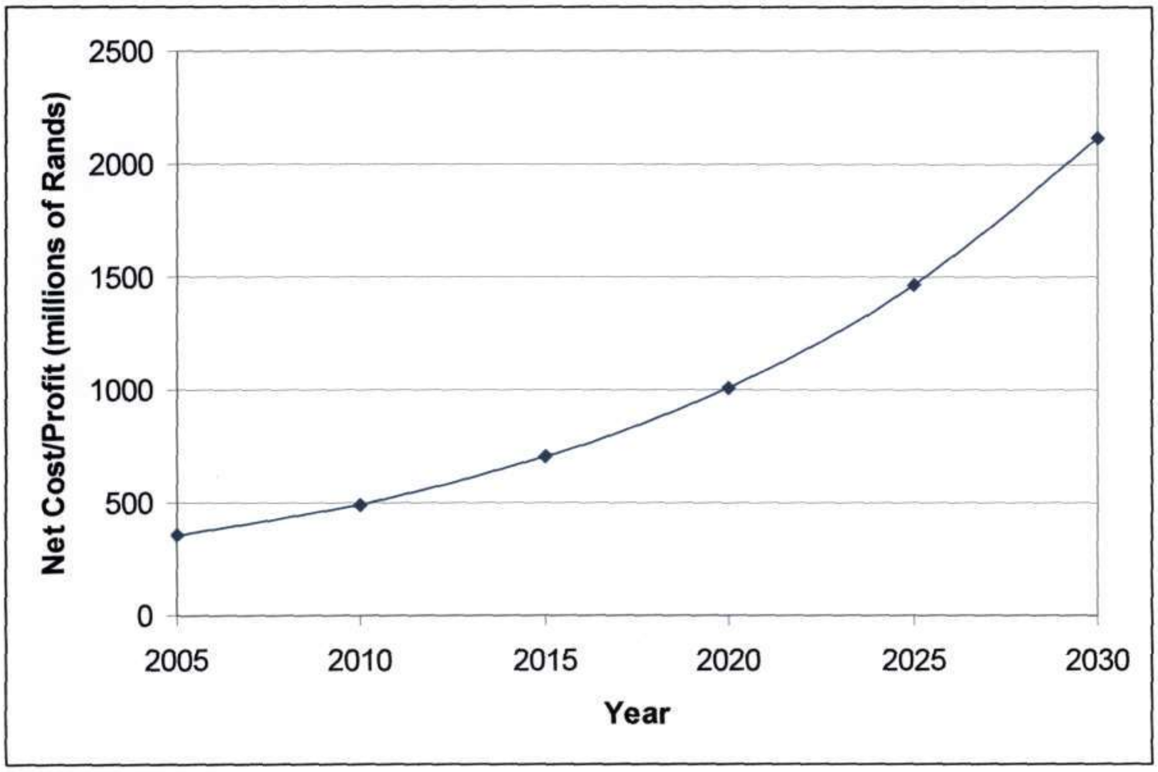

Figure 5.8: Plot of modelled net cost/profit (objective function values) for various years.

Figure 5.8 reveals that the implementation of the proposed changes to the Johannesburg MSWMS do not result in the system expenses exceeding the income generated, but merely slow down the increase in income until 2020, at which point the income increase becomes linear with time. The total calculated capital costs for the MRFs, Garden Waste and Mixed Waste Composting Facilities until 2030 are R75.9 million, R17.0 million, and R359.3 million respectively. This indicates that Pikitup requires a large amount of capital to start up the latter scheme, while the former two schemes require a minimal amount of capital. The MSWMS exhibits a large profit margin for all years, and continues to grow. This profit could be used to implement further projects to increase the recovery of waste materials, and thereby decreasing the amount of waste sent to landfills.

5.4 SENSITIVITY ANALYSIS

The effects of annual income and inflation rate changes on the net cost/profit values exhibited by the model are highlighted in the figure below.

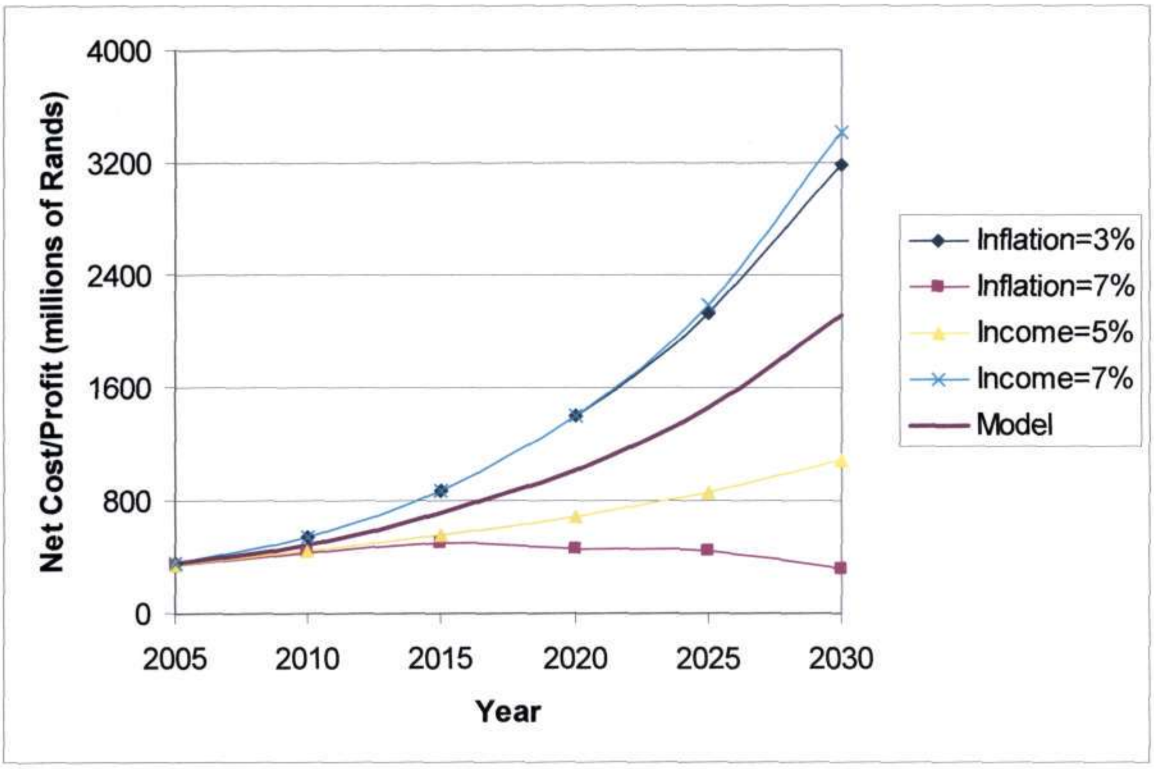

Figure 5.9: Sensitivity analyses of the income increase and inflation rates used in the model.

The model values used for the annual income increase and inflation rates are 6% and 5% respectively. Sensitivity analyses on these two important model parameters yielded the graphs shown in Figure 5.9. When carrying out the analyses only one parameter was changed at a time with the other being kept at its original model value. The inflation rate analysis at 3% revealed that a decrease in inflation rate greatly increases the profit margin of the MSWMS, while the inflation analysis at 7% revealed that such an inflation rate increase would prevent an increase in the profit margin and eventually result in a decreased profit margin. On the other hand when keeping the inflation rate at the original value of 5% and changing the annual income increase rate to 5% and 7%, the resultant graphs in relation to the model plot exhibit a slower profit margin increase and a faster profit margin increase respectively. These analyses have shown that changes in both the inflation rate and annual income increase rate have a major influence on the economic feasibility of the modelled MSWMS.

CHAPTER 6: CASE STUDY COMPARISONS

6.1 ECONOMIC DATA COMPARISON

The economic variables used in both the Cape Town (CT) and Johannesburg (JHB) models are illustrated in the Table below in order to allow for the comparison of the system costs for both Municipal Solid Waste Management Systems.

Table 6.1: Operating costs of the streams to be optimised by Solver for CT and JHB.

Stream	Operational Cost for CT 2004/2005 (R/tonne)	Operational Cost for JHB 2004/2005 (R/tonne)
Landfill Waste [12, 13]	42.1	26.7
Recovered Landfill Waste	-	-
Material Recovery Facilities – MRF (Dirty) [14, 15]	40.8*(M)+6041413*n	$40.3*M_d+164{,}365*N_{dmrf}+35*(M_d-M_r)+130*m_{dm}+90*m_{dg}+150*m_{dpc}+200*m_{dp}$
Recycling (Co-Collection) with MRF [14, 15]	$113.7*M_{co}+6041413*n$	$110.6*M_c+31{,}719*N_{cmrf}+35*(1-R)*M_c+130*m_{cm}+90*m_{cg}+150*m_{cpc}+200*m_{cp}$
Organics Collection [12, 13]	588.6	644.5
Recycling (Private)	-	-
Mixed Waste Composting [16, 17]	252.1	-
Drop-Off (DO) Composting [18]	N.A.	$69.9*M_{rgw}+491{,}273*N_{gwcf}$

Before analysing the data displayed in Table 6.1 above, it is important to note that the economic variables reported in the Cape Town Case Study (Chapter 4) were reported for the baseline year of 2003/2004, and hence these values were all inflated by 5% in order to convert this data to the same baseline year as Johannesburg, namely 2004/2005.

Table 6.1 indicates that the waste disposal costs in Cape Town are significantly higher than the same costs for landfill sites in Johannesburg, and the reason for this lies in the fact that all of Cape

[12] **Mega-Tech Inc, 2004**
[13] **Jarrod Ball & Associates, 2003**
[14] **Chang et al, 2005**; Glossary: M=input flow rate to MRFs, n=number of MRFs in operation.
[15] **DSM Environmental, 2004**; Glossary: M_d= dirty MRF input, M_r=recovered material, N_{dmrf}=no. of dirty MRFs, m_{di}=flow rate of recovered material *i* for dirty MRFs; M_c=Co-Collection material, R=stream recyclables fraction, N_{cmrf}=no. of clean MRFs, m_{ci}=flow rate of recovered material *i* for clean MRFs.
[16] **Renkow and Rubin, 1998**; Glossary: m_h=household waste sent to compost plant, m_s=separate organics collection.
[17] http://www.defra.gov.uk/corporate/consult/animalbyprod/purpose.htm; Glossary: D=degradation factor.
[18] http://europa.eu.int%00/comm/environment/waste/studies/pdf/euwastemanagement_annexes.pdf; Glossary: M_{rgw}=flow rate of recovered Green Waste, N_{gwcf}=no. of GW Composting Facilities ,D=degradation factor.

Town's Landfill Sites are classified as requiring leachate collection systems (B^+), while only one of the Pikitup operated landfill sites in Johannesburg is classified as requiring leachate collection systems. Landfill sites that require leachate collection systems incur significantly greater operational costs than those that do not require these systems, and hence the difference in costs described above. The Cape Town City Council waste collection costs are also greater than those exhibited by Pikitup, with the former incurring a waste collection cost of R329.3/tonne as compared to the same cost for Pikitup of R292.3/tonne (both values are reported for the year 2004/2005). The reason for this difference in cost is that Johannesburg has two more fully-functional centralised landfill sites than its Cape Town counterpart, which effectively only has three fully-functional centralised Council landfill sites, one of which is scheduled to be closed at the end of 2006 due to health concerns (namely the Bellville South landfill site). Despite the fact that refuse collection costs are greater in Cape Town, the average refuse tariff in Johannesburg is higher than that charged in Cape Town. Cape Town's average refuse tariff for 2004/2005 was R434.0/service point, while that of Johannesburg was R467.4/service point.

As is evident in Table 6.1, the Dirty MRF variable cost term of R40.8/tonne displayed for Cape Town is very similar to its Johannesburg counterpart exhibiting a R40.3/tonne cost, and the same is true for the Co-Collection stream which exhibits a variable cost of R113.7/tonne and R110.6/tonne for Cape Town and Johannesburg respectively. This observation reveals that the reported costs are relatively consistent due to the fact that two separate references were used to compile these costs. In analysing this result it is important to note that the variable costs for the Cape Town and Johannesburg MRFs were sourced from two separate references, the one being used to determine the cost of developing and operating Transfer Station MRFs in Cape Town and the other being utilized to provide the variables cost for Landfill MRFs which are to be developed in Johannesburg. As is evident from Table 6.1 the Co-Collection cost variables include the cost of the Clean MRFs required to process this stream into sorted recyclables. Unlike the Transfer Station MRFs proposed for Cape Town, the Landfill MRFs to be developed in Johannesburg include a tipping cost of R35/tonne, which is the cost incurred from material that is not recovered in this facility. The reason that a tipping cost is not included in the cost reported for Transfer Station MRFs is that Transfer Stations are designed for the transportation of waste and hence the waste from the adjacent MRFs is fed directly into the Transfer Station for further processing.

The final stream economic variables in Table 6.1 to be compared are the Organics Collection stream variables, which exhibit a marked difference in magnitude between the value reported for Cape

Town and Johannesburg respectively. The Organics Collection cost reported for Cape Town is significantly lower than the same cost reported for its Johannesburg counterpart due to the fact that the proposed collection of organics in Cape Town is a separate collection stream that is processed by a Clean Composting Facility, unlike the Organics Collection stream proposed for Johannesburg, which operates under the premise that mixed commercial waste is collected and processed in a Dirty Composting Facility. The income generated from the various streams is indicated in the following table:

Table 6.2: Income values of the streams to be optimised by Solver for CT and JHB.

Stream	Income Values for CT 2004/2005 (R/tonne)	Income Values for JHB 2004/2005 (R/tonne)
Landfill Waste [19, 20]	78.0 (private waste only)	85.22 (private waste only)
Landfill Waste Recovery	-	-
MRF Recovery (Dirty) [21, 22]	$(434*m_m+163*m_g+551*m_{pc}+2100*m_p)*R_m$	$(400*m_{dm}+250*m_{dg}+315*m_{dpc}+755*m_{dp})*R_d$
Co-Collection (2-Bag) [21, 22]	$(434*m_m+163*m_g+551*m_{pc}+2100*m_p)*R_{co}$	$(400*m_{cm}+250*m_{cg}+315*m_{cpc}+755*m_{cp})*R_c$
Organics Collection [19, 20]	$D*100*m_o$	$(565.5+100*D)$
Recycling (Private)	-	-
Mixed Waste Compost [19, 21]	$D*100*m_o+434*m_m$	N.A.
DO Waste Composting [19]	N.A.	$D*100$

As displayed in Table 6.2, the landfill waste disposal tariff reported for Cape Town is substantially lower than the disposal tariff charged by Pikitup in Johannesburg. This observation is unexpected due to the fact that the disposal costs are higher in Cape Town than they are in Johannesburg, and hence one would expect the reverse to be true. As a result it can be deducted that the Cape Town disposal tariff is well below the value at which it should be set. In analysing the amount of income generated from charging disposal tariffs it is important to note that the majority of waste sent to landfill sites is made up of Domestic and Area Collection waste, which is collected by the Council and hence does not generate disposal tariff income. Commercial and Industrial waste is generally

[19] **Mega-Tech Inc, 2004**
[20] **Jarrod Ball & Associates, 2003**
[21] **Beningfield, 2002**; Glossary: $m_{(i)}$=mass of material (i) recovered (m=metal, g=glass, pc=paper & cardboard, p=plastic), R_i=overall material recovery fraction for MRF (i).
[22] **DSM Environmental, 2004**; Glossary: m_s=separate organics collection, R_i=overall recovery fraction for MRF (i).

not collected by Municipal Councils and is thus the only waste that represents a potential income generator in the form of disposal tariffs.

The prices paid for recyclables depend on the form of the recyclables sold, for example glass sorted into its various colours would generate more income than mixed glass, and it is for this reason that the recyclables income reported in Table 6.2 differs between Cape Town and Johannesburg. Table 6.2 also reveals that a collection tariff is only generated from the Organics Collection scheme in Johannesburg, and amounts to R565.5/tonne. The reason for this is that the Organics Collection scheme in Cape Town involves the collection of sorted Domestic organic waste, and hence is proposed as a free service, while the Organics Collection scheme in Johannesburg involves the collection of mixed Commercial waste and thus generates income in the form of collection tariffs. Mixed Domestic waste composting only currently takes place in Cape Town and this scheme is not proposed as a future recovery scheme to be utilized by Pikitup. The Drop-Off garden waste composting scheme in Cape Town is operated by private companies, and hence the Cape Town City Council generates no income from this scheme. Conversely, Pikitup operates its own garden refuse facility for the recovery of garden waste from waste sent to Drop-Off facilities and hence generates income through the sale of the resultant compost product.

Table 6.3: Capital costs of the streams to be optimised by Solver for CT and JHB.

Scheme	Capital Cost CT 2004/2005 (Rand)	Capital Cost JHB 2004/2005 (Rand)
Transfer Stations [23]	$(54075*(M_{TS}/260)+50400000*n)/y$	$(54075*(M_{TS}/260)+50400000*n)/y$
Dirty MRFs [24, 25]	$(51320.5*(M_{MRF}/260)+14880665*n)/y$	$(251.9*M_d)/y$
Composting Facilities [26, 27, 28]	$234.0*m_h+$ $(290.0*m_s+4482479.1*n)/y$	$234.0*m_{com}+$ $(65.8*M_{rgw})/y$
Co-Collection [29]	$(10*S)/5+51.7*M_{CO}$	$(10*S)/5+51.7*M_{CO}$
Organics Collection [30]	$(675408*(m_s/T_{ct}))/y$	$(675408*(m_{com}/T_{JHB}))/y$

[23] **Coetzee and Botes, 2005**; Glossary M_{TS}=combined transfer station input flow rate; n=number of transfer stations, MRFs or Composting Facilities in operation; y=number of years over which capital was paid.

[24] **Chang et al, 2005**; Glossary: M_{MRF}=combined MRF input flow rate.

[25] **DSM Environmental, 2004**; Glossary: M_d= dirty MRF input.

[26] **Renkow and Rubin, 1998**; Glossary: m_h=household waste sent to compost plant, m_s=separate organics collection, m_{com}=household waste sent to compost plant.

[27] http://www.defra.gov.uk/corporate/consult/animalbyprod/purpose.htm; Glossary: n=no. of Composting Facilities.

[28] http://europa.eu.int%00/comm/environment/waste/studies/pdf/euwastemanagement_annexes.pdf; Glossary: M_{rgw}=flow rate of recovered Green Waste.

[29] **Jarrod Ball & Associates, 2003**; S=number of collection service points; M_{CO}=co-collection recyclables flow rate.

[30] http://www.dispatch.co.za/1997/11/18/page%203.htm; T_i=average annual refuse truck collection capacity for city i.

The majority of the capital cost equations reported in Table 5.3 above are equivalent for both Cape Town and Johannesburg. The reason for this is that several of the proposed schemes are to be utilised in both cities. In comparing the Organics Collection capital costs for both cities the annual refuse truck collection capacity for Cape Town and Johannesburg need to be compared. T_{ct} was calculated to be 2772 tonnes/year/truck (*Mega-Tech Inc, 2004)*, while T_{JHB} was reported as being 4015 tonnes/year/truck *(Jarrod Ball & Associates, 2003)*. It is evident from these values that the annual refuse truck collection capacity for Cape Town is significantly lower than that of Johannesburg, and this is attributed to several reasons. The main reason was alluded to earlier and involves the fact that Johannesburg has a more centralised collection system than its Cape Town counterpart due to physical land constraints exhibited by the latter city. This translates into refuse trucks in Cape Town travelling greater distances in order to empty their collected refuse in a landfill site when compared to refuse trucks in Johannesburg, which in turn means a greater travel time per collection trip. Another possible reason for the difference in refuse truck collection capacity between the two cities is the difference in the collection truck fleet age utilised by each respective city (bearing in mind that the older the vehicles the more frequently they need to be serviced and hence the greater the amount of replacement vehicles required – note that the calculated values include the need for replacement vehicles).

6.2 MATERIAL FLOW RATE COMPARISONS

The following comparisons deal with the material differences exhibited by the developed models for both Cape Town and Johannesburg.

6.2.1 COMPARISON OF RESULTANT MODEL STREAM FRACTIONS

The following table depicts the optimum mass percentages (from an economic perspective) of the various streams that form part of both cities' MSWMS, as determined by Solver.

Table 6.4: Optimum mass percentages of the various variable streams changed by Solver.

Stream Mass %	CT (2005)	CT (2030)	JHB (2005)	JHB (2030)
Waste Landfilled (excl. DO)	84.34	59.49	76.62	67.33
Recovered Landfill Waste	0.06	0.04	0.66	0.43
MRF Recovery (Mixed)	0.00	5.51	0.00	0.00
Co-Collection (2 Bag)	0.00	5.88	0.00	4.92
Separate Organics Collection	0.00	14.67	0.00	0.00
Waste Recycled (Private)	9.18	9.18	10.85	10.85
Mixed Waste Composting	1.19	0.00	0.00	6.45
Drop-off Waste Recovered	3.35	3.35	2.28	10.02
Drop-off Waste Disposed	1.88	1.88	8.70	0.00

As is evident in Table 6.4, for both cities it is favourable to decrease the amount of waste sent to landfill sites in order to improve the financial feasibility of the MSWMS of both respective cities. Table 6.4 indicates that it is both economically feasible to send mixed general waste and separately collected recyclables (Co-Collection) to the proposed MRFs in the Cape Town model, while the Johannesburg model indicates that it is only favourable to send separately collected recyclables to the proposed MRFs to be developed in this city. The reason for this, which has already been alluded to, is that transport and disposal costs are greater in Cape Town than in Johannesburg and hence this provides a platform for the greater recovery of recyclables which under the economic variables of Johannesburg would be considered uneconomical to recover. The MRFs, however, need to be operated under strict input constraints that specifiy that the input waste must contain less than 25% organic material (by mass), or else the operation bears serious health risks and the contamination factor of the waste would be too great to allow for a significant amount of uncontaminated recyclables to be recovered. As a result of this constraint the separate collection of organics waste in Cape Town is made favoured by the model, due to the fact that this scheme helps to regulate the quality of waste sent to the mixed MRFs.

The material recovered by the private recycling stream reduces the amount of recyclables available for recovery by the Council of both cities, however these stream mass fractions are kept constant due to the fact that this scheme will not likely fall away. The recovery of mixed compostable waste is indicated in Table 6.4 to be favoured by the Johannesburg model, but not by the Cape Town model. The reason for this is that the input for the former model is commercial waste which generates a greater collection cost, while the input for this scheme in the latter model is domestic waste (which provides a more modest income). The recovery of Drop-Off garden refuse is a favourable scheme, but is facilitated by private companies in Cape Town, while in Johannesburg this scheme is operated by Pikitup itself.

6.2.2 COMPARISON OF QUANTITY AND TYPE OF RECOVERED MATERIAL

The following figure depicts the optimum recovery rates for both cities for several years.

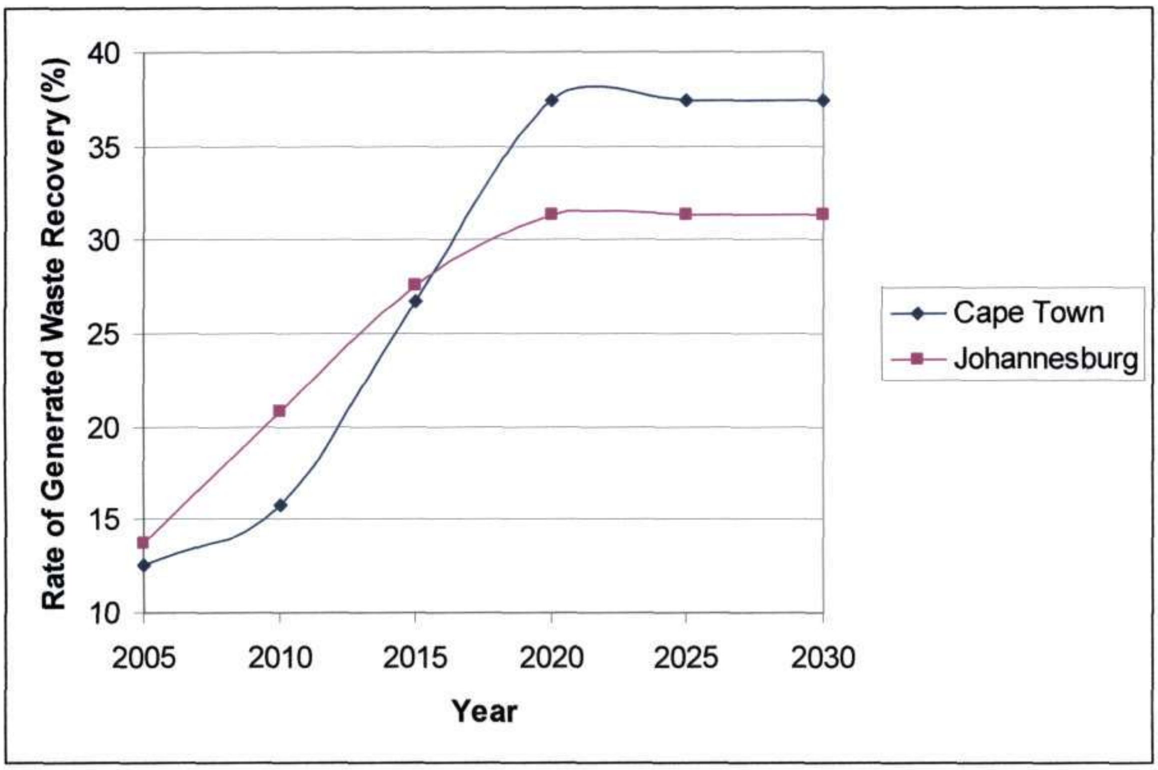

Figure 6.1: Modelled optimum waste recovery rates for several years for both CT and JHB.

Figure 6.1 illustrates that according to the developed models it makes economic sense to increase the recovery of waste materials until a certain threshold value for both Cape Town and Johannesburg. The threshold value represents the point at which, under the proposed management system, all of the available material that is economically feasible to recover is depleted.

An interesting observation determined for the Cape Town MSWMS model is that until the year 2010 it is more favourable to give extensive recycling subsidies (up to 100% subsidisation) to private recyclers than to send recyclable materials to the Council's landfill sites. This is as a result of the fact that the Cape Town City Council has developed very few recycling initiatives thus far, and this coupled with the fact that waste collection and disposal is becoming extensively more expensive translates into the need to support existing private recycling initiatives until the Council has developed its own recovery infrastructure. It will take some time before Cape Town has developed the material recovery infrastructure required to optimise its MSWMS and for this reason the plot of Cape Town's recovery rate, shown in Figure 5.1, initially increases at a slower rate than the recovery rate of Johannesburg (which currently has more extensive material recovery infrastructure).

The recovery rate increase for both cities levels off to a constant value after 2020, and the reason for this is explained above under the pretext of the threshold value. It is interesting to note that the threshold value for Cape Town is 6% higher than that of Johannesburg, and the reason for this was mentioned earlier, namely that the scope for recyclables collection in Cape Town is greater due to collection and disposal costs for the Cape Town City Council being significantly higher than those of the Solid Waste Co-ordinators of Johannesburg, namely Pikitup. The following figure illustrates the component flow rates of recovered material for both cities for the model year 2030/2031.

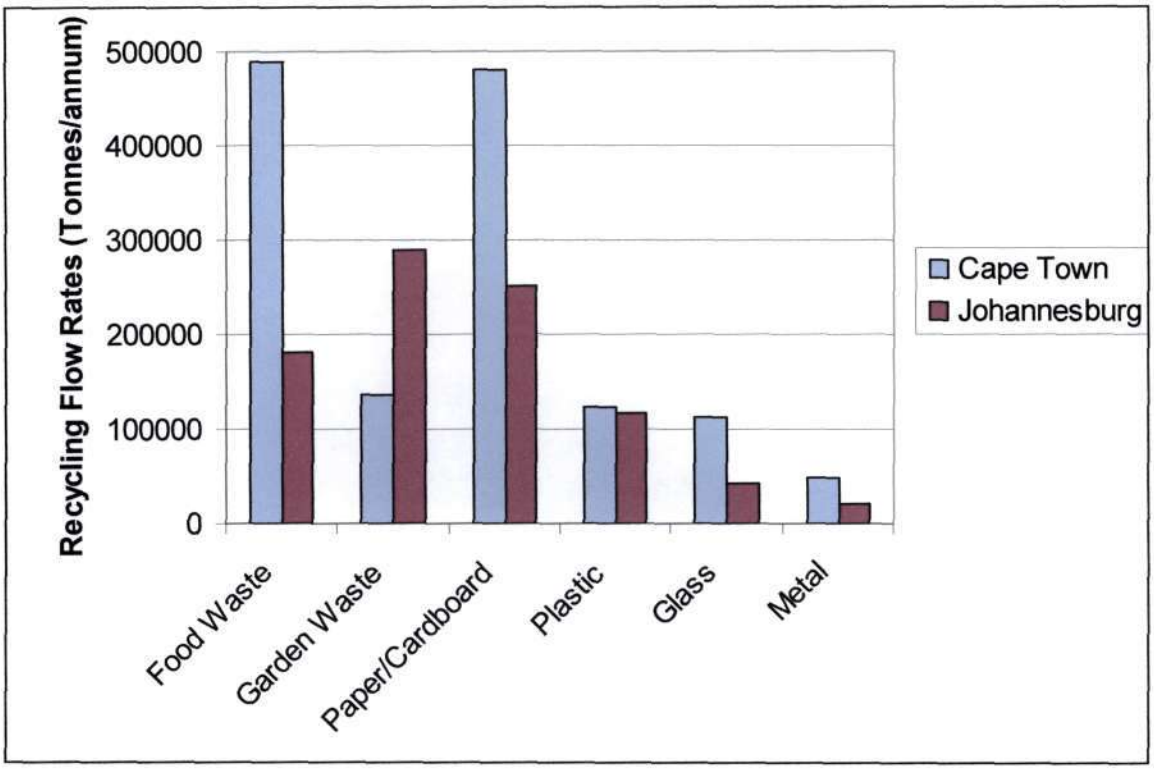

Figure 6.2: Recovered component flow rates for the model year 2030/2031 for CT & JHB.

Figure 6.2 reveals that a large portion of the recovered material in Cape Town is food waste (which is recovered from the separate organics collection stream), while very little food waste is recovered in Johannesburg. Garden waste is recovered to a larger extent in Johannesburg as compared to Cape Town. As is to be expected, Figure 6.2 also indicates that the most recovered recyclable material for both cities is Paper/Cardboard (which comprises the greatest portion of recyclable material in most waste streams). The importance of Figure 6.2 does not only lie in the fact that it illustrates the differences in material recoveries exhibited by the model for both respective cities, but it also acts as the basis for a market study into whether the modelled recovered material will be in demand by the market. This type of study is beyond the scope of this dissertation, but it is imperative that this type of study be conducted to determine whether the modelled material recoveries are realistic.

Figure 6.2 indicates that the amount of recovered material exhibited for Cape Town is significantly higher than the recovered material for Johannesburg for all recyclables except plastics. The reason for Cape Town's greater recyclables recovery is again as a result of the fact that Cape Town's threshold recovery rate is higher than its Johannesburg counterpart, and hence the greater recovery of recyclable material in Cape Town. It is interesting that plastics recyclables are the exception to this trend, and the reason for this is that the recovery of plastics is far more developed in Johannesburg than in Cape Town and hence despite the lower threshold recovery rate of materials in Johannesburg the amount of plastics recovered in Johannesburg is almost equivalent to Cape Town. This is due to the fact that, unlike Cape Town, Johannesburg operates the highly successful Green Cage project for the recovery of plastics. The Green Cage project involves the placement of large Green Cage containers at recycling depots for storage of all major plastic types. These containers are sponsored by the plastics industry and are serviced by private sorting companies that empty the containers and separate the plastics into the various types, which are then sold to buyers of the various respective plastic types. (*http://www.dispatch.co.za/2000/09/14/business/BUS5.HTM; accessed 22/06/2006*)

6.2.3 COMPARISON OF LANDFILL WASTE COMPOSITION

The following figure is plotted to depict the waste composition of waste sent to landfill sites for the model year 2030/2031 for both Cape Town and Johannesburg.

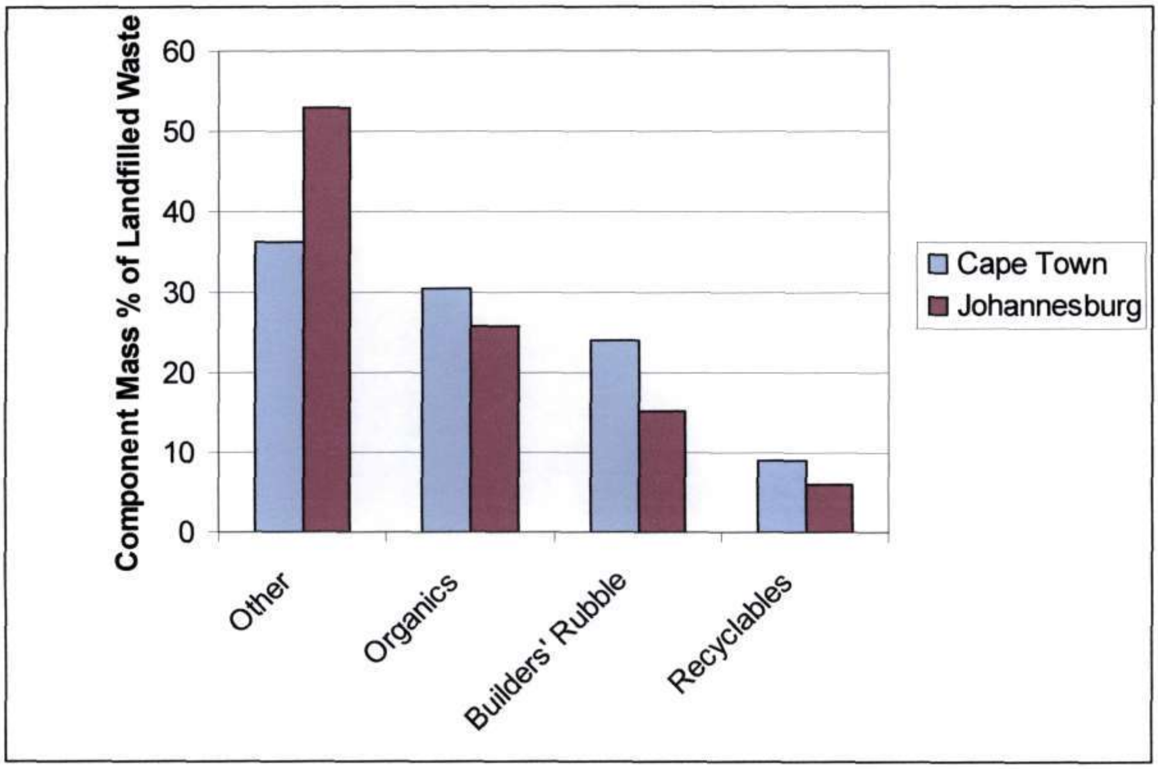

Figure 6.3: Landfill waste composition for the model year 2030/2031 for CT and JHB.

Figure 6.3 indicates that for both cities the greatest component of the material sent to landfill sites is the other fraction, which represents material that is not easily recoverable. In order to reduce the amount of other material and hence the amount of waste sent to landfills the government has to develop laws that ensure manufacturers only use readily recyclable material to produce products as well as in packaging materials.

6.3 OVERALL MSWMS ECONOMIC COMPARISON

The following graph plots the minimum overall operational costs, as determined by Solver, for both cities as a function of time.

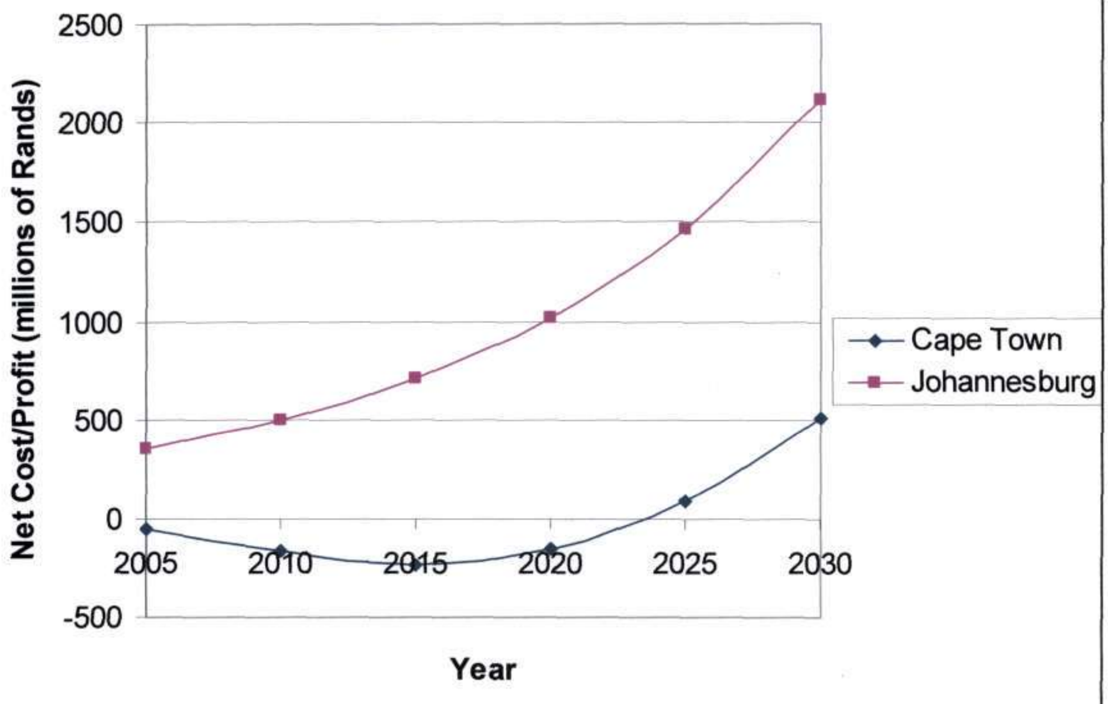

Figure 6.4: Modelled net cost/profit for various years for CT and JHB.

As is shown in Figure 6.4, the Solid Waste Division in Johannesburg (Pikitup) exhibits a profit margin while the Cape Town Solid Waste Department has a slight shortfall with regard to expenses incurred being covered by generated income. These graphs do not include the Area Collection costs, which are difficult to model, and in any event this incurred cost will always be necessary to keep both cities clean. It is important to bear this in mind when observing perceived versus actual profit margins. The 2004/2005 Area Collection costs for Cape Town was R243.13 million, while that of Pikitup was R245.85 million. Hence as is indicated by the similarity in these cost values the Area Collection costs are relatively constant because the function served by this division of both Solid Waste Departments is to fulfil an essential service. To determine the overall all-inclusive Solid Waste Services net cost both graphs need to be shifted down by an inflated index of the Area Collection costs detailed above (this is not carried out so that only the modelled scenario can be analysed).

Figure 6.4 also reveals that as time progresses the incurred expenses for Cape Town initially increase to a greater degree than the income increase and as a result the plot for Cape Town starts to increase the expenses versus income shortfall before the turning point at 2015 (which represents the point at which the income generated starts to increase above the expenses incurred, resulting in a gradual payback of the shortfall experienced in previous years). The reason that the Cape Town graph exhibits these characteristics is that Cape Town is running out of landfill space within the city, and hence to continue the centralised collection of waste several Transfer Stations are to be developed as alternatives in the various collection areas in Cape Town, and the function of these stations will be to compact waste and then send it to the proposed landfill site outside of Cape Town (still to be developed). For this reason the extra transportation and capital costs that will be incurred by this required scheme, as well as the costs incurred to try and minimise these costs in the long-term through the development of waste minimisation schemes, will initially create a growth in expenses above that of generated income. All these reasons contribute to explaining why it especially makes economic sense to minimise waste to be collected and disposed in the Cape Town region.

In contrast to the graph plotted for Cape Town, the Johannesburg plot indicated in Figure 6.4 reveals that the waste minimisation schemes to be implemented in Johannesburg will initially only slow down the growth in profit margin rather than creating a scenario in which the incurred expenses start to initially exceed the generated income. It is evident in Figure 5.4 that the income generated from the waste minimisation schemes to be implemented will eventually increase the Solid Waste Services profit margin for both cities once these schemes have been fully implemented and the capital costs paid back by the generated income. Only the Cape Town model incurs capital costs that are large enough to result in an overall MSWMS cost which exhibits a definite payback period. The payback period for the required changes to the Cape Town MSWMS was determined to be approximately 18 years.

CHAPTER 7: CONCLUSIONS AND RECOMMENDATIONS

7.1 CAPE TOWN CASE STUDY

Several conclusions can be drawn from the Cape Town case study with regard to the way the city's MSWMS operates, and these conclusions and associated recommendations are highlighted below.

7.1.1 CONCLUSIONS

It is evident that due to the shortage of land space within Cape Town the only viable option for the future MSWMS of Cape Town is the design of a network of transfer stations which act as the mechanism of waste delivery from collection points to a regional landfill site developed outside of the city. In order for the City Council to meet its targets of decreasing the amount of waste sent to landfills it needs to adopt a waste recovery scheme that works best with the future MSWMS described above. The developed model has shown that the recovery scheme that operates most effectively with this MSWMS is the creation of MRFs and Composting Facilities in conjunction with the proposed transfer stations. The capital costs required for the development of this particular MSWMS are very high, but once fully operational can generate a large amount of income for the City Council. It would also take a number of years before this proposed MSWMS becomes fully developed, and hence it is vital that the currently existing recovery schemes be fully utilised until the proposed MRF/Composting Facility recovery scheme is sufficiently developed to substitute the role of these schemes. In light of this the model has shown that it is in the interest of the City Council to provide airspace credit subsidies for the private organisations currently carrying out recycling operations in the city until the MRF/Composting Facility recovery scheme is in place.

7.1.2 RECOMMENDATIONS

i. The substitution of closing Landfill Sites with Transfer Stations must be implemented to ensure a sustainable waste management system in the city.
ii. It is imperative that the Cape Town Solid Waste Department develops the necessary waste recovery infrastructure needed to limit the amount of waste requiring disposal as soon as possible. The use of MRFs and composting facilities in conjunction with Transfer Stations to recover useful waste materials is the most recommended recovery scheme.
iii. The Cape Town Solid Waste Department should provide subsidies to private recycling ventures until its own recovery infrastructure is properly developed.

7.2 JOHANNESBURG CASE STUDY

The Johannesburg case study resulted in the formation of a number of conclusions that can be drawn with regard to the way the city's MSWMS operates. The developed conclusions as well as the associated recommendations are described in the following sub-chapters.

7.2.1 CONCLUSIONS

Johannesburg fortunately has not experienced a shortage of land space for the future development of Landfill Sites, and for this reason Pikitup will be able to continue operating a centralised waste management system that ensures minimal waste collection distances without the use of Transfer Stations. This situation may however change in the medium to long term and hence this provides no excuse for complacency with regard to minimising waste sent to disposal sites. Pikitup has already started to develop recovery infrastructure with regard to the recovery of garden refuse, and it is envisaged that in the short-term several composting plants will be developed with the aim of converting most of the garden refuse sent to Drop-off facilities into compost product. The developed model for Johannesburg has revealed that this composting scheme as well as the implementation of Clean MRFs on landfill sites are both favourable recovery schemes. The operation of clean MRFs is dependant on the implementation of an effective Separate Collection scheme for recyclables and this scheme requires the greatest amount of attention with regard to changing the current MSWMS employed to one that is more geared towards minimising waste than towards disposing of waste.

7.2.2 RECOMMENDATIONS

i. Pikitup should continue to develop garden refuse composting facilities in order to convert all of the garden refuse collected from Drop-off facilities into compost product.
ii. The development of a Separate Collection scheme for recyclables and the corresponding MRFs for the processing of this stream should be incorporated into the Johannesburg MSWMS as soon as possible.

7.3 CASE STUDY COMPARISON

7.3.1 CONCLUSIONS

The disposal of waste into Landfill sites is significantly more expensive in Cape Town than in Johannesburg due to the need to operate extensive leachate recovery systems in all of Cape Town's Landfill Sites. The costs involved in collecting waste from service points is also substantially more expensive in Cape Town than in Johannesburg, due to the large travel distances from collection to disposal point exhibited in Cape Town, which is not the case in Johannesburg. These differences in waste management costs create the scenario in which clean and dirty MRFs are a viable recovery option in the case of Cape Town but only the more feasible of these two schemes, namely clean MRFs, is a viable recovery scheme for Johannesburg.

According to the developed models for Cape Town and Johannesburg it makes economic sense to increase the recovery of waste materials until a certain threshold value for both Cape Town and Johannesburg. This proves that the traditional view that waste disposal is the most economical waste management scheme is not always necessarily true. The threshold recovery value for Cape Town is 6% higher than that of Johannesburg due to the greater waste management costs in Cape Town creating a bigger scope for the recovery of useful waste resources in Cape Town in relation to Johannesburg. The models predict that with the exception of garden refuse and plastics the recovery of all of the waste material components is significantly greater in Cape Town than in Johannesburg. The garden refuse recovery scheme is predicted to be greater in Johannesburg due to the fact that this scheme is co-ordinated by Pikitup itself, while in the case of Cape Town this scheme is operated by private companies that will only recover the portion of this waste stream that is of high value.

The predicted Landfill waste compositions for both Cape Town and Johannesburg reveal that the majority of waste going to landfill is material that is not readily recoverable (termed the Other Fraction). These materials are not readily recoverable due to the fact that this waste material is either impractical or too cost-intensive to recover. It is for this reason that only a limited amount of material can be recovered from waste without the intervention of government into regulating the type of materials used by companies to produce and package their products.

Hence laws need to be passed to limit the amount of non-recoverable material that is generated as waste.

The MSWMS of Johannesburg is operated much more cost-effectively than the MSWMS of Cape Town, with the latter system exhibiting a substantial economic shortfall. The waste management costs in Cape Town will also continue to rise significantly in the near future due to the need to substantially change the current MSWMS employed in Cape Town as a result of land space shortages to develop disposal facilities within the city. The waste management costs in Johannesburg are however not likely to increase nearly as dramatically as will be the case for Cape Town's waste management costs. The extra transportation and capital costs that will be incurred in Cape Town as a result of the need to develop several Transfer Stations to replace closed landfill sites within the city, as well as the costs incurred to try and minimise these costs in the long-term through the development of waste minimisation schemes, will initially create a growth in expenses above that of generated income. All these reasons contribute to explaining why it especially makes economic sense to minimise waste to be collected and disposed in the Cape Town region. In the Johannesburg MSWMS scenario the proposed waste minimization schemes will only initially slow down the growth in income from this system. The income generated from the waste minimisation schemes to be implemented will eventually increase the MSWMS profit margin for both cities once these schemes have been fully implemented and the capital costs paid back by the generated income.

7.3.2 RECOMMENDATIONS

i. MRFs should be implemented into the MSWMS of both cities in order to limit the amount of waste sent to disposal facilities. Economically feasible waste minimization schemes should be developed in both cities, as it has been shown that limiting the amount of waste sent to disposal sites helps to facilitate in the formation of a more economically sustainable MSWMS.
ii. Legislation that stipulates that product manufacturers either use recyclable materials to produce and package their products or else are liable for the disposal costs of products that contain materials that are not readily recyclable must be developed at national, provincial and then at local government level.

REFERENCES

1. Abou Najm, M., El-Fadel, M. (2004); "Computer-based Interface for an Integrated Solid Waste Waste Management Optimization Model"; *Environmental Modelling & Software*; **19**; pages 1151-1164.
2. Beningfield, S.E. (2002); "Recycling: Is Recycling Sustainable at the Current Rates"; Proceedings of WasteCon 2002; Durban; 1-3 October; pages 11-19.
3. Chang, N., Davila, E., Dyson, B., Brown, R. (2005); "Optimal Design for Sustainable Development of a Material Recovery Facility in a Fast-Growing Urban Setting"; *Waste Management*; **25**; pages 833-846.
4. Chang, T.J., Pickus, W., Murray, K.J., (1991); "Transfer Today, TRF Tomorrow – Combining Transfer and Materials Recovery Facilities in the New Generation of Transfer Stations"; Proceedings of the 7th International Conference on Solid Waste Management and Secondary Materials; Philadelphia, USA; 10-13 December; Session 3A.
5. Coetzee, J., Botes, F (2005); "Economic Viability Study: Helderberg, Oostenberg and Tygerberg Transfer Stations"; Presentation given to the Solid Waste Management Department of the City of Cape Town in August 2005.
6. DSM Environmental Services (2004); "Material Reclamation Study – Johannesburg"; Presented to Pikitup in March 2004; Final Draft.
7. Eriksson, O., Frostell, B., Bjorklund, A., Assefa, G., Sundqvist, J.-O., Granath, J., Carlsson, M., Baky, A., Thyselius, L. (2002); "ORWARE – A Simulation Tool for Waste Management"; *Resources, Conservation & Recycling*; **36**; pages 287-307.
8. Fiorucci, P., Minciardi, R., Robba, M., Sacile, R. (2003); "Solid Waste Management in Urban Areas Development and Application of a Decision Support System"; *Resources, Conservation & Recycling*; **37**; pages 301-328.
9. Ingerop Africa (1999); "Swartklip Refuse Transfer Station: Waste Characterisation Study"; Presented to the Solid Waste Management Department of Cape Town.
10. Jarrod Ball & Associates (2003); "Status Quo Report on the Current Waste Generation and Management in the City of Johannesburg"; Presented to Pikitup as part of Johannesburg's Integrated Waste Management Plan; Report No.1; Draft 1; January 2003.
11. Mega-Tech Inc. (2004-1); "City of Cape Town's Final Status Quo Report"; Presented to the Solid Waste Management Department of Cape Town as part of the city's Integrated Waste Management Plan; Contract No. 0098-0103-SUB-TA37; March 2004.

12. Mega-Tech Inc. (2004-2); "City of Cape Town's Draft Assessment Report"; Presented to the Solid Waste Management Department of Cape Town as part of the city's Integrated Waste Management Plan; Contract No. 0098-0103-SUB-TA37; May 2004.
13. MCCK & Consultancy (1998); "Waste Management, A Strategy for Dublin"; Dublin Local Authorities; Dublin.
14. Morrissey, A.J., Browne, J. (2004); "Waste management Models and their Application to Sustainable Waste Management"; *Waste Management*; **24**; pages 297-308.
15. Novella, P.H. (2002); "Development of a Waste Transfer and Disposal Philosophy for the City of Cape Town"; Proceedings of WasteCon 2002; Durban; 1-3 October; pages 54-61.
16. Renkow, M. and Rubin, A.R. (1998); "Does Municipal Solid Waste Composting Make Economic Sense?"; *Journal of Environmental Management*; **53**; pages 339-347.
17. van der Walt, M.L. and Liebenberg, C.J.; "Waste Reclamation in the Johannesburg Metro"; Proceedings of WasteCon 2004; Sun City; 11-15 October; pages 485-497.
18. Wright-Pierce, Lee International, Entech Consultants, Bham Tayob Khan & Matunda, Mallinicks (1999); "Feasibility Study Towards an Integrated Waste Management Plan for the Cape Metropolitan Area"; Annexure A.
19. http://www.akura.co.za/compactors/transfer%20durban%20site2.jpg; accessed 10/07/2006.
20. http://ceroi.net/reports/johannesburg/csoe/images/envissues/waste/landfill%20sites.jpg; accessed 16//03/2006.
21. http://www.defra.gov.uk/corporate/consult/animalbyprod/purpose.htm; accessed 05/01/2006.
22. http://www.dispatch.co.za/1997/11/18/page%203.htm; accessed on 31/03/2006.
23. http://www.dispatch.co.za/2000/09/14/business/BUS5.HTM; accessed 22/06/2006.
24. http://www.dslimited.biz/excel_tutorials/images/simultaneouslinearequations002.gif ; accessed 10/07/2006.
25. http://www.dwaf.gov.za/Documents/Other/WQM/RequirementsWasteDisposalLandfillSep05.asp; accessed 11/11/2006.
26. http://europa.eu.int/comm/environment/waste/studies/pdf/euwastemanagement_annexes.pdf; accessed 23/03/2006.
27. http://www.environment.gov.za/ProjProg/WasteMgmt/waste.html; accessed 18/09/2005.
28. http://www.engineered-linings.co.za/images/Shongweni%20landfill.jpg; accessed 10/07/2006.
29. http://www.gautengleg.gov.za/Publish/Legislature%20Documents/Committees%20-%20Portfolio/Agriculture,%20Conserv%20and%20Environment%20Committee/DRAFT/Second%20Legislature/2001/2001-06-20-e.003%20-

%20Draft%20Report%20on%20Illegal%20Landfill%20Site%20in%20Gauteng%20Province.pdf; accessed 20/03/2006.

30. www.godiversified.com/MRF.ht4.jpg; accessed 10/07/2006.
31. http://www.johannesburgnews.co.za/budget_2001/pickitup.html; accessed 10/03/2006.
32. http://www.joburg.org.za/services/electricity_tariffs.stm; accessed 15/03/2006.
33. http://www.joburg.org.za/services/water_tariffs.stm; accessed 15/03/2006.
34. http://www.mbb.co.za/documents/mbb/capability/Solid%20Waste%20Capability%20Statement.PDF; accessed 21/03/2006.
35. http://www.pikitup.co.za/upload/images/Composting-Machine.gif; accessed 12/04/2006.
36. http://www.pikitup.co.za/default.asp?id=624; accessed 21/03/2006.
37. http://www.pikitup.co.za/default.asp?id=629; accessed 21/03/2006.
38. http://www.pikitup.co.za/default.asp?id=686; accessed 21/03/2006.
39. http://www.pikitup.co.za/default.asp?id=763; accessed 21/03/2006.
40. http://www.statssa.gov.za/publications/P02772/P02772August2005.pdf; accessed 15/03/2006.
41. http://www.shell.co.za/vpower/pprice.htm; accessed 15/03/2006.

APPENDIX A

APPENDIX A1: Data Sheet for the City of Cape Town

Table A1.1: Cape Town Waste Characterisation *(Mega-Tech, May 2004)*

Recyclables Fractions	Household	Comm./Ind.	2-Bag stream	RC Stream	Landfill Recycling	DO Waste	Composting
Builder's Rubble	-	-	-	-	-	0.35	-
Green Waste	-	-	-	-	-	0.65	-
Organics	0.47	0.31	-	-	-	-	0.98
Metal	0.05	0.01	0.05	0.02	0.18	-	0.02
Glass	0.08	0.02	0.32	0.05	0.03	-	-
Paper & Cardboard	0.19	0.18	0.54	0.86	0.61	-	-
Plastic	0.13	0.02	0.09	0.07	0.18	-	-
Other	0.08	0.47	-	-	-	-	-
TOTAL	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table A1.2: Garden Waste Sources *(Mega-Tech, May 2004)*

Source	Amount (t/yr)	Mass Frac.
Garden Service / Drop-offs	81619	0.44
Topping up of bin	59359	0.32
Local Authority	44519	0.24
TOTAL	185497	1

Assumptions:

1. Waste components going through transfer stations as compared to waste going directly to landfill are split according to the ratio of the total flow for each stream respectively (own assumption).
2. 36% of garden waste sent to Drop-offs is not recovered while the rest is recovered *(Mega-Tech, pg. 5.14 Draft Assessment Report, May 2004)*.

Table A1.3: Analysis of Drop-off Waste (*Mega-Tech, May 2004*)

Source	Mass Frac.
Garden Waste Not Recovered	0.36
Garden Waste Recovered	0.64

APPENDIX A1: Data Sheet for the City of Cape Town (Continued)

Table A1.4: Analysis of Overall Waste Generated (*Mega-Tech, May 2004*)

Source	Amount (t/yr)	Mass Frac.
Household	1409778	0.38
Commercial and Industrial	1558176	0.42
Garden	185497	0.05
Builder's Rubble	556491	0.15
TOTAL	3709942	1

Parameters:

Total Generated Waste (t/yr)	3709942	
Transfer Station(s) Capacity (t/yr)	2364731	
Landfill Cost (R/tonne)	149.66	
Landfill/TS Splitting Ratio (F1):	0.98	
MRF/Landfill Split Ratio (F2):	1.00	
Private Vissershok Waste (t/yr)	0.00	
Baseline Year (2003/2004)	2003	
Year Analysed	2030	
Inflation Rate	0.05	
Overheads/Admin. For SWC	0.26	**Assumed same as Waste Disposal Department**
End-of-Life Deposit Bottles (t/yr)	6000	
Income Increase Rate	0.07	
Number of MRFs	7	

APPENDIX A2: Data Sheet for the City of Johannesburg

Table A2.1: Cape Town Waste Characterisation *(Mega-Tech, May 2004)*

Recyclables Fractions	Household	Comm./Ind.	Co-Collection	RC Stream	Landfill Recycling	Area Cleaning	Composting
Builder's Rubble	0.02	-	-	-	-	0.50	-
Green Waste	0.24	-	-	-	-	0.03	-
Organics	0.12	0.31	-	-	-	-	0.98
Metal	0.03	0.02	0.08	0.02	0.18	-	0.02
Glass	0.05	0.04	0.15	0.09	0.03	-	-
Paper & Cardboard	0.17	0.10	0.48	0.62	0.61	-	-
Plastic	0.10	0.07	0.29	0.27	0.18	-	-
Other	0.29	0.46	-	-	-	0.47	-
TOTAL	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table A2.2: Sources of Garden Waste *(Mega-Tech, May 2004)*

Source	Amount (t/yr)	Mass Frac.
Garden Service / Drop-offs	266472	0.61
Topping up of bin	153551	0.35
Street Cleaning	16292	0.04
TOTAL	436315	1

Assumptions:

1. Waste components going through transfer stations as compared **to waste** going directly **to landfill are** split **according to the ratio of the** total
   flow for each stream respectively (own assumption).
2. 36% of garden waste sent to Drop-offs is not recovered while **the rest is** recovered *(Mega-Tech, pg. 5.14 Draft Assessment Report, May 2004).*

Table A2.3: Analysis of Drop-off Waste (*Mega-Tech, May 2004*)

Source	Mass Frac.
Garden Waste Not Recovered	0.91
Garden Waste Recovered	0.09

APPENDIX A2: Data Sheet for the City of Johannesburg (Continued)

Table A2.4: Analysis of Overall Waste Generated (*Mega-Tech, May 2004*)

Source	Amount (t/yr)	Mass Frac.
Household	773907	0.27
Commercial and Industrial	1213134	0.42
Green (excl. Household GW)	315997	0.11
Area Cleaning	575170	0.20
TOTAL	2878208	1

Parameters:

Total Generated Waste (t/yr)	2878208	
Transfer Station Capacity (t/yr)	40000	
Landfilling Cost (R/tonne)	95.08	
Landfill/TS Splitting Ratio (F1):	0.01	
MRF/Landfill Split Ratio (F2):	0.00	
Private Chloorkop Waste (t/yr)	0.00	
Baseline Year (2004/2005)	2004	
Year Analysed	2030	
Inflation Rate	0.05	
Overheads/Admin. For SWC	0.26	Assumed same as Waste Disposal Department
End-of-Life Deposit Bottles (t/yr)	6000	
Income Increase Rate	0.06	
Number of MRFs	5	
Number of GW Compost Plants	4	
No. of Dailies Compost Plants	3	

APPENDIX B

APPENDIX B1: Stream Sheet (Mass Balance)

STREAM NO:	1	2A	2B	4A	4B	4
STREAM NAME:	Landfill Cover	2 Bag System	Organics Collection	Household Waste	Comm./Ind. Waste	Combined Collected Waste
COLLECTOR:	SWM	Enviroglass	SWM	SWM/Private	SWM/Private	SWM/Private
FLOWS:						
Total (t/yr):	52000	218242	544247	9199956	1558176	2412991
Components:						
Builder's Rubble (t/yr)						
Disposed	-	-	-	-	-	488571
Recycled	-	-	-	-	-	-
Landfill Cover (t/yr)						
Soil	52000	-	-	-	-	-
Organics (t/yr):						
Agricultural waste	-	-	-	-	-	-
Green Waste	-	-	54425	-	-	4934
Household Organics	-	-	489822	172773	486151	658924
Compost Product	-	-	-	-	-	-
Recyclables (t/yr):						
Metal	-	11584	-	70489	7791	59888
Glass	-	69709	-	112782	26489	52543
Paper & Cardboard	-	117857	-	267858	283588	140847
Plastic	-	19099	-	183271	23373	163717
Other	-	-	-	112782	730784	843567
Balance Check:	52000	218249	544247	919956	1558176	2412991
ECONOMIC ANALYSIS		*				*
Variable Cost (R/t)		259.0	1494.9	-	-	1170.8
Costs (R)		78519774	903979462	-	-	1834006889
Income-based Benefit (R)		0		-	-	3142201076
Airspace Cost Benefit (R)		0	0	-	-	-
Capital Cost (R)		46591393	471509894			
Total Profit/Loss (Mill. R)		-125.1	-922.8			1308.2

APPENDIX B1: Stream Sheet (Mass Balance) - Continued

STREAM NO:	5	5A	6	7	10
STREAM NAME:	Feed to TS/MRF	MRF Recovery	Direct Feed to Landfill	Recyclables	Drop-off (DO) Waste
COLLECTOR:	SWM/Private	SWM	SWM/Private	Private	Private Delivery/ACS
FLOWS:					
Total (t/yr):	2364731	2582974	48260	340397	194059
Components:					
Builder's Rubble (t/yr)					
Disposed	478799	478799	9771	-	67920
Recycled	-	-	-	-	-
Landfill Cover (t/yr)					
Soil	-	-	-	-	-
Organics (t/yr):					
Agricultural waste	-	-	-	-	-
Green Waste	4836	4836	99	-	126138
Household Organics	645746	645746	13178	-	-
Compost Product	-	-	-	-	-
Recyclables (t/yr):					
Metal	58690	70274	1198	6808	-
Glass	51492	121201	1051	17020	-
Paper & Cardboard	138030	255888	2817	292741	-
Plastic	160443	179542	3274	23828	-
Other	826695	826695	16871	0	-
Balance Check:	2364731	2582980	48260	340397	194059
ECONOMIC ANALYSIS	*		*		
Variable Cost (R/t)		207.6	-		-
Costs (R)		536274958	-	0	-
Income-based Benefit (R)	-	1265286093	-	-	-
Airspace Cost Benefit (R)	0	147490970	-	117451575	-
Capital Cost (R)		2358150840		-	-
Total Profit/Loss (Mill. R)	0.0	782.2	0	117.5	0

APPENDIX B1: Stream Sheet (Mass Balance) -Continued

STREAM NO:	12	15	17	18
STREAM NAME:	Transfer Station Output	DO Material Sent to Landfill	Recovered DO Waste	Recovered Landfill Recyclables
COLLECTOR:	Rail (SWM)	SWM	Interwaste	Informal Recyclists
FLOWS:				
Total (t/yr):	2160404	113330	80728	1469
Components:				
Builder's Rubble (t/yr)				
Disposed	478799	67920	-	-
Recycled	-	-	-	-
Landfill Cover (t/yr)				
Soil	-	-	-	-
Organics (t/yr):				
Agricultural waste	-	-	-	-
Green Waste	4836	45410	80728	-
Household Organics	645746	-	-	-
Compost Product	-	-	-	-
Recyclables (t/yr):				
Metal	29345	-	-	269
Glass	25746	-	-	37
Paper & Cardboard	69015	-	-	901
Plastic	80222	-	-	262
Other	826695	-	-	-
Balance Check:	2160404	113330	80728	1469
ECONOMIC ANALYSIS			*	*
Variable Cost (R/t)	199.4	1170.8		
Costs (R)	430712262	79522102		-
Income-based Benefit (R)			-	-
Airspace Cost Benefit (R)			27854770	219886
Capital Cost (R)	763926110		-	
Total Profit/Loss (Mill. R)	-461.3	-79.5	27.9	0.2

APPENDIX B1: Stream Sheet (Mass Balance) - Continued

STREAM NO:	24	OUTPUT
STREAM NAME:	Council Composting	Waste Landfilled
COLLECTOR:	SWM	SWM
FLOWS:		
Total (t/yr):	544247	2320531
Components:		
Builder's Rubble (t/yr)		
Disposed	-	556491
Recycled	-	-
Landfill Cover (t/yr)		
Soil	-	-
Organics (t/yr):		
Agricultural waste	-	-
Green Waste	54425	50344
Household Organics	489822	658924
Compost Product		
Recyclables (t/yr):		
Metal	0	30274
Glass	-	26759
Paper & Cardboard	-	70931
Plastic	-	83234
Other	-	843567
Balance Check:	544247	2320524
ECONOMIC ANALYSIS	*	
Variable Cost (R/t)	588.6	149.7
Costs (R)	320366348	347300047
Income-based Benefit (R)	202912675	171143915
Airspace Cost Benefit (R)	187788715	-
Capital Cost (R)	24306165	
Total Profit/Loss (Mill. R)	46.0	-176.2

Table B1: Optimum Stream Mass Fractions

Stream	Mass Frac.
Waste Landfilled (excl. DO)	0.59
Recovered Landfill Waste	4.E-04
MRF Recovery	0.06
Waste Recycled (2 Bag)	0.06
Separate Organics Collection	0.15
Waste Recycled (Centres)	0.09
Council Composted Waste	0.00
Drop-off Waste	0.05
TOTAL	1.00

Objective Function:	517.0

APPENDIX B2: Stream Sheet (Mass Balance)

STREAM NO:	1	2	4	5A	5B	5C	5D	5
STREAM NAME:	Landfill Cover	Co-Collection	Depot Feed	Hshd Waste	Comm./Ind. Waste	Area Cleaning	Dailies	Collected Waste
COLLECTOR:	Pikitup	Pikitup	Pikitup	Pikitup	Pikitup/Private	Pikitup	Pikitup	Pikitup/Private
FLOWS:								
Total (t/yr):	130461	80000	1988600	718019	1186343	575170	185610	2091747
Components:								
Builder's Rubble (t/yr)								
Disposed	-	-	299996	12411	-	287585	-	299996
Recycled	-	-	-	-	-	-	-	-
Landfill Cover (t/yr)								
Soil	130461	-	-	-	-	-	-	-
Organics (t/yr):								
Agricultural waste	-	-	-	-	-	-	-	-
Green Waste	-	-	489793	182031	-	19320	-	228906
Household Organics	-	-	200049	92618	371219	-	181624	282212
Compost Product	-	-	-	-	-	-	-	-
Recyclables (t/yr):								
Metal	-	5620	26824	15757	21556	-	3985	33403
Glass	-	10442	49378	27938	43965	-	-	56714
Paper & Cardboard	-	34899	168885	104515	114385	-	-	62622
Plastic	-	21038	100373	58858	81069	-	-	78908
Other	-	8000	653303	223891	554149	268265	-	1048985
Balance Check:	130461	80000	1988600	718019	1186343	575170	185610	2091747
ECONOMIC ANALYSIS		*	*					*
Variable Cost (R/t)		259.0		-	-		3952.2	1039.4
Costs (R)		20932798		-	-		733571294	1143040079
Income-based Benefit (R)		-		-	-		1493210630	2947636388
Airspace Cost Benefit (R)		0		-	-			-
Capital Cost (R)		15182440					314600496	
Total Profit/Loss (Mill R	0.0	-6.1	0.0	0.0	0.0	0.0	746.5	1804.6

APPENDIX B2: Stream Sheet (Mass Balance)-Continued

STREAM NO:	6	6A	6B	7	10
STREAM NAME:	MRF/Landfill Feed	MRF Recovery	Direct Feed to Landfill	Recyclables	Drop-off (DO) Waste
COLLECTOR:	Pikitup	Pikitup	Pikitup/Private	Private	Private Delivery/ACS
FLOWS:					
Total (t/yr):	2062676	80000	1982676	312410	288442
Components:					
Builder's Rubble (t/yr)					
Disposed	295827	0	295827	-	-
Recycled	-	-		-	-
Landfill Cover (t/yr)					
Soil	-	-		-	-
Organics (t/yr):					
Agricultural waste	-	-		-	-
Green Waste	225725	0	225725	-	288442
Household Organics	278290	0	278290	-	-
Compost Product	-	-		-	-
Recyclables (t/yr):					
Metal	32939	5620	27319	6169	-
Glass	55925	10442	45483	26792	-
Paper & Cardboard	61752	34899	26853	195054	-
Plastic	77811	21038	56773	84395	-
Other	1034407	8000	1026407	0	-
Balance Check:	2062676	80000	1982676	312410	288442
ECONOMIC ANALYSIS			*		
Variable Cost (R/t)		569.8	95.1		-
Costs (R)		45583123	188518420	0	-
Income-based Benefit (R)		78981165	-	-	-
Airspace Cost Benefit (R)		5476769	-	30529233	-
Capital Costs (R)				-	-
Total Profit/Loss (Mill. R)	0.0	37.2	0.0	30.5	0.0

APPENDIX B2: Stream Sheet (Mass Balance) - Continued

STREAM NO:	**12**	**15**	**16**	**17**	**18**
STREAM NAME:	TS Output	Landfilled DO Material	GW Composting	GW Sewage Composting	Recovered Landfill Recyclables
COLLECTOR:	Rail (Pikitup)	Pikitup	Pikitup	Sewerage Waste Dep.	Informal Recyclists
FLOWS:					
Total (t/yr):	29070	0	258705	29737	12321
Components:					
Builder's Rubble (t/yr)					
Disposed	4169	-	-	-	-
Recycled	-	-	-	-	-
Landfill Cover (t/yr)					
Soil	-	-	-	-	-
Organics (t/yr):					
Agricultural waste	-	-	-	-	-
Green Waste	3181	0	258705	29737	-
Household Organics	3922	-		-	-
Compost Product	-	-	-	-	-
Recyclables (t/yr):					
Metal	464	-	-	-	2253
Glass	788	-	-	-	314
Paper & Cardboard	870	-	-	-	7558
Plastic	1097	-	-	-	2196
Other	14578	-	-	-	-
Balance Check:	29070	0	258705	29737	12321
ECONOMIC ANALYSIS	?		*		*
Variable Cost (R/t)	189.9	0.0	519.7	519.7	-
Costs (R)	5519629	0	134443613	15453591	-
Income-based Benefit (R) Airspace Cost Benefit (R)					- 1171536
Capital Cost (R)				-	
Total Profit/Loss (Mill. R)	-5.5	0.0	-134.4	-15.5	1.2

APPENDIX B2: Stream Sheet (Mass Balance) - Continued

STREAM NO:	24	26	OUTPUT
STREAM NAME:	GW Compost	Dailies Compost	Waste Landfilled
COLLECTOR:	Pikitup	Pikitup	Pikitup
FLOWS:			
Total (t/yr):	258705	185610	2021825
Components:			
Builder's Rubble (t/yr)			
Disposed	-		299996
Recycled	-		-
Landfill Cover (t/yr)			
Soil	-		-
Organics (t/yr):			
Agricultural waste	-		-
Green Waste	258705		228906
Household Organics		181624	282212
Compost Product			
Recyclables (t/yr):			
Metal	0	3985	26654
Glass	-		48046
Paper & Cardboard	-		27145
Plastic	-		59881
Other	-		1048985
Balance Check:	258705	185610	2021825
ECONOMIC ANALYSIS	*		
Variable Cost (R/t)	262.5	3214.3	95.08
Costs (R)	67920077	596603519	192240807.5
Income-based Benefit (R)	70616871	56828657	151818086.0
Airspace Cost Benefit (R)	257713826	18138053	-
Capital Costs (R)	17031409	23166025	
Total Profit/Loss (Mill. R)	259.8	-544.8	-40.4

Table B2: Optimum Stream Mass Fractions

Stream	Mass Frac.
Waste Landfilled (excl. DO)	0.69
Recovered Landfill Waste	4.E-03
MRF Recovery	0.00
Waste Recycled (2 Bag)	0.03
Separate Organics Collection	0.06
Waste Recycled (Centres)	0.11
Drop-off Waste Recovered	0.10
Drop-off Waste Disposed	0.00
TOTAL	1.00

Objective Function:	2103.1

APPENDIX C

APPENDIX C1

Background Notes:

i. Component mass fractions for the system input streams ($\mathbf{X_{I;J}}$): These values for the Cape Town model are reported in Table A1.1 of **Appendix A1**, where:
I = the particular stream including R2B (2 Bag Recyclables); Hshd (Household Waste); C&I (Commercial/Industrial Waste); DO (Drop-off Waste); RC (Private Recycling); RLW (Recovered Landfill Waste); CW (Composted Waste).
J = the stream component including br (Builders' Rubble); gw (Green Waste); ho (Household Organics); m (Metal); g (Glass); pc (Paper & Cardboard); p (Plastic); o (Other).

ii. Variable stream mass fractions optimised by model ($\mathbf{Y_I}$): These values are changed by the developed model in order to optimise the MSWMS from an economic perspective, where:
I = the particular stream including WL (Waste Landfilled); RLW (Recovered Landfill Waste); MRF (Material Recovery Facility); R2B (2 Bag Recyclables); SOC (Separate Organics Collection); RC (Private Recycling); MWC (Mixed Waste Composting); DO (Drop-off).

iii. Waste source mass fractions ($\mathbf{Z_I}$): These values for the Cape Town model are reported in Table A1.4 of **Appendix A1**, where: **I** = Hshd (Household Waste); C&I (Commercial/Industrial Waste); BR (Builders' Rubble); GW (Green Waste).

iv. Mass fractions of different Green Waste sources ($\mathbf{U_I}$): Values reported in Table A1.2 of **Appendix A1**, where: **I** = DO (Drop-off); SB (Serviced Bin top-up); LA (Local Authority).

v. Mass fractions of Drop-off Green Waste that recovered/not recovered ($\mathbf{V_I}$): Values reported in Table A1.3 of **Appendix A1**, where: **I** = R (recovered GW); NR (GW not recovered).

vi. Total amount of generated Municipal waste for year t ($\mathbf{M(t)_{total}}$): These values where taken from the waste forecasts predicted in *Coetzee and Botes (2005)*.

vii. Split fraction separating the Combined Collected Waste stream into waste sent directly to Landfill Sites and into waste that is sent to Transfer Stations ($\mathbf{F_1}$): These values where again taken from the transfer station waste forecasts predicted in *Coetzee and Botes (2005)*.

viii. Second split fraction splits transfer station waste into waste that is first processed in an MRF from waste which is not sent through the MRF ($\mathbf{F_2}$): Values determined by the model.

ix. Annual inflation rate (i): This value was set at 5%.

x. Annual revenue increase rate (r): This value was set at 7%.

xi. Model year (t_m): The value ranges between 2005 and 2030 in increments of 5 years.

xii. Baseline year (t_b): The baseline year for the Cape Town model is 2003.

The equations for the various modelled streams are displayed on the following pages:

STREAM 2A: 2 Bag System

Total Flow Rate: $Y_{R2B} \times M(t)_{total}$

Components Flows:

Metals: $X_{R2B;m} \times Y_{R2B} \times M(t)_{total}$

Glass: $X_{R2B;g} \times Y_{R2B} \times M(t)_{total}$

Paper & Cardboard: $X_{R2B;pc} \times Y_{R2B} \times M(t)_{total}$

Plastics: $X_{R2B;p} \times Y_{R2B} \times M(t)_{total}$

Other: $X_{R2B;o} \times Y_{R2B} \times M(t)_{total}$

Economic Analysis:

$$\text{Variable Cost}: \quad C_{V;R2B} \times (1+i)^{(t_m - t_b - 1)}$$

$$\text{Costs}: \quad \frac{C_{V;R2B} \times (1+i)^{(t_m - t_b - 1)}}{R_{CMRF} \times P_{R2B}} \times Y_{R2B} \times M(t)_{total}$$

$$\text{Capital Costs}: \quad \left(\frac{C_B \times S \times G^{(t_m - t_b)}}{L} + C_{C;R2B} \times Y_{R2B} \times M(t)_{total} \right) \times (1+i)^{(t_m - t_b - 1)}$$

$$\text{Total Profit / Loss}: \quad - Y_{R2B} \times M(t)_{total} \times (1+i)^{(t_m - t_b - 1)} \times \left(\frac{C_B \times S \times G^{(t_m - t_b)}}{L} + C_{C;R2B} + \frac{C_{V;R2B}}{R_{CMRF} \times P_{R2B}} \right)$$

Notes:

$C_{V;R2B}$ = Variable operational cost of collecting tonne of recyclables through the 2 Bag System.
= R72.9/tonne of waste collected *(DSM Environmental; 2004)*

R_{CMRF} = Recyclables recovery fraction for clean MRFs.
= 0.8 *(http://europa.eu.int; accessed 23/03/2006)*

P_{R2B} = Purity of 2 Bag recyclables stream (what fraction of material is recyclable).
= 0.9 *(Mega-Tech Inc, 2004-1)*

$\mathbf{C_B}$ = Sales price of 100l round bins.
= R10/bin *(DSM Environmental; 2004)*

S = Municipal waste collection service points (represents number of recyclables bins).
= 600,000 *(Mega-Tech Inc, 2004-1)*

G = Service point growth index (assumed to be same as population growth index).
= 1.0157 *(Mega-Tech Inc, 2004-1)*

L = Lifespan of round bin.

= 5 years *(DSM Environmental; 2004)*

$C_{C;R2B}$ = Variable capital cost of running a separate recyclables collection system.

= R51.7/tonne of waste collected *(DSM Environmental; 2004)*

STREAM 2B: Organics Collection

Total Flow Rate: $Y_{SOC} \times M(t)_{total}$

Components Flows:

Green Waste: $X_{SOC;gw} \times Y_{SOC} \times M(t)_{total}$ .... $X_{SOC;gw}$ assumed to equal 0.1

Household Organics: $X_{SOC;ho} \times Y_{SOC} \times M(t)_{total}$ .... $X_{SOC;ho}$ assumed to equal 0.9

Economic Analysis:

$$\text{Variable Cost}: \quad C_{V;SOC} \times (1+i)^{(t_m - t_b)}$$

$$\text{Costs}: \quad \frac{C_{V;SOC} \times (1+i)^{(t_m - t_b)}}{P_{SOC}} \times Y_{SOC} \times M(t)_{total}$$

$$\text{Capital Costs}: \quad \frac{C_{REL}}{T} \times Y_{SOC} \times M(t)_{total} \times (1+i)^{(t_m - t_b)}$$

$$\text{Total Profit / Loss}: \quad -\left(\frac{C_{V;SOC}}{P_{SOC}} + \frac{C_{REL}}{T \times (t_m - t_b - 2)}\right) \times Y_{SOC} \times M(t)_{total} \times (1+i)^{(t_m - t_b)}$$

Notes:

$C_{V;SOC}$ = Variable operational cost of Separate Organics Collection stream.

= R400.4/tonne of waste collected *(DSM Environmental; 2004)*

P_{SOC} = Purity of Separate Organics Collection stream (fraction of material that is organic).

= 0.9 *(Mega-Tech Inc, 2004-1)* – assumed to be the same as for the 2 Bag System

C_{REL} = Sales price of Rear-end Loader (REL) refuse collection vehicle.

= R643,250/REL *(http://www.dispatch.co.za/1997/11/18/page%203.htm; accessed on 31/03/2006)*

T = Annual REL vehicle tonnage capacity.

= 2772 tonne/truck/year

STREAM 4A: Household Waste

Total Flow Rate: $(Z_{Hshd} - Y_{MWC} - X_{SOC;ho} \times Y_{SOC}) \times M(t)_{total}$

Components Flows:

Household Organics: $(X_{Hshd;ho} \times Z_{Hshd} - X_{MWC;ho} \times Y_{MWC} - X_{SOC;ho} \times Y_{SOC}) \times M(t)_{total}$

Metals: $(X_{Hshd;m} \times Z_{Hshd} - X_{MWC;m} \times Y_{MWC}) \times M(t)_{total}$

Glass: $X_{Hshd;g} \times Z_{Hshd} \times M(t)_{total}$

Paper & Cardboard: $X_{Hshd;pc} \times Z_{Hshd} \times M(t)_{total}$

Plastics: $X_{Hshd;p} \times Z_{Hshd} \times M(t)_{total}$

Other: $X_{Hshd;o} \times Z_{Hshd} \times M(t)_{total}$

STREAM 4B: Commercial/Industrial Waste

Total Flow Rate: $Z_{C\&I} \times M(t)_{total}$

Components Flows:

Household Organics: $X_{C\&I;ho} \times Z_{C\&I} \times M(t)_{total}$

Metals: $X_{C\&I;m} \times Z_{C\&I} \times M(t)_{total}$

Glass: $X_{C\&I;g} \times Z_{C\&I} \times M(t)_{total}$

Paper & Cardboard: $X_{C\&I;pc} \times Z_{C\&I} \times M(t)_{total}$

Plastics: $X_{C\&I;p} \times Z_{C\&I} \times M(t)_{total}$

Other: $X_{C\&I;o} \times Z_{C\&I} \times M(t)_{total}$

STREAM 4: Combined Collected Waste

Total Flow Rate: Sum of component flows

Components Flows:

Builders' Rubble: $(Z_{BR} - X_{DO;br} \times Y_{DO}) \times M(t)_{total}$

Green Waste: $(Z_{GW} - X_{DO;gw} \times Y_{DO} - X_{SOC;gw} \times Y_{SOC}) \times M(t)_{total}$

Household Organics: $(X_{Hshd;ho} \times Z_{Hshd} + X_{C\&I;ho} \times Z_{C\&I} - X_{MWC;ho} \times Y_{MWC} - X_{SOC;ho} \times Y_{SOC}) \times M(t)_{total}$

Metals: $(X_{Hshd;m} \times Z_{Hshd} + X_{C\&I;m} \times Z_{C\&I} - X_{R2B;m} \times Y_{R2B} - X_{RC;m} \times Y_{RC} - X_{MWC;m} \times Y_{MWC}) \times M(t)_{total}$

Glass: $(X_{Hshd;g} \times Z_{Hshd} + X_{C\&I;g} \times Z_{C\&I} - X_{R2B;g} \times Y_{R2B} - X_{RC;g} \times Y_{RC}) \times M(t)_{total}$

Paper & Cardboard: $(X_{Hshd;pc} \times Z_{Hshd} + X_{C\&I;pc} \times Z_{C\&I} - X_{R2B;pc} \times Y_{R2B} - X_{RC;pc} \times Y_{RC}) \times M(t)_{total}$

Plastics: $(X_{Hshd;p} \times Z_{Hshd} + X_{C\&I;p} \times Z_{C\&I} - X_{R2B;p} \times Y_{R2B} - X_{RC;p} \times Y_{RC}) \times M(t)_{total}$

Other: $(X_{Hshd;o} \times Z_{Hshd} + X_{C\&I;o} \times Z_{C\&I}) \times M(t)_{total}$

Economic Analysis:

Variable Cost: $C_{V;C} \times (1+i)^{(t_m - t_b)}$

Costs: $(Z_{Hshd} + U_{DO} \times V_{NR} + U_{SB} + X_{DO;br} \times Y_{DO}) \times M(t)_{total} \times C_{V;C} \times (1+i)^{(t_m - t_b)}$

Income: $(I_R + I_{V;T} \times S \times G^{(t_m - t_b)}) \times (1+r)^{(t_m - t_b)}$

Total Profit / Loss: $(I_R + I_{V;T} \times S \times G^{(t_m - t_b)}) \times (1+r)^{(t_m - t_b)}$
$- (Z_{Hshd} + U_{DO} \times V_{NR} + U_{SB} + X_{DO;br} \times Y_{DO}) \times M(t)_{total} \times C_{V;C} \times (1+i)^{(t_m - t_b)}$

Notes: (S, G are defined under **Stream 2A**)

$C_{V;C}$ = Variable solid waste collection cost
= R313.6/tonne

I_R = Solid Waste rate income (based on city inhabitants property value) for 2003/2004.
= R128,000,000 *(Mega-Tech Inc, 2004-1)*

$I_{V;T}$ = Average tariff charged by Municipality for collection of solid waste.
= R413.3 *(Mega-Tech Inc, 2004-1; Jarrod Ball & Associates, 2003)*

STREAM 5: Feed to TS/MRF

Total Flow Rate: F_1 x Total Flow Rate of **Stream 4**

Components Flows:

Builders' Rubble: $F_1 \times [(Z_{BR} - X_{DO;br} \times Y_{DO}) \times M(t)_{total}]$

Green Waste: $F_1 \times [(Z_{GW} - X_{DO;gw} \times Y_{DO} - X_{SOC;gw} \times Y_{SOC}) \times M(t)_{total}]$

Household Organics: $F_1 \times [(X_{Hshd;ho} \times Z_{Hshd} + X_{C\&I;ho} \times Z_{C\&I} - X_{MWC;ho} \times Y_{MWC} - X_{SOC;ho} \times Y_{SOC}) \times M(t)_{total}]$

Metals: $F_1 \times [(X_{Hshd;m} \times Z_{Hshd} + X_{C\&I;m} \times Z_{C\&I} - X_{R2B;m} \times Y_{R2B} - X_{RC;m} \times Y_{RC} - X_{MWC;m} \times Y_{MWC}) \times M(t)_{total}]$

Glass: $F_1 \times [(X_{Hshd;g} \times Z_{Hshd} + X_{C\&I;g} \times Z_{C\&I} - X_{R2B;g} \times Y_{R2B} - X_{RC;g} \times Y_{RC}) \times M(t)_{total}]$

Paper & Cardboard: $F_1 \times [(X_{Hshd;pc} \times Z_{Hshd} + X_{C\&I;pc} \times Z_{C\&I} - X_{R2B;pc} \times Y_{R2B} - X_{RC;pc} \times Y_{RC}) \times M(t)_{total}]$

Plastics: $F_1 \times [(X_{Hshd;p} \times Z_{Hshd} + X_{C\&I;p} \times Z_{C\&I} - X_{R2B;p} \times Y_{R2B} - X_{RC;p} \times Y_{RC}) \times M(t)_{total}]$

Other: $F_1 \times [(X_{Hshd;o} \times Z_{Hshd} + X_{C\&I;o} \times Z_{C\&I}) \times M(t)_{total}$

STREAM 5A: MRF Recovery

Total Flow Rate : $\dfrac{F_1 \times FR_{Total} \text{ of Stream 4}}{R_{DMRF} \times \sum \text{Stream 5 Recyclables}} \times (Y_{MRF} + Y_{R2B}) \times M(t)_{total}$

Components Flows:

Builders Rubble : $\dfrac{Y_{MRF} \times M(t)_{total} \times F_1 \times M(t)_{total}}{R_{DMRF} \times \sum \text{Stream 5 Recyclables}} \times (Z_{BR} - X_{DO;br} \times Y_{DO})$

Green Waste : $\dfrac{Y_{MRF} \times M(t)_{total} \times F_1 \times M(t)_{total}}{R_{DMRF} \times \sum \text{Stream 5 Recyclables}} \times (Z_{GW} - X_{DO;gw} \times Y_{DO} - X_{SOC;gw} \times Y_{SOC})$

Household Organics : $\dfrac{Y_{MRF} \times M(t)_{total} \times F_1 \times M(t)_{total}}{R_{DMRF} \times \sum \text{Stream 5 Recyclables}} \times (X_{Hshd;ho} \times Z_{Hshd} + X_{C\&I;ho} \times$
$Z_{C\&I} - X_{MWC;ho} \times Y_{MWC} - X_{SOC;ho} \times Y_{SOC})$

Metals : $\dfrac{Y_{MRF} \times M(t)_{total} \times F_1 \times M(t)_{total}}{R_{DMRF} \times \sum \text{Stream 5 Recyclables}} \times (X_{Hshd;m} \times Z_{Hshd} + X_{C\&I;m} \times Z_{C\&I} -$
$X_{R2B;m} \times Y_{R2B} - X_{RC;m} \times Y_{RC} - X_{MWC;m} \times Y_{MWC}) + X_{R2B;m} \times Y_{R2B} \times M(t)_{total}$

Paper & Cardboard : $\dfrac{Y_{MRF} \times M(t)_{total} \times F_1 \times M(t)_{total}}{R_{DMRF} \times \sum \text{Stream 5 Recyclables}} \times (X_{Hshd;pc} \times Z_{Hshd} + X_{C\&I;pc} \times$
$Z_{C\&I} - X_{R2B;pc} \times Y_{R2B} - X_{RC;pc} \times Y_{RC}) + X_{R2B;pc} \times Y_{R2B} \times M(t)_{total}$

Plastics : $\dfrac{Y_{MRF} \times M(t)_{total} \times F_1 \times M(t)_{total}}{R_{DMRF} \times \sum \text{Stream 5 Recyclables}} \times (X_{Hshd;p} \times Z_{Hshd} + X_{C\&I;p} \times$
$Z_{C\&I} - X_{R2B;p} \times Y_{R2B} - X_{RC;p} \times Y_{RC}) + X_{R2B;p} \times Y_{R2B} \times M(t)_{total}$

Other : $\dfrac{Y_{MRF} \times M(t)_{total} \times F_1 \times M(t)_{total}}{R_{DMRF} \times \sum \text{Stream 5 Recyclables}} \times (X_{Hshd;o} \times Z_{Hshd} + X_{C\&I;o} \times Z_{C\&I})$

The other stream equations follow the same format as those presented above. The constraints programmed into the Cape Town model are reported in below:

CONSTRAINTS (Cape Town):

i. $(Y_{SOC}+Y_{MWC}) \times M(t)_{total} > 29{,}328$ .... composting capacity of current Compost Plants.

ii. $F_2 \leq 1$

iii. $Y_{I,J} \geq 0$

iv. $\sum Y_{I,J} = 1$

v. $Y_{RLW} = 1469 \div M(t)_{total}$ .... mass fraction is kept constant at the 2002/2003 value.

vi. $Y_{RC} = 0.0918$ .... mass fraction kept constant at the original 2002/2003 value.

vii. $Y_{DO} = [(U_{DO}+U_{LA}) \times Z_{GW}] \div X_{DO;gw}$

viii. $Y_{R2B}+Y_{RC} \leq (X_{Hshd;m}+X_{Hshd;g}+X_{Hshd;pc}+X_{Hshd;p}) X Z_{Hshd}+(X_{C\&I;m}+X_{C\&I;g}+X_{C\&I;pc}+X_{C\&I;p}) X Z_{C\&i}$

ix. The constraint that limits the organics composition of the dirty MRF feed is as follows:

$$\frac{Y_{MRF} \times M(t)_{total} \times (X_{Hshd;ho} \times Z_{Hshd} + X_{C\&I;ho} \times Z_{C\&I} - X_{MWC;ho} \times Y_{MWC} - X_{SOC;ho} \times Y_{SOC}))}{FR_{Total} \text{ of Stream } 4 \times (Y_{MRF} + Y_{R2B})} \leq 0.25$$

Various streams that tended to give values below zero were also given the constraint of being greater than zero.

APPENDIX C2

Background Notes:

i. Component mass fractions for the system input streams ($\mathbf{X_{I;J}}$): These values for the Johannesburg model are reported in Table A2.1 of **Appendix A2**, where:
   I = the particular stream including CO (Co-Collection); Hshd (Household Waste); C&I (Commercial/Industrial Waste); DO (Drop-off Waste); RC (Private Recycling); RLW (Recovered Landfill Waste); AC (Area Collection); CW (Composted Waste).
   J = the stream component including br (Builders' Rubble); gw (Green Waste); ho (Household Organics); m (Metal); g (Glass); pc (Paper & Cardboard); p (Plastic); o (Other).
ii. Variable stream mass fractions optimised by model ($\mathbf{Y_I}$): These values are changed by the developed model in order to optimise the MSWMS from an economic perspective, where:
   I = particular stream including WL (Waste Landfilled); RLW (Recovered Landfill Waste); MRF (Material Recovery Facility); CO (Co-Collection); SOC (Separate Organics Collection-Dailies); RC (Private Recycling); DOR (Recovered Drop-off waste); DOD (Disposed Drop-off waste).
iii. Waste source mass fractions ($\mathbf{Z_I}$): These values for the Johannesburg model are reported in Table A2.4 of **Appendix A2**, where: **I** = Hshd (Household Waste); C&I (Commercial/Industrial Waste); BR (Builders' Rubble); GW (Green Waste).
iv. Mass fractions of different Green Waste sources ($\mathbf{U_I}$): Values reported in Table A2.2 of **Appendix A2**, where: **I** = DO (Drop-off); SB (Serviced Bin top-up); SC (Street Cleaning).
v. Mass fractions of Drop-off Green Waste that recovered/not recovered ($\mathbf{V_I}$): Values reported in Table A2.3 of **Appendix A2**, where: **I** = R (recovered GW); NR (GW not recovered).
vi. Total amount of generated Municipal waste for year t ($\mathbf{M(t)_{total}}$): These values where taken from the waste forecasts predicted in *Jarrod Ball & Associates (2003).*
vii. Split fraction separating the Combined Collected Waste stream into waste sent directly to Landfill Sites and into waste that is sent to Transfer Stations ($\mathbf{F_1}$): Value kept constant.
viii. Second split fraction splits landfill waste into waste that is first processed in an MRF from waste which is not sent through the MRF ($\mathbf{F_2}$): Values determined by the model.
ix. Annual inflation rate (i): This value was set at 5%.
x. Annual revenue increase rate (r): This value was set at 6%.
xi. Model year (t_m): The value ranges between 2005 and 2030 in increments of 5 years.
xii. Baseline year (t_b): The baseline year for the Johannesburg model is 2003.

The stream equations for the Johannesburg model follow the same format as those for Cape Town.

CONSTRAINTS (Johannesburg):

i. $F_2 \leq 1$

ii. $Y_{I,J} \geq 0$

iii. $\sum Y_{I,J} = 1$

iv. $Y_{RLW} = 12350 \div M(t)_{total}$ .... mass fraction is kept constant at the 2001/2002 value.

v. $Y_{RC} = 0.1085$ .... mass fraction kept constant at the original 2001/2002 value.

vi. $Y_{DO} = [(U_{DO}+U_{SW}) \times Z_{GW}] \div X_{DO;gw}$

vii. $Y_{R2B}+Y_{RC} \leq (X_{Hshd;m}+X_{Hshd;g}+X_{Hshd;pc}+X_{Hshd;p}) \times Z_{Hshd}+(X_{C\&I;m}+X_{C\&I;g}+X_{C\&I;pc}+X_{C\&I;p}) \times Z_{C\&I}$

viii. The constraint that limits the organics composition of the dirty MRF feed is as follows:

$$\frac{Y_{MRF} \times M(t)_{total} \times (X_{Hshd;ho} \times Z_{Hshd} + X_{C\&I;ho} \times Z_{C\&I} - X_{MWC;ho} \times Y_{MWC} - X_{SOC;ho} \times Y_{SOC}))}{FR_{Total} \text{ of Stream } 4 \times (Y_{MRF} + Y_{R2B})} \leq 0.25$$

Various streams that tended to give values below zero were also given the constraint of being greater than zero.

APPENDIX D

APPENDIX D1 (CAPE TOWN)

i. Procedure used for the conversion of cost equations in foreign currencies from a certain time to South African Rand terms for the current year.

Operational cost equation of dirty MRF for 2003 (\$) = 1519.9 x Daily Plant Capacity + 864,572 *(Chang et al, 2005).*

The following equation is used to convert this cost equation to current South African terms:

$C_{RSA}(2005) = E \times C_{USA} \times (L_{RSA} \div 1) \times (I_{2005} \div I_{2003})$

where C_{RSA}=cost equation in South African terms; E=Rand/Dollar exchange rate; C_{USA}=original cost equation; L_{RSA}=cost location factor for South Africa relative to USA; I_{2003},I_{2005}=Chemical engineering Plant Cost Indexes for the years 2003 and 2005 respectively.

The Rand/Dollar exchange rate was taken to be R6.05 per Dollar. The location factor for South Africa relative to USA is 1.1 (http://www.icoste.org/intldata.htm; accessed 20/02/2006). The CEPCI values were extracted from http://ca.geocities.com/fhcurry@rogers.com/CEIRev3.xls (accessed 20/02/2006). The reported CEPCI value for 2003 is 402.0, while the CEPCI value for 2005 is 467.6. Hence the equation is converted as follows:

$$C_{RSA}(R;\ 2005) = 6.05 \times [1519.9 \times \text{Daily Plant Capacity} + 864{,}572] \times (1.1) \times (467.6 \div 402.0)$$
$$= 11765.5\ 9 \times \text{Daily Plant Capacity} + 6{,}692{,}643$$

The same procedure was used to determine the capital and operating cost of the composting facilities.

ii. Calculation of Average Annual Refuse Truck Collection Capacity:

It is reported on page 6.9 of the City of Cape Town's Solid Waste Management Status Quo Report *(Mega-Tech Inc, 2004-1)* that the amount of waste collected by the City Council compactor refuse trucks for the year 2003/2004 was 557,180 tonnes. The number of refuse compactor trucks stated to be owned by the City council totals 201 trucks *(Mega-Tech Inc,* *2004-1)* and hence by dividing the annual collected waste by the number of trucks allocated to the collection of waste the resultant value of 2772 tonnes/truck/year is determined.

iii. Curve fit of data used to determine Transfer Station capital cost:

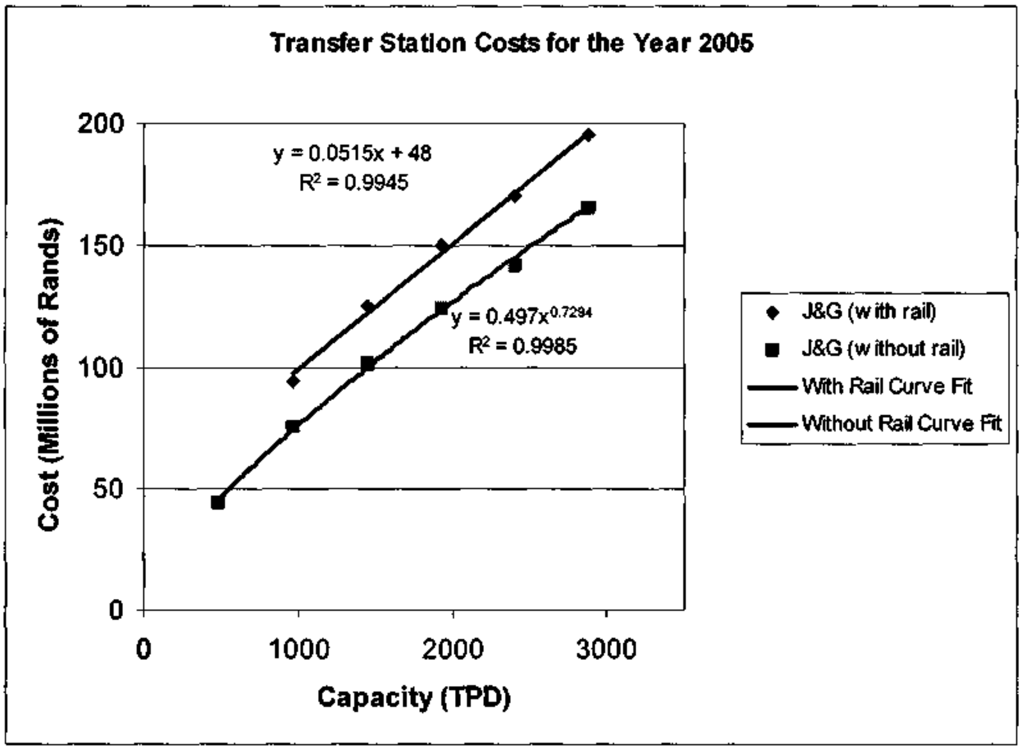

Figure D1.1: Curve fits of Transfer Station capital cost data.

The above graph depicts the curve fit of data presented in *Coetzee and Botes (2005)* for the capital costs required for the development of Transfer Stations of different input capacities.

APPENDIX D2 (JOHANNESBURG)

i. System operational cost calculations:

Table D2.1: Operational Cost of Various Solid Waste Services.

Service	Tonnage 2001/2002	Costs 2001/2002 (R/yr)	Tonnage 2004/2005	Costs 2004/2005 (R/yr)	Overhead Costs
RCW [1]	451,248	**105,634,000**	479,714	122,284,559	40,161,581
Dailies	15,094	-	16,046	5,703,397	1,873,151
Bulk Services [1]	194,700	**25,542,000**	206,982	29,568,058	9,710,956
Garden Waste	172,369	-	183,242	22,813,588	7,492,604
Informal Settlements	11,218	-	11,926	28,516,985	9,365,755
Illegal Dumping [2]	247,795	-	263,426	**41,581,573**	**13,656,522**
Street Cleaning [2]	95,911	-	101,961	**121,877,026**	**40,027,736**
Depot Management [1]	1,188,334	**51,050,000**	1,263,296	45,459,043	14,929,989
Landfilling [3]	1,516,787	**14,981,400**	1,612,469	20,305,689	-
Landfilling Overheads [3]	-	**4,920,300**	-	9,631,787	-
Non-Disposal Overheads	-	-	-	-	137,218,294

Table D2.1 depicts the operational costs of the various services provided by Pikitup. All values highlighted in bold represent those values that were reported in the references given or else are a derivative of these values. Only three of the service operational costs were directly reported in the City of Johannesburg's Solid Waste Management Status Quo Report *(Jarrod Ball & Associates, 2003)*, namely for RCW (Round Collected Waste), Bulk Services and Depot Management. These values were reported as excluding Overhead Costs.

The operational costs of operating the Illegal Dumping Collection and Street Cleaning services are reported in Pikitup's website as cited in the footnotes, and were reported for the year 2005/2006 as being R58 million and R170 million respectively. In order to convert these values to the baseline year of 2004/2005 these values were divided by an inflation factor of 1.05. It is important to note that the operational cost is made up of a variable cost (Reported as "Costs" column) and a fixed cost (represented by the "Overhead Costs" column). These and other inclusive operational costs were split into these two segments through the use of the determined overhead cost fraction for the Landfill operations, namely 0.2472. The calculation of this value is described below.

---

[1] **Jarrod Ball & Associates, 2003**

[2] http://www.pikitup.co.za/default.asp?id=624; accessed 21/03/2006

[3] http://www.gautengleg.gov.za; accessed 20/03/2006

The landfill operational costs were extracted from http://www.gautengleg.gov.za (accessed 20/03/2006). The costs were reported for individual expenses and hence these expenses were analysed to determine whether they represented variable or overhead costs and these two segment expenses were tallied up to give the total variable and overhead operational costs which are depicted in Table D2.1 above.

The operational costs of the Dailies, Garden Waste and Informal Settlement services were determined through the use of service cost fraction estimates reported in *Jarrod Ball & Associates (2003)*. These service cost estimates represented the portion of the total Solid Waste Services expenses that was allocated to the different services, and the values reported for Dailies, Garden Waste and Informal Settlement services are 0.02, 0.08 and 0.10 respectively. Hence if the total Solid Waste Services expenses are known then that portion of these expenses that has not been spent on the other services already given operational costs represents the collective operational cost for the Dailies, Garden Waste and Informal Settlement services. The total Solid Waste Services expenses value was extracted from http://www.johannesburgnews.co.za (accessed 10/03/2006) and totals R584,960,000 for the year 2004/2005. The cost fraction estimates were then used to determine what portion of the remaining operational cost is allocated to each of the three services described above.

ii. Calculating the Collection Services operational cost:

The addition of the RCW (Round Collected Waste), Bulk Services and Informal Settlement Collection services as well as the portion of the Depot Management costs that involve waste collection yields the overall collection services cost. The depots serve both a waste collection and area cleaning function and hence to determine the portion of this cost that represents the former activity the fraction of waste collected by the waste collection services in relation to the total waste handled by these two streams was used as the factor to split the Depot Management cost into these two sections. The resultant factor is 0.53. Hence the collection cost was calculated as follows:

Collection cost = RCW Cost + Bulk Services Cost + Informal Settlement Cost + 0.53 x Depot Management Cost

= R271.29 million (including overhead costs)

iii. Calculation of Garden Waste Composting operational cost:

The following table represents an operational cost determination for operating a Garden Refuse composting facility. The capital cost of developing a GW Composting Plant of the size analysed was found to be R3,950,000 (www.joburg-archive.co.za/2004/budget/ch7.pdf; accessed 01/04/2006). This is the total investment that is referred to in the table below.

Table D2.2: Garden Waste Composting Plant Cost Calculations for 2004/2005.

Cost	No's	Unit	Unit Price (R/unit)	Total (tonnes)	Cost/tonne (R/tonne)
Fixed Costs					
Salaries	3	person	85416 [4]	256248	-
Maintenance, civil works	2	% of investment	1610415	32208	-
Maintenance, equipment	10	% of investment	1738395	173840	-
Electricity basic	12	months	91.5 [5]	8372	-
Misc.	10	%	206048	20605	-
Total Fixed Costs				**491273**	-
Variable Costs					
Power	40000	kWh	0.4174 [5]	16696	1.67
Water and Wastewater	1500	cum	109.8 [6]	164700	16.47
Fuel	75000	litre	5.475 [7]	410625	41.06
Disposal of Residuals	800	ton	54.66 [8]	43729	4.37
Miscellaneous	10	%	635750	63575	6.36
Total Variable Costs				**699325**	69.93

The template used to determine the operational costs of a typical Garden Waste Composting Facility, which are depicted in Table D2.2 above, was extracted from http://europa.eu.int/comm/environment/waste/studies/pdf/euwastemanagement_annexes.pdf (accessed 23/03/2006).

[4] http://www.statssa.gov.za/publications/P02772/P02772August2005.pdf; accessed 15/03/2006.
[5] http://www.joburg.org.za/services/electricity_tariffs.stm; accessed 15/03/2006.
[6] http://www.joburg.org.za/services/water_tariffs.stm; accessed 15/03/2006.
[7] http://www.shell.co.za/vpower/pprice.htm; accessed 15/03/2006.
[8] http://europa.eu.int/comm/environment/waste/studies/pdf/euwastemanagement_annexes.pdf; accessed 23/03/2006.