An Integrated Waste Management System

Data and Recommendations for Guelph, Ontario

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Summary

This report presents the results of a study to develop a new integrated waste management system for the City of Guelph for the 25 year period 1992-2017. Although based on the specific needs of this medium-sized Ontario community, many of the recommendations made are generally applicable. The data presented, which has been collected from many sources, is also generally relevant to the design of any integrated solid waste management system.

Six primary areas of concern are considered: waste quantities and composition, public habits, costs, compost quality, recyclables, and collection practices. In addition to these considerations the study also analyses six secondary environmental and political areas of concern which are less readily quantified. The primary source of information is the data from the Guelph Wet/Dry Pilot Program, which was begun in May 1989, and certainly one of the longest and most comprehensive of such North American studies, yielding more than two years of waste data. The Pilot Program was designed to assess both the public acceptance and the technical aspects of a two-stream Wet/Dry program vs a three-stream Wet/Dry/Garbage program.

This report compares five distinct test systems, ranging from basic one-stream garbage to three-stream garbage, recyclables and compostables, comparisons being based on three equally weighted areas: economic cost, waste diversion capability and an environmental and political category. These criteria define the (nonexistent) 'ideal' system to be that which requires no additional operational cost over basic garbage collection, diverts the theoretical maximum (determined to be about 80%) from landfill, and satisfies all the stated environmental and political factors.

It is estimated that 2.8 million tonnes of waste will be generated in Guelph over the 25 year planning period, excluding clean fill, which is inert and required for landfill operations, sewage sludge and fiberglass waste. Detailed composition into over 30 categories of waste is provided, including approximate mass to volume conversion for each category. This information shows that non-residential waste accounts for twice the quantity of residential waste and that about 40% of the overall waste stream is paper and about 30% is compostable. The Pilot Study also showed that the public strongly supports aggressive waste management practices and that, given sufficient education, the required sorting can be achieved to a high degree of success. Estimates are given for the costs associated with waste management, including preparation, collection, processing and disposal. Compost quality is assessed using data from the Pilot Study, in particular it is shown that there is little difference in finished compost quality on account of the source separation practice, whether two or three-stream. It appears that either compost can meet Ontario Provincial guidelines. Results of Pilot Dry stream sorting trials are given, including trials of a ballistic separator, which was seen to be unsatisfactory. The large quantities of newsprint make a significant impact on any processing system which must be addressed. Both residential and commercial waste collection practices are discussed.

Operating costs of a two-stream Wet/Dry system for Guelph are shown to be about $19 million annually, based on the 1991 waste quantity of 90,000 tonnes. This value includes preparation costs of some $7 million annually, the cost of preparing waste for collection, which is often ignored in spite of its significant impact on the total operational cost. A capital cost of about $56 million is estimated, including a Wet/Dry processing facility, a collection system, promotion and advertising, and a landfill. The capability to collect waste in a single vehicle is a major advantage to the two-stream system, compared to the three-stream, which would require two vehicles or two passes of a single vehicle. Either bins or bags have been seen to be workable, although bins have a greater visual impact at the curbside. The development of an effective hazardous waste system is crucial to the success of the Wet/Dry system and the current program operating in Ontario is not adequate for the new system. Residential collection of HHW will be required. Processing in the recommended system consists of maximum recycling from the Dry stream, representing about a third of overall waste, and producing high quality compost from the Wet stream to meet Provincial compost guidelines. A separate program should be established for demolition waste, which, including new construction debris, makes up about 17% of the overall waste stream. The primary disposal option is landfilling for both processing residue and non-processable waste, but some limited energy generation by a large (non-local) incineration facility may be appropriate.

The principal conclusion herein is that a two-stream Wet/Dry system, similar to that operating in many European centres, has the potential to divert more waste at less cost than a three-stream system. The current system is diverting about 10,000 tonnes of waste annually in Guelph at a cost of $2 million for collection and processing of Blue Boxes. An expanded recycling system may be able to divert up to 18% of waste at an total annual operating cost of about $17 million, however a Wet/Dry system can divert about 52% of waste for a small additional annual cost of $2 million. Ensuring markets for the large quantitie's of recyclables diverted will be an important objective, especially with respect to paper fibres, which make up the majority of the recyclables. The largest single item is newsprint and serious and immediate attention should be given to reduce the use of this commodity, which is seen to dramatically affect a waste management system at all levels, collection, processing and disposal (recyclable market). In terms of future planning it is essential not to allow the individual interests of industrial groups to unduly influence development, and it should also be noted that single-family dwellings account for only 25% of the total waste stream, a fact often ignored in the design of waste management systems. Recommendations are given for establishing a user-based fee for waste collection. Education is of paramount importance for the efficient operation of a Wet/Dry system and it is anticipated that ten times the resources required by the Blue Box Program will be needed for public education, with each home or business receiving at least one personal visit. Specific recommendations are given for phasing in the operation of a two-stream Wet/Dry system over a two year period from facility construction to full-scale operation.

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The authors and publisher believe the data in this report to be accurate, but do not accept any responsibility for errors.

This document is a 2002 reprint of an original 1993 report. The text has not been edited to reflect any political, technological, or other changes in waste management which have occurred over the past decade.

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1 Introduction

1.1 Objectives

The purpose of this study is to develop a new integrated waste management system for the City of Guelph and surrounding area, based on stated waste management aims and other considerations. A waste management system has a mandate to address the diverse and often conflicting interests of many groups: the City of Guelph, which has the legislated responsibility to collect and dispose of waste in Guelph; the citizens of Guelph, in both a residential and non-residential context; the Province of Ontario; interest groups such as environmental organizations and businesses; the neighbouring residents of Wellington County; employees of the City of Guelph, especially those who will be involved in operating the program; and, to some extent, observers from other communities and possibly even other countries. To address these interests, and also environmental concerns, the following aims for the new waste management system are defined:

1. *Public health and safety* should be maintained, with particular emphasis placed on the working conditions of employees, in both collection and processing operations.

2. *Environmental impact* of waste processing and disposal must be minimized, with by-products that are at least benign or, better, enhance the environment.

3. *Economy* of operation requires that only financially sound programs be adopted by a municipal government, even though financial costs do not always reflect corresponding environmental or social costs.

4. *Social acceptability*, in the form of public acceptance and a willingness and ability to participate fully, are essential to correct and efficient operation.

5. *Technical feasability* requires the system to operate on sound scientific principles, since a municipality is generally not able to invest significant resources towards research and development (some limited experimentation is possible).

6. *Waste diversion* must meet municipal, provincial and federal waste diversion targets, for example, the province of Ontario requires a minimum 50% diversion of waste from disposal before the year 2000 (based on 1987 per capita generation rates).

7. *Environmental education* of waste generators is a key component in the societal shift towards resource conservation, both for individual and collective values.

Primary considerations, those for which actual experience or research studies exist, were determined by six research projects designed in the Guelph Pilot Study [13] as follows: (1) waste quantities and composition, (2) public habits, (3) costs, (4) compost quality, (5) recyclables, and (6) collection practices.

Secondary considerations, those for which data is not currently available or which are difficult or impossible to quantify, may have a significant impact on the design or operation of a new waste management system: (1) environmental impacts, (2) energy saving, (3) environmental threat, (4) politics, (5) waste trends, and (6) other experience. These considerations are examined through relevant data from the literature and through experience.

This study analyses data relating to the primary and secondary considerations and makes recommendations for a new waste management system for Guelph to best address the stated aims, with a 25 year period of applicability from 1992 to 2017.

1.2 Five Waste Management Test Systems

Five distinct test systems are compared to establish a basis for an operational waste management system for Guelph. These systems incorporate the three main types of waste processing: composting, recycling and incineration, with processing residues assumed to be disposed of exclusively at a suitable, provincially approved, sanitary landfill site. *Recyclables* are materials which can be re-introduced into manufacturing processes, replacing virgin resources, and are separated, where possible, to meet market requirements. *Compostables* are those organic materials that can be aerobically degraded to produce compost of sufficient quality to pose no environmental threat.

(1) One-Stream Garbage

This system, in place in Guelph and most other communities prior to 1985, is the minimal or baseline option for waste management, with a single waste stream collected from residences and businesses and all materials considered to be non-processable garbage.

(2) Two-Stream Garbage/Recyclables

This system, the current 'Blue Box Program', operating in Guelph and many other communities, has two separate distinct waste streams: a main waste stream of mixed garbage and a second stream of recyclables. Waste generators are requested to place specified recyclables out for collection in separate containers (often 'Blue Boxes'). Mixed garbage is considered non-processable and requires proper disposal.

(3) Two-Stream Garbage/Compostables

This system has two distinct waste streams: mixed garbage, for disposal, and a stream of compostables, collected and processed to manufacture quality compost, which can be environmentally beneficial when applied to receiving soils. In this system recyclables are discarded in the mixed waste stream.

(4) Two-Stream Wet/Dry

Waste generators are required to separate wastes into two streams: Wet and Dry, as defined in the list shown in Table 1, and these are collected and processed separately, thus requiring two separate waste containers. Wet wastes are processed to produce quality compost, Dry wastes are processed for removal and marketing of recyclables and the residue from both processes is disposed. This system is similar to that of Areas B, C, and E in the Guelph Pilot Study (see Section 1.4).

(5) Three-Stream Garbage/Recyclables/Compostables

Three distinct streams, defined in Table 2, are separated by waste generators in this system: Wet (compostables), Dry (recyclables) and garbage, thus requiring three separate waste containers for collection. Wet wastes are processed to produce quality compost, Dry wastes are processed for removal and marketing of recyclables and the garbage stream goes to disposal, together with processing residues from the Wet and Dry streams. This system is similar to Areas A and D in the Guelph Pilot Study (see Section 1.4).

1.3 Methodology of System Comparison

These five test systems are simplifications of an operational waste management system, which may be designed using one of them as a basis. Based on studies of the primary and secondary considerations listed above, the test systems are compared by assigning a numerical rating from 0 to 50 in each of three major areas:

1. *Economic cost* is estimated and the excess operational cost required over the baseline system is used to assign the rating.
2. *Waste diversion* capability is determined and the rating assigned according a maximum theoretical diversion of 80%.
3. *Environmental and political categories* are defined and a subjective rating from 0 to 10 assigned to each of eight factors: conservation of resources, local impacts, avoidance of pollution, positive societal changes, impact on new waste management alternatives, flexibility, public implementation and political implementation. The total is converted to a scale of 0 to 50.

These criteria define the (non-existent) 'ideal' system to be that which requires zero operational cost over the baseline, achieves the theoretical maximum diversion rate of 80% and satisfies perfectly all the stated environmental and political factors.

Much material has appeared in the literature comparing waste management systems, ranging from relatively simple [55, 25, 43] to complex [50, 57, 66, 2].

1.4 Guelph Pilot Study

Like many other communities the City of Guelph began a Blue Box Recycling Program in 1987, for recycling newspapers, glass bottles and jars, metal food and beverage cans, plastic containers, aluminum foil and containers, and telephone books, collected from single-family and some multi-unit residences. Commercial and institutional generators also separate corrugated cardboard and fine paper for collection. Immediately upon start-up of the program the public demanded more waste diversion opportunities, so, with an extremely supportive population and identification of inherent limitations with the Blue Box Program (in spite of aggressive expansion), the City of Guelph sought an alternative waste management system. R. Cave and Associates, the consulting firm for the City's Waste Management Master Plan (WMMP) [11] felt that an investigation of the European 'Wet/Dry' system would be appropriate. A number of complementary studies have been undertaken to ensure that any developed system is applicable to Guelph.

The City of Guelph Wet/Dry Pilot Program provides extremely useful data, since, as well as measuring what the public thinks it is willing to do with respect to waste separation, it also measured how well the public actually performs the requested sorting. The study enabled planners to determine how much public assistance can realistically be assumed. Similar North American studies are now operating but few have the same degree of thoroughness or length of operation.

During the summer of 1988 a researcher was retained by the City of Guelph to evaluate selected waste streams entering Guelph's Eastview Road Landfill [4]. Based on 1987 masses, an estimate of the compacted volume occupied by seven major waste classes was determined and visual volume estimates of cardboard and wood were made. This study placed a special emphasis on demolition waste and new home construction refuse, and illustrated the difficulty of assessing the waste stream by inspecting the 'back-end' refuse received at landfills.

During 1988 a study was done to determine the feasibility of implementing a Pilot Program to compost organic waste. 400 randomly selected City of Guelph residents were surveyed by telephone to assess public attitudes towards a program to source separate organic wastes, to be collected and composted at a central location [4]. The results of this survey were published in March 1989 [8] and this report provided the impetus to begin the Wet/Dry Pilot Program in Guelph.

During January 1989 Guelph representatives made on-site studies of several waste management programs in Austria, Germany, Denmark and the Netherlands, observing Wet/Dry programs by visting Dry processing centres and composting facilities. The City of Guelph Wet/Dry Pilot Program, begun in May 1989, was designed to provide assurances that the observed European programs would be applicable to Guelph. A residential area of 565 single-family homes in one Wednesday collection route (age range from 5 to 25 years) was selected and divided into three, roughly equal areas: Areas A, B and C (203, 185 and 177 homes respectively). Residents were asked to separate their waste in the following manner (see Table 1 and 2 for definitions of the categories):

Area A: Three-Stream Wet/Dry/Garbage

All organic food and yard waste is placed in a 120 litre, wheeled, green container; recyclable Dry wastes are placed in a 240 litre, wheeled, blue container; and non-processable garbage is placed in regular garbage bags or pails. Both containers are provided by the City, although residents may bag their waste instead, if preferred.

Area B: Two-Stream Wet/Dry

All organic food and yard waste, and soiled items such as diapers and tissues, are placed in a 120 litre, wheeled, green container; Dry wastes, both recyclable and non-recyclable, are placed in the existing waste container, either bags or pails.

Area C: Two-Stream Wet/Dry

This area has the same sorting regime as Area B, however the Dry waste is placed in a 240 litre, wheeled, blue container provided by the City.

Table 1

Wet Stream (Compostable)	Dry Stream (Recyclable)	(Disposed)
food waste	paper	inert wastes
yard waste	boxboard	clothing
ashes/coals	cardboard	china
diapers	newsprint	ceramics
floor sweepings	fine	plate glass
vacuum catchings	glossy	rubber
dryer lint	mixed	leather
pet droppings	glass containers	multi-mat. pkg
paper towels	metal cans	bulky goods
tissues	other metal	
sanitary napkins	plastic	
	film	
	containers	
	other	
	styrofoam	
	wood	

Two-stream waste categories (Pilot Areas B,C, and E)

Weekly collection of bins in modified single operator side-loading garbage trucks required two or three passes in each area. Blue Box participation rates were studied for eight weeks (May to July 1989) prior to distributing the collection bins, which was done in August, after a public meeting with the residents.

Waste composition studies were begun in November 1989, on the output of 10 homes selected randomly from each area, with wastes collected on a three week rotation and taken to a facility for detailed analysis. Sample homes remained constant throughout the study to assist in observing long term waste trends. The 10-home-sum of total waste in each of 32 categories was recorded, with components under 5 kg measured to an accuracy of 1 g and others to an accuracy of 100 g.

Table 2

Wet Stream (Compostable)	Dry Stream (Recyclable)	Garbage (Disposed)
food waste	paper	inert wastes
yard waste	boxboard	clothing
	cardboard	china
	newsprint	ceramics
	fine	plate glass
	glossy	rubber
	mixed	leather
	glass containers	multi-mat. pkg
	metal cans	bulky goods
	other metal	ashes/coals
	plastic	diapers
	film	floor sweepings
	containers	vacuum catchings
	other	dryer lint
	styrofoam	pet droppings
	wood	paper towels
		tissues
		sanitary napkins

Three-stream waste categories (Pilot Areas A and D)

Recyclable material was considered soiled, and sorted and massed separately, if it had not been rinsed and contained sufficient food residue to interfere with the recycling process. Other materials, such as newspaper and fine paper, were considered soiled if they had come into contact with food. Wet waste from all Pilot Areas was taken to a Pilot Composting Facility at the Eastview Road Landfill [72] where it was composted debagged (by hand) for nine weeks and cured.

For the first four months of the Pilot Program each and every container was visually inspected and the amount of waste and the apparent cleanliness recorded. Pilot Area B was regarded to be non-viable and discontinued after six months of operation, because this group was sorting wastes extremely poorly as compared to Areas A and C, presumably due to the lack of a Dry container. For a detailed description of sampling protocol see [45].

Two additional residential Pilot Areas were added in July 1990 to assess the difference between bins and bags for waste collection: Areas D and E (131 and 129 homes respectively):

Area D: Three-Stream Wet/Dry/Garbage

This area is the same as Area A, except that the collection bins were replaced by *translucent* 120 litre bags, blue for Dry waste and green for Wet waste, provided by the City.

Area E: Two-Stream Wet/Dry

This Area is the same as Area C, except that Wet and Dry waste bins are replaced by translucent green and blue bags provided by the City.

Also involved in the Pilot Program were a McDonalds Restaurant and a 45 unit townhouse complex from which material received only a visual inspection.

In each of the five Pilot Areas a survey was mailed to residents 12 weeks after program start-up, and a second survey followed one year later for residents in Areas A,B and C. Also, as part of a household conservation study [46], 81 residents in Areas A and C were personally surveyed. In addition to detailed, representative, waste composition analyses, all Pilot Area wastes were massed separately when delivered to the Eastview Road Landfill. The Guelph Pilot Study has yielded more than two years of waste data.

In the summer of 1992 a Dry waste sorting trial was done using a sorting belt, similar in design to that being proposed for a full-scale facility, complete with sorters, to measure sorting efficiencies for two-stream and three-stream Dry material. To estimate the potential sorting ease of the Dry waste fraction 9 tonnes of Area C Dry material were sent for sorting trials to Florida in October 1990. Results of the Florida trials are presented in this report in Section 2.5.

Detailed compost quality and design considerations related to this study are published in [72] which gives an analysis of the Guelph Pilot Composter.

2 Primary Considerations

2.1 Waste Quantities and Composition

Quantities

The City of Guelph has achieved an impressive reduction in per capita waste generation rates from a peak of 2100 kg per year in 1985 (see Tables 3 and 4) and these are expected to decline over the next two decades. In spite of this per capita reduction, total waste quantities are expected to increase by some 50% over the 25 year planning period of this study, due to a projected Guelph population increase of 1.5% per annum. Table 5 gives estimates for expected waste generation

Table 3

	Waste Quantities (10^3 tonnes)					
	1986	1987	1988	1989	1990	1991
Residential						
Drop-Off Bins	3.2	3.0	1.9	1.6	1.2	1.0
Municipal	23.0	22.3	22.6	21.8	20.8	19.5
Private	15.0	13.6	17.6	18.0	16.4	14.5
Non-Residential						
Tires	0.4	0.5	0.5	0.4	0.6	0.6
Demolition	19.8	21.5	19.9	24.0	16.3	15.3
Liquid	2.6	1.5	-	-	-	-
Fiberglass	12.2	15.4	16.5	13.7	9.8	13.6
Foundry	24.2	23.3	15.5	2.4	-	-
Horticultural	1.9	1.3	0.9	1.0	0.6	0.3
Sewage Sludge	8.8	11.6	12.0	10.6	12.0	15.3
Commercial	8.0	15.3	19.5	15.4	13.7	15.8
Industrial	25.1	20.7	23.0	27.7	30.2	28.8
Special Trash	0.4	0.7	1.0	1.1	1.5	0.8
PW Cleanings	2.7	1.5	1.5	5.8	1.4	1.1
Clean Fill	22.7	17.4	21.1	48.5	58.7	143.0
Total Waste$^{(1)}$	147	153	153	144	124	127

Waste quantities delivered to Eastview Road Landfill, Guelph. Values include approximately 17,500 tonnes generated within the County of Wellington. Diverted recyclables are not included in totals but are now estimated at 9,000 tonnes per year. Some waste streams are no longer being received. Note: (1) Excluding clean fill, which is inert and is required for landfill operation.

Table 4

Year	Population (1000)	Waste Generated (10^3 tonnes)	Per Capita (tonnes/yr)
1983	79.5	148.8	1.9
1984	82.0	154.3	1.9
1985	83.6	176.8	2.1
1986	84.3	143.4	1.7
1987	85.9	146.4	1.7
1988	87.4	134.5	1.5
1989	90.3	124.6	1.4
1990	93.0	108.0	1.2
1991	94.8	109.2	1.2

Per capita waste generation, City of Guelph. Population figures and 1983-85 waste values from City of Guelph WMMP [11]. Population includes university students and prison inmates. Post-1985 waste values from Table 3 total waste (excluding clean fill) and less estimated 17,500 tonnes Wellington County waste.

in Guelph, showing a requirement to accommodate approximately 4 million tonnes of MSW (municipal solid waste), excluding clean fill which is inert and required for landfill and land reclamation operations.

The total waste estimate includes approximately 500,000 tonnes of fiberglass waste, which, since it is non-combustible and relatively non-processable, is assumed to go directly to landfill disposal. Largely as a result of tipping fees (about $50,000,000 during the 25 year study period) Fiberglas Canada is actively exploring disposal alternatives for their process wastes, with a declared corporate goal of 90% waste reduction by 1998, so the figure of 500,000 tonnes represents a worst-case scenario. There is also a disposal requirement for 400,000 tonnes of sewage sludge, which, because of its heavy metal contamination (see Table 34), may require a specialized program for disposal or composting, independent of the rest of the waste stream. Demolition waste, much of it inert, is also a large component of the overall waste stream, with a 25 year total of 800,000 tonnes, so a separate program for this material, which includes debris from new construction, may be beneficial.

Waste quantities are a function of population and per capita generation rates. Forecasts of annual population increases are provided by the City of Guelph Planning Department as follows: 1986-1991, 2.2%; 1991-1996, 1.5%; 1996-2001, 1.3%; and 2001-2017, 0.8%. Based on these assumptions, it is estimated that Guelph's population will rise to 128,000 by 2017, a figure which includes a population equiv-

Table 5

	Waste Generation Estimates (10^3 tonnes)						
	1992	1995	2000	2005	2010	2015	Total$^{(1)}$
Domestic	46.0	48.5	54.5	60.0	66.0	74.0	1,440
Demolition	25.5	27.0	30.0	32.5	36.0	40.0	786
Sewage Sludge	12.5	13.5	14.5	16.0	18.0	20.0	393
Commercial	17.0	18.0	20.0	22.0	25.0	27.5	538
Industrial	22.5	24.0	27.0	30.0	33.0	36.0	708
Public Works	1.7	1.8	2.0	2.2	2.4	2.7	52
Fiberglass	16.0	18.0	20.0	22.0	24.0	27.0	524
Total	141	153	168	185	204	227	4,441
Revised Total	135	140	150	159	166	175	3,950

Waste generation estimates, City of Guelph. From WMMP [11]. Component values and totals are original WMMP estimates (1987). Revised totals from updated addendum (1991). All totals exclude clean fill which is inert and required for landfill operation. Note: (1) Total for period 1987 to 2016 inclusive.

alent of 7000 for university students. Per capita generation rates are generally more difficult to predict than population projections. Table 4 shows the steady decline Guelph's per capita rates have experienced since the peak year of 1985. The generation rates for 1983-85, estimates obtained from the WMMP, may not be as accurate as those for post-1985, obtained from comprehensive weigh scale records given in (Table 3), but these records alone show an estimated 35% decline in per capita waste generation. Taking the 1983-5 values into account the overall decline is likely in excess of 50%.

This significant decline in waste generation rates is believed to be a result of: steeply increasing tipping fees (1985 $0.0/tonne — 1991 $92.00/tonne); the City's Blue Box Recycling Program; an economic downturn, especially noticeable through the reduction of foundry wastes due to business closures (23,000 tonnes in 1987, none in 1991); and enhanced public awareness about waste management issues.

For purposes of this study it is estimated that per capita waste generation will decline by an additional 15% and Guelph's population will increase as outlined above. These assumptions result in a projected waste increase of 50% over the 25 year planning period (2% per year, non-cumulative).

Table 6

	Two Stream Areas (kg/week)		Three Stream Areas (kg/week)	
	C (Bins)	E (Bags)	A (Bins)	D (Bags)
Wet	11.4	10.8	7.6	6.6
Dry	11.9	9.3	6.9	6.8
Garbage	-	-	4.6	5.2
Total	23.3	20.1	19.0	18.6

Pilot Area weekly household waste generation. Weights averaged over eight months in 1989 and 1990.

Waste Composition

The Wet/Dry Pilot Study provided an excellent opportunity to obtain detailed data on waste composition, including seasonal fluctuations because the study was carried out over a one year period [54]. Table 6 and 7 show the composition of the weekly waste from a Pilot Area single-family home, totalling about 21 kg. The top ten items in the residential waste stream, both by volume and mass, are listed in order in Table 8. These values are in general agreement with similar published data, although they are more detailed and were obtained over a longer period of time. For example, the residential component of the Ontario Waste Composition Study measured waste composition in three Ontario communities [32]. The sampling procedure used in that study did not allow observation of seasonal fluctuations, especially significant in the yard waste category, which accounts for 22% of the Guelph single-family residential waste stream.

The per capita annual generation rates presented in Table 7 are assumed to be similar for all residential wastes in Guelph, with three exceptions: yard wastes are a large fraction in the waste stream of single-family homes, generated at a rate depending on the size and age of a residential lot; wood and hazardous wastes are generated by apartments and other multi-unit dwellings at a slightly reduced rate.

Table 9 compiles various sources to provide an estimate of overall waste composition in Guelph. Accurate values are available for projecting residential waste composition but this same degree of accuracy is not available for non-residential waste, which is generally more heterogeneous than residential waste due to the wider range of generators. Much commercial waste is ‘off-spec’ manufacturing waste and so the composition is dependent on the business make-up of the com-

Table 7

	Combined Weekly Waste				Per Capita$^{(2)}$
	Mass		Volume$^{(1)}$		
	kg	percent	litres	percent	kg/yr
Food	1,598	22.2	6,070	9.0	81.8
Yard	1,611	22.4	4,830	7.2	82.5
Sanitary Napkins	11	0.2	140	0.2	0.7
Diapers	146	2.0	830	1.2	7.3
Pet Droppings	101	1.4	210	0.3	5.1
Ashes	16	0.2	80	0.1	0.7
Vacuum Bag	16	0.2	100	0.2	0.7
Paper					
News	881	12.2	5,550	8.2	44.9
Glossy	317	4.4	1,020	1.5	16.1
Fine	115	1.6	1,000	1.5	5.8
Boxboard	182	2.5	4,830	7.2	9.5
Mixed	217	3.0	3,940	5.9	7.3
Corr. Cardboard	163	2.3	7,060	10.5	8.4
Plastic					
Film	142	2.0	9,710	14.4	7.3
Containers	75	1.0	2,350	3.5	4.0
Foam	16	0.2	840	1.2	0.7
PET	8	0.1	580	0.9	0.4
Other	83	1.2	2,260	3.4	4.4
Metal					
Cans	212	2.9	3,620	5.4	11.0
Other	57	0.8	740	1.1	2.9
Glass					
Clear	275	3.8	1,150	1.7	13.9
Coloured	160	2.2	700	1.1	8.0
Non-container	11	0.2	50	0.1	0.4
Ceramics	32	0.4	140	0.2	1.5
Multi Material Pkg.	133	1.8	4,540	6.7	6.9
Wood	83	1.2	280	0.4	4.4
Textiles	134	1.9	980	1.5	6.9
Inert	108	1.5	310	0.5	5.5
Rubber	6	0.1	20	0.0	0.4
Leather	4	0.1	10	0.0	0.4
Hazardous	22	0.3	130	0.2	1.0
Residue	266	3.7	3,240	4.8	13.5
Total	7,200	100	67,300	100	368
Per Household	21	-	200	-	-

Weekly residential waste stream composition, Guelph Pilot Area. Sampling of 340 Area A and C residences 15 Nov 1989 to 7 Nov 1990. Notes: (1) Loosely packed volume under 75.8 Pa (0.011 psi) pressure; (2) Based on average 3 residents per household.

Table 8

	Volume (Percent)		Mass (Percent)
Plastic Film	14.4	Yard	22.4
Corr. Cardboard	10.5	Food	22.2
Food	9.0	Newspaper	12.2
Newspaper	8.2	Glossy Paper	4.4
Yard	7.2	Clear Glass	3.8
Boxboard	7.2	Residue	3.7
Multi Material Pkg.	6.7	Mixed Paper	3.0
Mixed Paper	5.9	Metal Cans	2.9
Metal Cans	5.4	Boxboard	2.5
Plastic Containers	3.5	Corr. Cardboard	2.3
Total	78.0	Total	79.4

Ten largest components of residential waste stream ranked by volume and by mass.

munity. Although estimating the non-residential waste stream requires more assumptions, this data is considered sufficiently accurate for purposes of this study. Excluding community specific waste variations, for instance single industry types such as Fiberglas Canada in Guelph, this composition estimate could be applied, with caution, to most Southern Ontario and perhaps North American, communities.

About 35% of MSW in Guelph is generated in the home. Organics (food–24%, yard–15%) and paper products (news– 13%, other paper–16%) make up the majority (68%) of the residential waste stream. The non-residential waste stream is equally high in paper products (31%) but is lower in organics (14%). The variation between residential and non-residential waste illustrates the increased complexity of developing waste diversion programs that address all waste generators. By diverting only three components of residential waste: food, yard and newspapers, over 50% of the waste stream could be diverted. To accomplish the same diversion rate with the non- residential waste stream would require the separation of at least 10 distinct items, excluding demolition waste which is also highly variable and makes up as much as one quarter of the non-residential waste stream. Due to the make-up of demolition waste and the fact that it is generated by a relatively small group, a separate diversion program could be established.

By reviewing Table 9 some waste diversion priorities become apparent:

Table 9

	Quantity (10^3 tonnes)		Per Capita[6] (kg/yr)		Composition (Percent)		
	Res.[4]	Non.[5]	Res.	Non.	Res.	Non.	Total
Food	7.2	6.0	82.3	68.6	24	10	14.7
Horticultural	4.5	2.4	51.4	27.4	15	4	7.7
Diapers	0.6	0.3	6.9	3.4	2	0.5	1
Other Organic	0.6	0.3	6.9	3.4	2	0.5	1
Paper							
News	3.9	2.4	44.6	27.4	13	4	7
Glossy	1.5	1.2	17.1	13.7	5	2	3
Fine	0.6	3.0	6.9	34.3	2	5	4
Boxboard	0.9	2.4	10.3	27.4	3	4	3.7
Mixed	1.1	1.8	12.0	20.6	3.5	3	3.2
Corr. Cardboard	0.8	7.8	8.6	89.1	2.5	13	9.5
Plastic							
Film	0.6	0.9	6.9	10.3	2	1.5	1.7
Containers	0.5	0.6	5.1	6.9	1.5	1	1.2
Other	0.5	1.2	5.1	13.7	1.5	2	1.8
Metal							
Cans	0.9	0.6	10.3	6.9	3	1	1.7
Other	0.3	0.6	3.4	6.9	1	1	1
Glass							
Containers	2.0	0.6	22.3	6.9	6.5	1	2.8
Other/Ceramic	0.3	0.3	3.4	3.4	1	0.5	0.7
Multi-Mat. Pkg.	0.6	0.9	6.9	10.3	2	1.5	1.7
Wood	0.3	2.7	3.4	30.9	1	4.5	3.3
Textiles	0.6	1.2	6.9	13.7	2	2	2
Inert	0.5	0.6	5.1	6.9	1.5	1	1.2
Rubber/Leather	0.2	0.6	1.7	6.9	0.5	1	0.8
Residue	1.2	0.9	13.7	10.3	4	1.5	2.3
Hazardous	0.2	0.6	1.7	6.9	0.5	1	0.8
Scrap Metal[1]	-	0.6	-	6.9	-	1	0.7
Appliances	-	0.3	-	3.4	-	0.5	0.3
Tires	-	0.9	-	10.3	-	1.5	1
Demolition	-	15.0	-	171.4	-	25	16.7
Mun. Housekeeping[2]	-	1.2	-	13.7	-	2	1.3
Furniture	-	0.3	-	3.4	-	0.5	0.3
Electronic Items[3]	-	0.3	-	3.4	-	0.5	0.3
Other	-	1.5	-	17.1	-	2.5	1.7
Total	30.0	60.0	343	686	100	100	100

Annual waste composition, City of Guelph. Estimates compiled from Tables 3 and 7, Ontario Waste Composition Study [32, 33] and [48]. 1991 tonnages include recyclables currently being diverted through Guelph Blue Box Recycling Program. Additional wastes generated in Guelph include: 13,600 tonnes Fiberglass, 15,300 tonnes sewage sludge and 142,000 tonnes clean fill (1991 values). Notes: (1) Pieces in excess of 20 kg; (2) Public works sweepings and sewer cleanings; (3) Stereos, televisions, computers, *etc*; (4) Residential waste; (5) Non-residential waste approximately 25% commercial, 45% industrial, 25% demolition and 5% 'other' (off-spec manufactured items and discarded goods); (6) Based on aggregate population of 87,500 (single family and multi-unit).

- There is twice as much garbage generated outside of the home than inside.
- Excluding demolition waste, over 40% of the overall waste stream is paper.
- Compostables make up another 30%.
- The largest single item is food waste, of which each person disposes some 150 kg per year.

Other items with an annual per capita rate in excess of 25 kg are: yard (or horticultural for non-residential sources), news, glossy paper, fine paper, boxboard, mixed paper, corrugated cardboard, container glass, wood, and demolition waste. Large bulky items such as appliances, scrap metal, and furniture take up much volume but are relatively low in mass (less than 15 kg/person/yr for all three).

Table 10 provides estimates for the composition of the total 2.8 million tonnes waste (excluding clean fill, sewage sludge and fiberglass) to be generated in Guelph over the 25 year planning period. Mass to volume conversion factors, determined for the Guelph Pilot Area waste, are given in Table 11 at light compaction pressures of 75.8 Pa (0.011 psi) and 5.65 kPa (0.82 psi). The approximate volume equivalents shown in Tables 7 and 10 use these conversion factors. A waste management strategy must consider both volumes and masses, since volume is important for the design of collection and processing systems and mass is significant for accounting purposes. More reliable and detailed information is available on waste mass than volumes.

2.2 Public Habits

Background

When designing a waste management system public willingness and ability to participate is of paramount concern, since the effectiveness of requested separations by a waste generator is usually the most critical component. Measuring these public waste separation habits is difficult and a true measure can generally be obtained only with a fully operating program. Surveys are useful, but due to the complexity of public habits and demographics, they still contain a measure of uncertainty.

The costs associated with the design of new waste systems often preclude the aggressive investigation of alternatives in waste management. Fortunately the Guelph Pilot Study provided an opportunity to intensively investigate public habits with respect to waste management, both current and potential, for a period of at least one year. A City-wide survey was also undertaken in June 1988 [48], when Guelph residents were questioned by phone to assess public attitudes

Table 10

	Mass (10^3 tonnes)	Loose		Compacted	
		Conv. Factor(2)	Volume (10^3 m^3)	Conv. Factor(2)	Volume (10^3 m^3)
Organic					
Food	412.5	3.8	1,568	2.5	1,031
Horticultural	215.6	3.0	647	1.9	410
Diapers	28.1	5.7	166	3.3	93
Other	28.1	4.0	113	3.0	84
Paper					
Newsprint	196.9	6.3	1,240	4.0	788
Glossy	84.4	3.2	270	2.6	219
Fine	112.5	8.7	979	5.4	608
Boxboard	103.1	26.5	2,733	16.7	1,722
Mixed	89.1	18.2	1,621	8.9	793
Corr. Cardboard	267.2	43.2	11,543	43.2	11,543
Plastic					
Film	46.9	68.3	3,202	11.1	520
Containers	32.8	31.5	1,034	31.5	1,034
Other	51.6	27.3	1,408	14.1	727
Metal					
Cans	46.9	17.1	802	17.1	802
Other	28.1	13.0	366	7.5	211
Glass					
Containers	79.7	4.3	343	4.3	343
Other	18.8	4.3	81	4.3	81
Multi-Mat. Pkg.	46.9	34.2	1,603	15.2	713
Wood	93.8	3.4	319	3.2	300
Textiles	56.3	7.3	411	4.2	236
Inert	32.8	2.9	95	2.9	95
Rubber/Leather	23.4	3.6	84	0.9	21
Residue	65.6	12.2	801	6.3	413
Hazardous	23.4	-	-	-	-
Scrap Metal(1)	18.8	25	469	25	469
Appliances	9.4	30	281	30	281
Tires	28.1	5	141	5	141
Demolition	468.8	-	-	-	-
Mun. Hsekpng.	37.5	-	-	-	-
Furniture	9.4	35	328	35	328
Electron. Items	9.4	25	234	25	234
Other	46.9	-	-	-	-
Total	2,813	-	-	-	-

Estimated Guelph total waste quantities for period 1992-2017, excluding clean fill, sewage sludge and fiberglass. Figures based on a 25 year planning period with a 50% total increase (2% per year, non-cumulative). Notes: (1) Excluding vehicles; (2) Volumes based on loose pressure of 75.8 Pa (0.011 psi) and packed pressure 5.65 kPa (0.82 psi), which is insufficient to compact corrugated cardboard, glass, plastic containers and metal cans.

Table 11

	Loose (75.8 Pa)			Packed (5.65 kPa)		
	Mass (kg)	Volume (L)	Ratio (L/kg)	Mass (kg)	Volume (L)	Ratio (L/kg)
Food	21.5	82	3.8	32.8	82	2.5
Yard	27.7	82	3.0	42.4	82	1.9
Sanitary Napkins	1.9	24	12.6	1.9	10	5.3
Diapers	10.6	60	5.7	10.6	35	3.3
Pet Droppings	12.4	26	2.1	12.4	23	1.9
Ashes	7.5	36	4.8	7.5	30	4.0
Vacuum Bag	7.1	44	6.2	7.1	24	3.4
Paper						
News	13.0	82	6.3	20.5	82	4.0
Glossy	23.4	76	3.2	23.4	60	2.6
Fine	9.4	82	8.7	15.3	82	5.4
Boxboard	3.1	82	26.5	4.9	82	16.7
Mixed	4.5	82	18.2	9.2	82	8.9
Corr. Cardboard	1.9	82	43.2	1.9	82	43.2
Plastic						
Film	1.2	82	68.3	7.4	82	11.1
Containers	2.6	82	31.5	2.6	82	31.5
Foam	1.4	74	52.9	1.4	36	25.7
PET	1.2	82	68.3	1.2	82	68.3
Other	3.0	82	27.3	3.4	48	14.1
Metal						
Cans	4.8	82	17.1	4.8	82	17.1
Other	4.0	52	13.0	4.0	30	7.5
Glass						
Clear	19.6	82	4.2	19.6	82	4.2
Coloured	18.8	82	4.4	18.8	82	4.4
Non-container	19.2	82	4.3	19.2	82	4.3
Ceramics	19.2	82	4.3	19.2	82	4.3
Multi Material Pkg.	2.4	82	34.2	5.4	82	15.2
Wood	10.5	36	3.4	10.5	34	3.2
Textiles	11.2	82	7.3	19.6	82	4.2
Inert	12.6	36	2.9	12.6	36	2.9
Rubber	2.2	8	3.6	2.2	2	0.9
Leather	2.2	8	3.6	2.2	2	0.9
Hazardous	2.2	13	5.9	2.2	13	5.9
Residue	6.7	82	12.2	13.1	82	6.3
Tissue	6.3	82	13.0	15.8	82	5.2

Mass to volume ratios from compacting Guelph Pilot Area waste under 75.8 Pa (0.011 psi) loose pressure and 5.65 kPa (0.82 psi) packed pressure.

toward a program to source separate organic wastes for collection and composting at a central location. The survey found a very positive attitude toward such a composting program, with 88% of respondents in favour and a clear preference for central composting over backyard composting. The survey also found an extremely high claimed participation rate of 97% in the then 12 month old Blue Box Recycling Program. As a result of the encouraging survey results the City began the 600 household Pilot Program in 1989. The number of households was felt to be sufficiently large to give representative data for analysis of household sorting, collection and processing habits.

Household monitoring for Blue Box participation rates prior to starting the Pilot Program determined that 87% of the 565 Pilot homes were participating (Table 12), a rate similar to that found in other areas in Guelph and Southern Ontario. The Ontario Waste Composition Study [32] found a participation rate

Table 12

Blue Box Set-Out Rate Minimum	Percent Recorded			
	Area A	Area B	Area C	All Areas
Once in 8 weeks	86	85	89	87
Twice in 8 weeks	81	80	80	80
Four times in 8 weeks	61	67	54	61

Blue Box participation rates prior to Pilot Study

of 85% and also measured the diversion success of Blue Boxes in terms of 'capture rate' and contents (Tables 13 and 14). Approximately 50% of the desired materials are being 'captured', resulting in total net single-family residential diversion rates of about 15%.

Another indication of public willingness to separate waste is shown by the interest in backyard composting (Table 15). Guelph and many other Ontario communities have distributed subsidized composters, sold to local residents for less than one quarter of the regular retail cost of $80 by means of a provincial subsidy. It is estimated that 40% of households are composting, diverting 1,300 tonnes of waste annually or approximately 10% of residential organics.

Composition Analysis of Sorted Waste Streams

Table 16 provides an overview of the effectiveness of public sorting habits. Processing systems can be developed by closely measuring the composition of the residential waste stream, either two-stream or three-stream. The relative cleanliness of

Table 13

	Capture Rate	
	Fergus	East York
High Income		
detached housing	65.2	67.3
mixed housing	-	52.0
Medium Income		
detached housing	41.6	56.3
mixed housing	32.9	44.3
mixed housing	53.5	-
multiple housing$^{(1)}$	16.4	-
Low Income		
mixed housing	-	48.0
multiple housing$^{(1)}$	33.6	-

Blue Box Program capture rates for Fergus and East York. From Residential Waste Composition Study [32]. Based on median income of $30,936 for Fergus and $33,900 for East York. 'Capture Rate' is mass of recyclables in Blue Boxes as percent of total recyclables generated in curbside waste. Blue Box set-out rate estimated at once every two weeks. Note: (1) Values affected by apartments not served by Blue boxes in area.

Table 14

	Percent of Residential Waste Stream	
	Fergus	East York
Paper		
Newsprint	5.08	5.87
Corrugated Cardboard	-	0.07
Glass		
Liquor/Wine Bottles	1.00	0.59
Other Bottles/Food Jars	1.30	0.58
Cans		
Ferrous		
Food	0.55	0.37
Beer	0.02	0.00
Softdrink	0.16	0.04
Non-Ferrous		
Food	0.11	0.00
Beer	0.04	0.01
Softdrink	0.23	0.11
American Beer	0.01	0.00
Plastic		
PET Bottles	0.09	0.01
Jugs	-	0.09
Total	8.59	7.74

Blue Box contents in Fergus and East York. From Ontario Waste Composition Study [32].

Table 15

	Household Generation (kg/yr)	Diversion		
		Rate (percent)	Household (kg/yr)	Total (tonnes/yr)
Food	220	40	88	490
Yard	230	75	173	950

Estimated current waste diversion through backyard composting in Guelph. From Table 7 and estimated 2.7 residents per household. Estimated 5,550 households, representing 30% participation rate of 18,500 households.

Table 16

	Two Stream Areas (Percent)		Three Stream Areas (Percent)	
	C (Bins)	E (Bags)	A (Bins)	D (Bags)
Food	2	0.5	0.5	1.5
Yard	1	*	1	2
Sanitary Napkins	*	*	*	*
Diapers	*	*	*	*
Pet Droppings	2	*	*	*
Ashes	*	*	*	*
Vacuum Catchings	*	*	*	*
Paper				
Newsprint	23	31	35	39
Glossy	8	6.5	11	7
Fine	3	2	3	2
Boxboard	5	4	5	4
Mixed	5	4	5	4
Corr. Cardboard	4	3	5	2.5
Plastic				
Film	3	3	2	2.5
Containers	2	2	2	2
Foam	*	*	*	*
PET	*	*	*	*
Other	2.5	2	1	1
Metal				
Cans	5	5	7	8
Other	1.5	2	1	*
Glass				
Clear	7	7	9	11
Coloured	5	2	4	5
Non-Container	*	0.5	*	*
Ceramic	1	1	*	*
Multi-Mat. Pkg.	3	2.5	2	2
Wood	2	1	1.5	*
Textiles	4	3	0.5	*
Inert	3	1	*	*
Rubber/Leather	*	*	*	*
Hazardous	4	1	*	*
Residue	6	9	1	3
Per Capita[(1)] (kg/yr)	206.4	160.9	118.7	117.3

Composition of residential Dry stream. * denotes less than 0.3% by mass. Note: (1) Based on 3 residents per residence.

both two-stream and three-stream Dry waste is particularly noticeable, with only about 2% cross-contaminated organics (Table 21). Another interesting observation is the large percentage of the residential Dry waste stream that is made up of newspapers, ranging from 25% to almost 40%.

Tables 16 to 26 show the results of extensive waste separation trials (all percentages by mass), with separate data for two-stream and three-stream, as well as bags and bins. These results are extremely useful for determining what long term, consistent public waste sorting habits are achievable. Table 17 shows that up to 97% of organic wastes can be diverted with a two-stream system and about 85% with three-stream. Tables 18 and 19 show a high separation potential for both

Table 17

	Two Stream Areas (Percent)		Three Stream Areas (Percent)	
	C (Bins)	E (Bags)	A (Bins)	D (Bags)
Food	95	90	80	68
Yard	98	98	92	92
Total Organics	97	95	85	81

Organic materials recovered in Wet stream, Guelph Pilot Areas.

Dry and Wet waste. Two-stream separation of recyclables diverted as much as 94% and three-stream about 79%, both figures referring to *clean* recyclables only (acceptable for existing markets). Table 19 shows that three-stream recyclables are slightly cleaner than two-stream, 99% *vs* 96% of collected recyclables being sufficiently clean to market.

Tables 20, 21 and 22 show the composition, by mass, of the Wet, Dry, and garbage streams, respectively.

A useful baseline of actual waste composition is given by Table 7, since Tables 20 to 22 show 'percentages as sorted'. In two-stream Wet waste approximately 13% of the material would be considered as 'non-desirable' in the composting process, while only 4% of three-stream Wet waste material is non-desirable. A similar distinction is observed in Dry waste, for which 23% of collected material is not potentially recyclable in two-stream and 7% in three-stream (all percentages given for bins).

Two-stream Dry waste yields five times the residue of three-stream, which is not surprising since the 'missing' third stream requires the two-stream Wet and Dry streams to absorb these materials. The fact is an important consideration

Table 18

	Two Stream Areas (Percent)		Three Stream Areas (Percent)	
	C (Bins)	E (Bags)	A (Bins)	D (Bags)
Plastic				
Film	74	57	28	39
Containers	87	62	59	64
Paper				
Newspaper	98	95	96	95
Corr. Cardboard	98	81	79	53
Boxboard	90	82	69	65
Mixed	91	85	59	67
Metal Cans	87	80	84	83
Blue Box Materials	95	89	90	88
Recyclable Materials	94	86	79	77

Recyclable materials recovered in Dry stream, Guelph Pilot Areas.

Table 19

	Two Stream Areas (Percent)		Three Stream Areas (Percent)	
	C (Bins)	E (Bags)	A (Bins)	D (Bags)
Plastic				
Film	84	87	95	96
Containers	90	79	97	91
Paper				
Newspaper	99	98	100	100
Corr. Cardboard	100	88	100	98
Boxboard	93	96	100	98
Mixed	97	96	99	98
Metal Cans	90	91	99	96
Blue Box Materials	96	94	99	98
Recyclable Materials	96	94	99	98

Clean recyclables recovered in Dry stream, Guelph Pilot Areas.

Table 20

	Two Stream Areas (Percent)		Three Stream Areas (Percent)	
	C (Bins)	E (Bags)	A (Bins)	D (Bags)
Organic	87.4	79.5	96.6	96.9
Other Wet Waste	6.2	7.0	0.1	0.1
Recyclable	2.5	7.0	1.5	2.3
Other Dry Waste	2.6	1.2	1.0	0.1
Residue	1.3	4.8	0.8	0.6
Hazardous	0.03	0.25	0.05	0.06

Wet stream composition (by mass), Guelph Pilot Areas. *Organic waste* includes food and yard wastes. *Other Wet waste* includes vacuum bag catchings, ashes, pet droppings, diapers and feminine hygiene products. *Recyclable* includes all papers and cardboards, all plastics, all metals and all glass containers. *Other Dry waste* includes non-container glass, ceramics, multi-material packaging, textiles, inert, rubber and leather. *Residue* includes all pieces of waste too small to be recovered by hand, as well as small bulky items such as rugs, broken toasters etc. *Hazardous* includes batteries, paints and paint thinners, lightbulbs, aerosol cans, flammables, chemicals, strong household cleaners, syringes, motor oils, pesticides, medicines and bleaches.

Table 21

	Two Stream Areas (Percent)		Three Stream Areas (Percent)	
	C (Bins)	E (Bags)	A (Bins)	D (Bags)
Potentially Recyclable	77.3	76.0	93.2	90.0
Other Dry Waste	11.2	7.6	3.4	2.7
Organic	3.0	5.4	1.6	3.4
Other Wet Waste	2.6	1.4	0.3	0.8
Residue	5.5	8.8	1.1	3.0
Hazardous	0.4	0.9	0.3	0.1

Dry stream composition (by mass), Guelph Pilot Areas.

Table 22

	Three Stream Areas (Percent)	
	A (Bins)	D (Bags)
Organic	24.6	24.8
Other Wet Waste	14.4	12.3
Recyclable	34.1	31.9
Other Dry Waste	12.3	9.0
Residue	13.4	20.3
Hazardous	1.2	1.6

Garbage stream composition (by mass), Guelph Pilot Areas.

for process system design, because two-stream waste will undoubtedly be more difficult to process. However the degree of this difficulty is of critical concern since two-stream separation may offer benefits in other areas. A major drawback of three-stream separation is highlighted by Table 22 which shows that about 60% of the third garbage stream is actually compostable organics or recyclables. Even with extensive education this material represents a significant contribution to the final waste stream.

A comparison of two-stream and three-stream waste separation with respect to bins and bags is shown in Table 23. In all areas bins provided better separation results than bags, but the difference was generally small (1% to 5%). Two-stream separation yielded a higher diversion rate for organics of 97% compared to 85% for three-stream, and 94% of the recyclables were recovered in the two-stream compared to 79% for three-stream (figures given for bins). Table 23 also implies a theoretical maximum diversion rate of about 71% of the total waste stream, for diversion of compostable organics and recyclables currently being processed through existing markets (Blue Box materials, fine paper and corrugated cardboard). Establishing markets for recycled glossy paper, mixed paper, boxboard, film and other plastics will increase this diversion rate by about 10%. Table 23 highlights the difference in residue which amounts to 50% from two-stream *vs* 34% from the three-stream system, for materials currently recycled in Guelph.

Tables 24 and 25 give the overall masses from the Pilot Areas from one year of Guelph Landfill weigh scale records. Each home produced an average 20 kg of waste per week, or roughly 6.5 kg per person per week. Table 25 shows the average proportions of waste streams as collected over the same one year period. The variability of the Wet stream by as much as 40% is an important observation,

Table 23

	Two Stream Areas (Percent)		Three Stream Areas (Percent)	
	C (Bins)	E (Bags)	A (Bins)	D (Bags)
Wet Container				
Food	94.7	89.6	80.0	68.3
Yard	98.0	98.4	92.0	92.1
Organics(1)	96.5	94.5	85.4	80.7
Dry Container				
Clean Blue Box Items(2)	94.8	88.8	90.0	88.1
Clean Recyclables(3)	93.8	86.0	78.5	77.6
Theoretical Total(4)	70.1	71.5	71.8	72.0

Summary of materials recovered. Notes: (1) Percentage of all organics (food and yard waste) recovered; (2) Percentage of glass, cans, rigid plastic containers and newspaper, recovered in uncontaminated marketable condition; (3) Percentage of all Blue Box materials, glossy paper, fine paper, boxboard, mixed paper, corrugated cardboard, plastic film, styrofoam, other plastics and other metals, recovered in uncontaminated marketable condition; (4) Percentage of total waste stream which could be diverted, assuming householders make no sorting errors, *i.e.* the theoretical maximum if all recyclable materials were clean and sorted correctly into the designated containers.

Table 24

	Two Stream Areas (Percent)			Three Stream Areas (Percent)	
	B (Combo)	C (Bins)	E (Bags)	A (Bins)	D (Bags)
Number of Houses	185	177	131	203	129
Residents/House(1)	3.46	3.11	-	3.36	-
Mean Weekly Mass(2) (tonnes)	4.08	3.66	2.60	4.42	2.39
Weekly Mass/House(2) (kg)	22.0	20.7	20.4	21.8	18.6
Weekly Mass/Person(2) (kg)	6.4	6.7	-	6.5	-

Wet, Dry and garbage masses collected, Guelph Pilot Areas. Notes: (1) Average number of residents per house as determined by a mail-out survey completed and returned by more than 50% of Pilot residents; (2) Average mass collected Wet, Dry and garbage streams, over one year period.

Table 25

Percent	Two Stream Areas						Three Stream Areas					
	C (Bins)			E (Bags)			A (Bins)			D (Bags)		
	mean	max	min	mean	max	min	mean	max	min	mean	max	min
Wet	47	62	16	50	77	32	38	57	19	37	58	13
Dry	53	84	38	50	68	23	32	49	22	31	58	17
Garbage	-	-	-	-	-	-	31	42	21	32	48	22

Wet, Dry and garbage ratios, Guelph Pilot Areas.

but this effect may be explained by the seasonal nature of yard waste. The three-stream overall waste stream divided into approximately 38% Wet waste, 31% recyclables and 31% garbage while the two-stream system divided about equally into Wet and Dry streams. These values are particularly important for sizing processing facilities and designing collection vehicles.

Common source separation errors are summarized in Table 26. Common errors in the two-stream system are: (1) cross-contamination between Wet and Dry streams; and (2) a higher incidence of household hazardous waste. In the three-stream area most errors involve recyclables, organics and household hazardous wastes being placed in the garbage stream. Tables 27 and 28 give a detailed breakdown of the household hazardous wastes received, the three most frequent being lightbulbs, aerosol cans and batteries.

Three comprehensive surveys were carried out to assess public attitudes towards waste separation: (1) a City-wide random survey in 1988; (2) mailed surveys to Pilot Area homes; and (3) personal visits.

The *City-wide random survey* noted a supportive public towards composting organics (88% in favour of a central composting program), results which provided the impetus to undertake the Wet/Dry Pilot Program.

The *Pilot Area mailed survey*, sent directly to residents about 12 weeks after their program began, consisted of a 13 page, 27 question, answer form which had a return rate of about 50%. A summary of the survey results is given below:

- The Wet/Dry systems piloted were satisfactory to those using them: 86% of all respondents were either 'slightly' or 'very' satisfied with their system and this figure was very similar for each of the four systems (range from 82% to 88%). Therefore, any of the four systems would likely be acceptable to the residents of Guelph if implemented City-wide.

- All four of the Wet/Dry systems piloted were rated as being convenient:

Table 26

Sorting Error	Two Stream Areas (Percent)		Three Stream Areas (Percent)	
	C (Bins)	E (Bags)	A (Bins)	D (Bags)
Wet Stream				
Recyclables	11.8	28.0	3.5	3.1
Hazardous	2.4	18.7	3.5	1.9
Dry Stream				
Food	17.1	16.0	3.5	5.0
Yard	1.2	5.3	2.4	1.2
Hazardous	24.7	20.0	5.9	7.5
Garbage Stream				
Recyclables	-	-	39.4	25.6
Food	-	-	28.8	31.9
Yard	-	-	4.7	7.5
Hazardous	-	-	32.9	26.9

Common source separation errors. Percentage of samples containing materials in incorrect stream. All recyclables are Blue Box items. Hazardous waste includes light bulbs.

Table 27

	Two Stream Areas (Percent)		Three Stream Areas (Percent)		Mean
	C (Bins)	E (Bags)	A (Bins)	D (Bags)	
Lightbulbs	16	13	20	17	16.5
Aerosol Cans	9	15	7	16	11.8
Batteries	2	7	8	9	6.5
Paint	2	4	4	1	2.8
Chemicals/Cleaners	0	2	3	0	1.3
Fuel/Oil	0	1	0	1	0.5
Medicines	0	0	2	1	0.8
Solvents	0	1	0	2	0.8

Hazardous waste, Guelph Pilot Areas. Number of samples per 100 that contained each item.

Table 28

	Two Stream Areas (Percent)		Three Stream Areas (Percent)		Mean
	C (Bins)	E (Bags)	A (Bins)	D (Bags)	
Lightbulbs	1.8	6.7	2.9	0.6	3.0
Aerosol Cans	0	4.7	0	0	1.2
Batteries	0	3.3	1.2	0.6	1.3
Paint	0	2.0	0	0	0.5
Chemicals/Cleaners	0	0.7	0	0	0.2
Fuel/Oil	0	0.7	0	0	0.2
Medicines	0	0	0	0.6	0.2
Solvents	0	1.3	0	0	0.3

Wet stream hazardous waste, Guelph Pilot Areas. Number of samples per 100 that contained each item.

64% of respondents indicated that their system was either slightly or very convenient, with a range from 49% to 52% in the bag areas, and from 72% to 79% in the bin areas.

- The Wet/Dry bin systems were found to be more convenient than the bag systems: 75% of those using bins found Wet/Dry to be either slightly or very convenient, whereas only 51% of those using bags found the program convenient.

- The two-stream and three-stream systems were considered to be of almost equal convenience. In bin areas 72% found three-stream convenient and 78% found two-stream, but in the bag areas only 52% found three-stream convenient and 49% found two-stream convenient.

- Bins were considered to be more convenient than bags, however there were still numerous inconveniences associated with bins. Respondents cited problems with odours 23%, snowbanks 21%, waste sticking to the Wet bin 15%, and difficulties associated with cleaning the Wet bins 15%. Some respondents indicated the Green Bin was too large 11%. No major inconveniences were associated with bags.

- When asked to give reasons for inconvenience there was nothing to suggest that sorting waste in the home was more difficult in the three-stream area than in the two-stream area: 12% of two-stream respondents and 9% of three-stream respondents said that Wet/Dry required too much time or space in the home.

- The most commonly made suggestions to improve the Wet/Dry program were as follows: 8% suggested that Household Hazardous Waste should be collected at curbside; 4% felt the City should offer a more detailed list of how to sort waste; and 4% said they would like more general information or more public meetings.
- A slight majority of respondents who indicated a preference for one Wet/Dry system over the others said they would prefer a three-stream system over a two-stream system: 58% of those indicating a preference said they would prefer three-stream and 42% said they favoured two-stream.
- In all four areas the system being used was preferred over the alternatives, but three-stream was favoured by 73% of those using it, while two-stream was favoured by 58% of its users.
- The majority of respondents would not be willing to pay more to use a three-stream system than a two-stream system: 59% of respondents who indicated a preference said they would not like to pay more and 41% said they would pay more to use a three-stream system.
- Half the people who are now using a three-stream system are generally willing to pay more to use a three-stream system: of those in three- stream areas who indicated a preference, 51% said they would pay more to use a three-stream system.
- Less than one third of people now using a two-stream system said they would be willing to pay more to use a three-stream system: of respondents in two-stream areas who indicated a preference 29% said they would be willing to pay more for a three-stream system.
- Bins were the container of choice: 78% said they would prefer bins over coloured bags, because they were convenient, animal-proof and/or reusable. Those who preferred bags cited that they required less storage space, were easy to handle and did not remain at the curb after collection.
- Although bins were preferred by a large majority of respondents, they also received more negative comments than the bags. This suggests that people either find the bins very convenient or very inconvenient and are generally willing to put up with the associated inconveniences for the overall benefits of the bins.

- People now using bins would generally be willing to pay more to use them rather than bags. People now using bags would generally not be willing to pay more to use bins. Of decided respondents in the bin areas 66% of respondents said they would be willing to pay more for bins, but in the bag areas only 27% said they would pay more to use bins.

- Respondents would generally be willing to pay more for whichever system diverted the most waste from landfill: 69% of respondents either 'agreed' or 'strongly agreed' that Guelph should implement whichever system diverts the most waste, even if it costs the taxpayer more than other options.

- Respondents considered convenience and cost to be of almost equal importance in choosing one Wet/Dry system over others. Generally, respondents would not be willing to pay more for convenience; nor would they put up with considerably lowered convenience merely to save money.

- Most respondents would be willing to put up with less convenience and put more effort into whichever Wet/Dry system diverted the most waste: 63% of respondents either disagreed or 'strongly disagreed' that convenience is more important than waste diversion.

- In the final survey question under 'other comments' the most common response given could be characterized as enthusiastic and positive: 12% of respondents made comments such as 'Keep up the good work' or 'We are proud of Guelph'.

Personal interviews were conducted with randomly selected Pilot Area residents in early 1991, as part of a Kreutzwiser and Hamilton-Wright study for the Ontario Ministry of the Environment and Energy. The aims of this Study were to: 'determine the relationship between degree of involvement in municipal recycling programs and selected other conservation behaviours; and determine the relationship between degree of involvement in recycling and attitudes about municipal solid waste issues' [46].

The Guelph Wet/Dry Pilot provided the unique opportunity for 161 randomly selected households to be interviewed to 'record recycling behaviour, energy and water conservation behaviour in the home, consumer behaviour and attitudes about solid waste problems and solutions'. Half of the households interviewed were participants in Guelph's Blue Box Program and the other half were in Areas A or C of the Wet/Dry Pilot Area. The study initially hypothesized that changes to people's waste management practices may cause changes in other related environmental activities such as water and energy conservation. Although limited support for these related benefits was found a definite relationship was observed with respect to 'environmentally responsible consumer behaviour'. Compared to the less demanding Blue Box Program the Wet/Dry participants exhibited significantly greater environmentally responsible consumer behaviour, as measured by such actions as using a reusable shopping bag, purchasing drinks in returnable bottles and refusing to purchase over-packaged products. Other findings of the study included difficulties associated with hazardous wastes, such as aerosol cans and paint cans. Participants in the two-stream Wet/Dry Pilot were more diligent than three-stream residents about using the Household Hazardous Waste Depot. Sorting problems were encountered more frequently from three-stream residents than from two-stream. Very few of the Wet/Dry respondents saw Blue Box recycling as a 'sufficient response to the waste management issue'. 25% of the Wet/Dry respondents, compared to 15% of the Blue Box respondents, viewed incineration as a good waste management option. Overall there was a higher commitment, albeit less enthusiastic, towards recycling displayed by Wet/Dry residents than by Blue Box participants, but this commitment appears to be given with more emphasis directed towards other waste management options. Even though a majority recognized that Blue Box recycling, even with full participation, would be insufficient to solve Guelph's waste management problems, most respondents felt that recycling should be mandatory, with enforcement and fines. Fewer than half of the respondents viewed recycling as more effective than waste reduction and reuse [46].

Additional Pilot Studies

Residential pilot programs provide an indication of public willingness and ability to source separate waste, however further study was needed to provide sufficient information on which to base system decisions. Since only about 25% to 30% of Guelph's total waste stream is generated in single-family dwellings the pilot program was expanded to include multi-unit residences and businesses. McDonalds Restaurant has had a pilot two- stream Wet/Dry program in place since September, 1990 at its Guelph, Gordon Street location. Simple instruction for employees resulted in minimal problems with behind the counter separation, but the program experienced early difficulties with public perception of what should be 'Wet' and what should be 'Dry'. For instance many patrons simply pour the contents of left-over beverages into the Wet container, or packaging from coffee creamers, which results in a very small amount of Wet waste being generated by McDonalds' customers. A similar expanded recycling program operating at an Oakville, Ontario, McDonalds Restaurant, even with no sorted organic fraction, has shown difficulties, with most material ending in the waste container. Even without composition tests or patron surveys, as in the single- family Pilot Areas, the McDonalds pilot program provides an extremely valuable insight into 'natural waste sorting tendencies'. Early indications are that education is crucial and that a community- wide effort is likely to be needed (Section 4.2).

Results from a fifty unit townhouse complex (rent geared to income), also involved in the Guelph Wet/Dry Pilot, appear to be encouraging. Residents were given free colour-coded bags to be placed in marked, outdoor waste bins and the required sorting was of the same quality as in the sinale family bag area.

2.3 Costs of Waste Collection, Processing and Disposal

Preparation Costs

The cost of preparing waste for collection is usually not associated with waste management cost accounting, but this cost is significant, especially for non-residential waste generators because of the need for custodial staff and space for storage of waste prior to collection. Table 29 presents the preparation cost estimates used in this study. The business make-up and employment records of Guelph [12] have

Table 29

	Costs ($/tonne)			
	Residential		Non-Residential	
	Preparation	Collection	Preparation	Collection
Garbage	25	70	100	50
Two Stream	35	95	140	65
Three Stream	45	125	180	90
Blue Box	-	115	-	-

Waste preparation and collection costs, City of Guelph.

been used to provide a (conservative) estimate of business waste preparation costs of approximately $100 per tonne, and these are likely to be similar to those of other Ontario communities. In the residential waste stream the preparation costs are lower, because no costs are associated with the labour required to 'put out the garbage' and an estimate of $25 per tonne is used. For all waste generators pre-collection costs include waste containers, such as bags, cans, and bin rentals. These estimates are used to predict total overall increases in waste management costs for different collection systems.

Collection Costs

Collection cost estimates are also given in Table 29. The City of Guelph has a relatively efficient recycling program which collects materials in top-loading vehicles having only two compartments. This practice results in a recycling collection cost of approximately $115 per tonne (averaged residential and non- residential), about 30% lower than the Provincial average [3]. Much concern has been directed at the relatively high cost of recyclables collection, which is thought to be threatening recycling programs [68, 29, 28].

Residential garbage collection costs are estimated to be $70 per tonne in Guelph [14], lower than recycling collection costs, since the wastes can be compacted and lack of sorting means materials can be loaded faster. These costs are an estimated average of both single-family residences, usually picked up by City crews, and multi-unit dwellings, usually collected by the private sector.

The collection cost estimates are given for two possible forms of residential Wet/Dry collection: two-stream and three-stream. It is assumed that two-stream waste collection requires a single vehicle, which may also be possible for three-stream collection as well, but not likely. Extra curb-side sorting time for three-stream collection is also factored into the collection cost estimates. Two-stream collection is estimated to cost $95 per tonne and three- stream collection at $125 per tonne, based on current vehicle operating costs and expected collection times. For non-residential waste, more waste is usually collected per stop, giving an estimate about 30% lower than for residential waste.

Processing Costs

Table 30 provides estimates of waste processing costs, which are especially difficult since there is little actual operating experience. The processing cost for standard Blue Box recyclables is about $100 per tonne, including delivery of recyclables to market, but excluding revenue from the sale of recyclables. These revenues are difficult to predict, due to market fluctuations, but, at present, the estimated average revenue for municipal recyclables is around $25 per tonne. Due to the high percentage of newspaper and corrugated cardboard in the recyclables, the overall price is greatly affected by the market value of these commodities. Table 31 lists typical prices which can be obtained for standard recylable materials.

Dry stream processing costs are anticipated to be lower than for recyclables, since more sophisticated and larger plants will be required. It is expected that processing of three-stream Dry waste will be cheaper than two-stream processing, about $80 per tonne for two-stream compared to $65 for three-stream. As outlined in Section 2.1 there is less material 'along for the ride' in the three-stream Dry,

Table 30

	Costs ($/tonne)
Recyclables	100
Two-Stream Delivered	
Dry	80
Wet	60
Average	75
Three-Stream Delivered	
Dry	65
Wet	50
Average	60
Demolition	15
Incineration(1)	70
RDF(2)	35
Landfilling	30
Loading/Unloading	10
Transportation	0.25/km

Waste processing cost estimates, City of Guelph. Notes: (1) Less energy sale revenue of $15/tonne electricity generation (@$0.04/kWh); (2) Preparation of refuse derived fuel.

Table 31

	Revenue ($/tonne)
Colour Sorted Glass Containers	
Clear	35
Green/Amber	5
Aluminum	
Beverage Containers	1000
Scrap	700
Steel Scrap[1]	35
Wood	4
Compost	0–5
Plastic	
Film	200
Containers	200
Other	50
Paper	
Newsprint	25
Glossy	10
Fine	65
Boxboard	15
Corrugated Cardboard	20
Mixed	10
Tires	0–5
Average	20

Revenue from sale of recyclables. Prices based on 1992 industrial survey. Average based on typical waste stream composition. Note: (1) Includes tin plated cans, automobiles and appliances.

therefore separation costs are assumed to be lower, based on staff sorting times and total quantities requiring processing.

With respect to composting, Wet stream waste is assumed to be slightly less expensive to process than Dry stream. Three-stream, again, is assumed to be cheaper than two- stream since there is slightly less material preparation required prior to composting. The composting costs for clean separated material are estimated to be around $40 per tonne.

Other waste processing costs that are estimated include: (1) refuse derived fuel (RDF) preparation at $35 per tonne; (2) mass-burn incineration, including ash disposal costs and energy sales, estimated to be $70 per tonne; and (3) the cost of transporting garbage from a transfer station to a disposal site, estimated to be $0.25 per tonne per kilometre (assuming a 40 tonne capacity transfer truck), to which must be added a $10 per tonne loading and unloading charge. These cost estimates are based on a compilation of available data and experience [7, 8, 10, 11, 14, 6, 18, 66, 71, 9, **?**, 59, 27, 49].

Disposal Costs

Tipping fees in Ontario have undergone very rapid increases over the last ten years. For example, in Guelph, these have gone from $0 in 1985 to $92 in 1991, typical of the average tipping fee for Southern Ontario of about $100 per tonne. These tipping fees represent a significant cost to Ontario residents, but, from a financial point of view, they are seen to be grossly inflated over the true cost of tipping.

This study considers a single form of waste disposal: landfill. Composting and incineration are considered to be waste processing, although a residue remains that requires disposal. The budget estimate assumes that the incinerator ash (mixed bottom and fly ash) will go to a general purpose sanitary landfill. This may not be the case for Ontario, but, with ash solidification and stabilization programs, it is the common practice elsewhere [37, 25, 35, 57, 24, 67] (also personal visits to Wheelabrator Inc. facilities in Gloucester NJ, Millbury MA, and Claremont NH).

The true cost of landfilling is an issue that has received much discussion in Ontario, so much so that the Waste Reduction Advisory Committee of the Ministry of the Environment and Energy commissioned a study to determine the 'true costs' [70]. The hypothesis was that if all costs associated with a landfill are considered: closure costs, acquisition costs and related environmental costs, Ontario municipalities were not charging realistic landfill tipping fees. The 1991 study found that the actual cost for landfilling a tonne of waste in an Ontario landfill, similar to that proposed in the County of Wellington/City of Guelph WMMP, is approximately $35 per tonne, comparable to the $30 per tonne forecasted in the

WMMP [11]. For purposes of this study the cost of landfilling is assumed to be $30 per tonne, which does not reflect the cost of environmental hearings and other approval costs.

Summary of Costs

Table 32 summarizes 1991 waste management costs for the City of Guelph, using the preparation cost estimates of Table 29 and values obtained from the City of Guelph 1991 waste management budget [14]. This table also provides the annual

Table 32

	Quantity (10^3 tonnes)	Costs ($Million)		
		Preparation	Collection	Other
Residential				
Private	10	0.25	0.5	-
City	20	0.5	1.4	-
Non-Residential	45	4.5	3.0	-
Demolition	15	-	-	-
Landfill	-	-	-	3.5
Recycling Program	-	-	-	1.6
Total	90	5.25	4.9	5.1

Waste quantities and management costs 1991, City of Guelph. Quantities generated within Guelph city limits. Based on Table 20, Table 29 and City of Guelph 1991 Budget [14].

waste quantities which are used in the economic comparisons of this study (1991 values), which include materials currently being diverted through the Recycling Program or Wet/Dry Pilot (est. 5,000 tonnes).

2.4 Compost Quality

The quality of finished compost is a critical consideration in the development of an effective waste management system. Apart from easing material handling requirements it makes little sense, economically or environmentally, to produce compost that is so severely contaminated that it cannot be used for agricultural or horticultural purposes. The definition of ‘good quality’ compost is difficult and varied: Table 33 shows numerous compost quality guidelines.

Table 33

Organization	Metal Concentration (ppm)										
	As	Cd	Cr	Co	Cu	Pb	Hg	Mo	Ni	Se	Zn
Min. Env. Ontario	10	3	50	25	60	150	0.15	2	60	2	500
'Eco Logo' Canada	14	1.5	100	20	50	60	0.5	4	32	1.6	220
Agriculture Canada(1)	75	20	-	150	-	500	5	-	180	14	1850
Min. Env. B.C.	13	2.6	210	26	100	150	0.83	7	50	2.6	315
Germany 'Blue Angel'	-	1	100	-	75	100	1	-	50	-	300
Germany Fed. Limits	-	2	100	-	100	150	1.5	-	50	-	400
Swiss 1986	-	3	150	25	150	150	3	5	50	-	500
Austria 1984	-	6	300	-	1000	900	4	-	200	-	1500
Italy 1989	10	10	510	-	600	500	10	-	200	-	2500
Netherlands 1995	5	1	50	-	60	100	0.3	-	20	-	200
W.H.O. 1985	-	40	-	-	260	400	5	10	-	-	1200
U.S. Current(2)	-	2	1000	-	450	250	5	10	50	-	900
U.S. Waste Compost(3)	-	22	100	-	900	1500	1.9	-	90	-	2500
Soil Conc'n Cont. U.S.(4)	-	0.27	-	-	30	17	-	-	24	-	57
Soil Conc'n Ontario(5)	7	0.8	15	5	25	15	0.1	2	16	0.4	55
City of Guelph Pilot	-	0.5	7.1	1.4	20.2	21.3	0.16	-	3.8	-	80.2
Agripost Florida	3.7	4.1	20.5	-	246	124	2.4	-	34	-	607

Compost quality guidelines — Maximum metal concentrations. Notes: (1) Legal limits imposed under the Fertilizer Act; (2) Compilation of most stringent State guideline per metal; (3) U.S. Bureau of Mines [69]; (4) From [16]; (5) Mean values from Ontario Sewage Sludge Guidelines [51].

The Ontario Ministry of the Environment and Energy has released compost quality guidelines that appear to be among the most stringent in the world [43, 22], as are the Eco-Logo guidelines of the Canadian Standards Association [21].

In developing compost quality guidelines the area of most concern is usually heavy metals. Organo-chlorine compounds, such as PCBs and dioxins, are also of concern, but are generally considered less of an environmental threat. Other components of guidelines often include: degree of maturity, amount of foreign material, such as glass, and nutritive value. If compost is of sufficient quality to meet stringent heavy metal guidelines it is usually considered acceptable in other areas and for this reason the emphasis is placed on heavy metals.

Determining what heavy metal levels are 'safe' is not a straightforward exercise. The receiving soil background level varies, as does the soil and plant crop's susceptibility to heavy metals. Also the potential environmental threat varies with different metals. Many jurisdictions, particularly in the United States, have developed compost guidelines around compost plants already producing compost, but the majority of these plants were built to compost sewage sludge. As Table 34 shows, the heavy metal contamination of composted sewage sludge is sometimes an order of magnitude greater than for source separated organics.

Guidelines that provide a useful target are: the Ontario Ministry of the Environment and Energy, the CSA Eco-Logo, the British Columbia Ministry of the Environment, the German 'Blue Angel', Austria and the various Dutch standards. As noted above, the combination of the Eco-Logo and Ontario Provincial guidelines are amongst the most stringent in the world, which is a cause of considerable concern to the City of Guelph plan. When comparing the Ontario Provincial Guidelines with the average metal concentrations in rural soils in Ontario, it appears that mercury and molybdenum are the most restrictive. Mercury is expected to be the most difficult metal guideline to meet and its ubiquitous nature increases the difficulty. Some of the anticipated major sources of mercury are household batteries, some seafoods and fluorescent lightbulbs. Table 35 shows heavy metal concentrations in vacuum cleaner bags, representing another potential source of mercury, which ranges from 0.339 ppm to 7.46 ppm, and other heavy metals.

Table 33 provides an interesting comparison between the metal concentrations in compost of Agripost, Florida *vs* the City of Guelph Wet/Dry Pilot. Agripost metal contaminants in compost from mixed, unsorted garbage, from a now closed plant [41, 47], are three to 12 times greater than in the Guelph compost. To meet Provincial compost guidelines an extremely high degree of source separation will be required. Special attention will also need to be placed on developing an effective hazardous waste diversion program.

An experimental composting program is also underway to investigate the feasibility of composting sewage sludge from Guelph. Tables 34 and 36 show that it

Table 34

	Composted Sludge[1]		Ontario Guidelines	
	Batch 1	Batch 2	Sludge[2]	Compost[3]
pH	7.2	6.8		
Solids (Percent)				
Total	50.3	42.9		
Volatile	40.9	47.8		
Pathogens (CFU/g)				
Fecal Coliforms	1,500	2,300		
Fecal Strep	< 100	< 100		
Metal Conc. (ppm)				
Arsenic	0.6	0.6	170	10
Cadmium	22.9	22.8	34	3
Chromium	333	451	2,800	50
Cobalt	5.57	7.2	340	25
Copper	284	383	1,700	60
Lead	146	108.4	1,100	150
Mercury	0.643	.39	11	0.15
Molybdenum	9.2	3.0	94	2
Nickel	22.4	28.7	420	60
Selenium	0.2	< 0.1	34	2
Zinc	2,129	56	4,200	500

Typical quality of finished compost from sewage sludge. Notes: (1) Guelph Pilot Program average of 3 samples for 2 separate batches; (2) From [51]; (3) From [33].

Table 35

Sample	Metal Concentration (ppm)									
	As	Cd	Cr	Co	Cu	Pb	Hg	Mo	Ni	Zn
East York										
1	3.6	5.2	38	1.8	57	140	3.0	<1	10	520
2	0.8	2.6	72	1.5	46	14	0.9	<1	4.7	230
3	2.9	3.3	33	3.5	67	68	1.0	1.5	18	330
4	2.5	17	62	5.8	43	74	1.1	1.6	9.4	250
5	3.8	3.8	50	2.7	58	120	6.0	<1	16	310
6	8	3.4	120	2.6	120	110	3.2	<1	18	500
7	3.2	2.6	24	1.9	27	160	7.5	<1.6	8.6	160
Fergus										
1	1.9	460	66	9	77	160	0.59	3	54	570
2	5.2	2	24	4	28	<10	0.34	<1	11	240
3	5.7	39	110	10	160	120	1.7	3	56	530
4	6.4	3	43	5	53	56	0.91	3	32	280
5	1.7	<2	27	4	59	49	0.43	<1	17	330
6	11.4	2	41	3	99	120	2.3	3	29	310

Heavy metal content in residential vacuum cleaner bags. Adapted from Ontario Waste Compostion Study Vol. 1 [32].

Table 36

	Material Source					
	Filter Cake Sludge(1)	Sewage Sludge Compost(1)	University of Guelph Compost(2)	Softwood Shavings	Weeping Willow Sawdust	Poultry Manure (layers)
%TS(3)	24	28	34	91	94	28
Volatile Solids (%TS)	52	73	94	99	> 97	68
Organic C (% mass)	6.5	10.6	16.2	45.6	45.8	10.8
	Concentration (ppm)					
Ammonia (as N)	12,000	13,000	2,600	2,800	16	38,000
TKN	44,000	24,000	14,000	520	200	58,000
P	30,000	16,000	1,830	13	78	8,200
As	0.4	0.3	0.7	< 0.2	< 0.2	< 0.2
Cd	57	32	0.34	0.18	0.44	2.9
Cr	2,100	900	2.8	< 1.2	< 1.8	5.6
Co	13	7.0	< 2.8	< 1.2	< 1.8	12
Cu	1,400	700	10	< 1.2	2.1	27
Pb	650	320	2.8	< 1.2	2.7	< 3.4
Hg	2.59	1.9	0.01	< 0.005	0.005	< 0.005
Ni	83	53	5.2	< 1.2	< 1.8	< 3.4
Se	0.4	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Zn	19,000	10,000	78	8	33	2,400

Quality of some common organic materials. Guelph Sewage Sludge Composting Project [31]. Notes: (1) City of Guelph Water Pollution Control Plant; (2) Composted livestock manure and bedding; (3) Percent total solids.

will not be possible to meet the Provincial compost guidelines with this composted sewage sludge. The finished compost is, however, lower in metal contamination than the more permissible Provincial sewage sludge application guidelines. The compost may therefore be suitable for controlled land application, however, for purposes of this study it is assumed that the composted sludge will be disposed at the future landfill site. With the introduction of MISA (Municipal and Industrial Strategy for Abatement) it is possible that the metal contamination of Guelph sewage sludge will be significantly reduced. The program to bring about these reductions would complement a similar effort for reducing metal contaminants in composted organic wastes (Wet fraction).

Part of the original scope of the Guelph Wet/Dry Pilot Program was to investigate the impact of source separation on compost quality. The pilot area was sized to provide a suitable amount of organics for processing and comparison purposes. Tables 37 and 38 provide data on the quality of incoming material from two-stream and three-stream areas.

Table 37

	Two Stream					Three Stream				
	1	2	3	4	Mean	1	2	3	4	Mean
	Percent									
N	2.00	1.70	2.10	1.30	1.78	2.85	1.85	1.60	2.55	2.21
P	0.27	0.30	0.44	0.37	0.35	0.52	0.31	0.26	0.75	0.46
K	1.05	0.86	0.86	0.90	0.92	1.12	1.19	0.99	0.83	1.03
Ca	1.39	3.78	3.44	2.41	2.76	3.84	3.22	5.34	5.18	4.40
Mg	0.26	1.00	0.86	0.47	0.65	0.51	0.60	1.53	1.15	0.95
C	40.60	38.40	41.20	34.70	38.73	47.70	38.30	36.70	40.60	40.83
LOI(1)	77.70	69.10	77.83	69.20	73.46	85.02	72.54	67.60	73.79	74.74
	Concentration (ppm)									
Co	36.80	20.70	13.56	16.41	21.87	5.19	16.69	16.48	12.37	12.68
Cr	29.14	37.86	24.21	19.30	27.63	13.73	24.87	22.39	17.91	19.73
Cu	12.14	46.13	29.63	21.52	27.36	21.40	27.37	28.10	32.41	27.32
Mn	108.47	252.75	171.63	166.90	174.94	101.63	390.63	236.49	141.44	218.00
Pb	10.95	30.50	31.50	30.65	25.90	8.55	15.50	43.55	30.50	24.53
V	9.46	0.11	3.43	5.82	4.71	0.74	4.46	7.68	2.42	3.83
Zn	69.04	7.33	165.31	135.92	94.40	60.43	117.24	168.43	126.86	118.24
pH	4.38	5.10	4.95	4.86	4.82	4.93	5.02	5.61	5.22	5.20

Quality of incoming organic material, Guelph Pilot Areas. Aggregate samples taken prior to composting. Sampled over four consecutive weeks (April – May, 1990). Note: (1) Loss on ignition.

Table 38

	N	P	K	Ca	Mg	C	LOI	DM	pH	Cd	Co	Cr	Cu	Mn	Ni	Pb	Zn	EC
	Percent								-	Concentration (ppm)								mS/cm
Oct 31																		
2 Stream	2.1	0.5	1.0	2.6	0.5	41.7	85.3	26.5	5.3	0.2	0.1	8.7	13.4	114	1.5	5.6	49.3	3.5
3 Stream	2.6	0.9	0.9	3.7	0.6	43.3	86.2	25.1	5.6	0.2	0.6	9.9	11.2	155	2.0	6.8	77.9	2.9
Nov 7																		
2 Stream	2.9	0.5	1.2	3.3	0.3	46.9	89.0	20.5	4.6	0.3	0.2	6.1	13.5	136	1.3	4.8	35.2	3.8
3 Stream	2.0	0.3	1.6	3.3	0.8	43.4	80.6	21.5	5.5	0.3	0.4	5.3	10.9	120	0.6	7.2	49.4	4.3
Nov 14																		
2 Stream	2.4	0.3	1.6	2.0	0.3	45.6	84.7	28.6	5.4	0.3	-	7.0	13.8	106	1.7	2.2	43.0	4.6
3 Stream	2.5	0.4	1.0	3.2	0.2	48.2	97.8	20.1	5.1	0.2	-	3.6	7.1	38	0.7	-	28.9	4.5
Nov 21																		
2 Stream																		
Yard	1.2	0.1	0.4	2.8	0.3	44.3	84.3	41.1	5.7	0.4	0.3	2.2	10.2	95	2.0	21.4	41.3	-
Kitchen	3.0	0.5	1.4	1.1	0.2	50.2	88.3	73.7	5.2	0.3	0.1	4.2	8.4	76	1.2	0.9	78.2	4.4
3 Stream																		
Yard	1.1	0.2	1.1	3.4	0.5	39.8	72.5	52.1	5.7	0.4	0.1	3.3	15.0	193	3.0	9.3	75.5	2.5
Kitchen	1.1	0.2	1.1	3.4	0.5	39.8	72.5	52.1	5.7	0.3	-	2.0	7.3	38	1.0	1.0	29.0	3.8
Nov 28																		
2 Stream																		
Yard	1.3	0.2	0.6	3.1	0.5	36.2	48.6	40.8	5.6	0.4	1.0	3.0	14.9	190	3.5	22.3	55.9	-
Kitchen	1.7	0.3	0.8	3.2	0.2	38.8	78.0	59.3	4.8	0.0	0.2	1.8	9.2	40	2.0	2.5	21.1	4.4
3 Stream																		
Yard	1.3	0.2	0.5	3.2	0.6	44.9	82.6	22.7	5.4	0.5	0.5	3.5	10.2	86	2.3	6.0	49.4	1.9
Kitchen	2.6	0.3	0.9	1.6	0.6	54.0	88.6	68.9	4.7	0.2	-	1.8	6.7	39	1.6	3.3	29.3	4.5
Dec 5																		
2 Stream																		
Yard	1.9	0.3	1.7	3.3	0.7	41.3	73.1	48.9	5.2	0.4	0.8	4.0	9.3	138	2.0	8.2	87.5	-
Kitchen	2.0	0.4	1.5	1.1	0.2	63.1	92.2	70.2	4.8	0.0	-	2.7	6.3	36	0.7	-	24.8	4.4
3 Stream																		
Yard	1.7	0.3	0.9	3.0	0.3	43.9	85.9	54.3	5.1	0.0	-	2.8	8.5	63	1.8	2.3	38.5	2.5
Kitchen	2.2	0.3	0.8	0.8	0.1	51.6	94.7	68.7	4.7	0.0	-	2.7	8.5	56	1.0	-	19.1	3.8
Dec 12																		
2 Stream	1.0	0.1	0.3	3.6	0.3	48.7	90.0	25.8	5.4	0.3	0.3	2.2	7.9	47	1.0	-	26.7	3.8
3 Stream	2.4	0.5	1.1	2.7	0.2	41.5	81.8	76.5	6.8	0.4	0.7	2.5	28.7	118	2.2	8.2	45.0	5.0
Dec 19																		
2 Stream	2.3	0.3	1.2	2.3	0.4	43.7	84.5	65.6	5.8	0.4	0.3	3.5	11.4	127	2.5	16.3	50.2	3.9
3 Stream	2.8	0.4	1.0	2.9	0.8	47.8	84.8	66.7	4.6	1.3	0.5	8.0	28.5	106	2.0	34.8	48.8	4.8
Mean																		
2 Stream	2.0	0.3	1.1	2.6	0.4	45.5	81.6	45.5	5.3	0.3	0.3	4.1	10.8	100	1.8	7.7	46.7	4.1
3 Stream	2.2	0.3	1.0	2.7	0.4	45.9	85.8	48.2	5.2	0.3	0.2	12.9	3.6	92	1.6	7.1	44.6	4.1

Quality of incoming organic material, Guelph Pilot Areas. Samples taken after contaminants were removed by hand. Sampled over eight week period (31 Oct. – 19 Dec. 1990).

The four consecutive weeks (March-April, 1990) of samples taken prior to composting, given in Table 37, show no statistical difference between two-stream and three-stream material. Table 38 verifies this finding with samples taken over eight weeks, in three of which yard wastes were analyzed separately. Table 39 shows the results of an additional experiment to determine a difference in compost quality from two-stream or three-stream areas. In this experiment, no wastes

Table 39

	Concentration (ppm)			
	Two Stream		Three Stream	
	Day 1	Day 20	Day 1	Day 20
Co	2.4	2.6	< 0.8	5.0
Zn	140	140	82	220
Cd	0.60	0.56	0.33	0.71
Fe	5,080	7,040	2,460	13,900
Mn	260	460	140	680
Cu	51	24	16	56
Mo	3.3	2.0	< 0.8	2.2
Pb	51	28	35	46
Ni	18	7.2	12	12
Cr	35	14	26	21
P	2,430	2,200	6,150	3,720
Ca	41,500	76,000	45,500	66,900
Mg	15,200	24,100	6,560	21,700
K	6,800	6,480	13,900	11,800
Na	2,400	1,100	3,500	1,580
B	9.4	9.6	17	13
Be	0.18	0.24	0.09	0.39
Si	130	103	250	150
Al	5,240	4,570	1,670	9,290
V	9.6	10	5.1	21
As	1.74	2.82	0.72	5.87
Se	< 0.05	< 0.05	< 0.1	< 0.08
Hg	0.050	0.196	0.016	0.226
%TS$^{(1)}$	45.3	54.0	24.4	32.3

Worst-case analysis in compost quality, Guelph Pilot Areas. Material was composted as received with no contaminants removed, thus providing a worst-case scenario. Each sample is an aggregate of one week's material from 200 homes. Sampled at Day 1, as received, and at Day 20, after three weeks of high rate composting (June, 1990). Note: (1) Percent total solids.

were removed prior to sampling. Materials were sampled as received (Day 1) and then after three weeks of composting (Day 20). A representative sample received extensive laboratory preparation (grinding and mixing), representing a 'worst case scenario' since no contaminants were removed prior to sampling. The quality of the incoming material and finished compost are slightly better for the three-stream material.

Table 40 presents 12 weeks of finished compost quality data for a mixture of two and three-stream material, and all constituents tested are below Provincial guidelines. This data is limited by the absence of some component testing (*e.g.* mercury) and the degree of difficulty and cost associated with processing and testing two-stream and three-stream materials separately. With these noted limitations it appears that there is no discernable difference between the quality of two-stream and three-stream material and that either two- stream or three-stream compost could meet Provincial guidelines, although there may be some areas that require careful monitoring [64].

Table 40

	N	P	K	Ca	Mg	C	LOI	DM	pH	Cd	Co	Cr	Cu	Pb	Mn	Ni	Zn	EC
	Percent								-	Concentration (ppm)								mS/cm
Apr 20	1.3	0.3	0.4	4.8	0.8	26.2	41.8	48.9	6.2	5.5	3.3	29.0	32.8	36.8	248	5.5	157	-
May 4	1.7	0.3	0.6	4.3	0.9	35.3	73.7	73.1	5.9	-	2.3	11.5	17.3	47.5	227	6.0	145	-
May 25	1.6	0.3	0.7	5.2	1.4	29.1	54.4	62.9	6.2	-	2.3	19.5	30.3	66.5	382	12.5	148	-
Jun 14	1.7	0.3	0.8	5.8	1.1	34.4	56.5	59.7	6.1	0.4	-	13.0	28.0	38.6	306	6.2	182	-
Jun 28	1.5	0.3	0.6	6.9	1.5	24.7	45.9	57.6	6.1	0.6	-	7.9	18.3	39.6	286	7.7	142	-
Jul 11	1.1	0.2	0.7	8.8	3.0	24.9	46.5	51.1	6.7	0.8	-	6.5	18.9	20.9	324	8.2	157	-
Sept 9	1.5	0.4	1.1	7.3	2.6	21.1	38.9	52.3	7.0	0.5	1.5	12.6	20.5	85.2	272	7.5	126	2.4
Oct 3	1.9	0.4	1.3	6.2	2.2	26.1	45.4	55.6	7.4	0.6	2.0	9.5	25.0	36.6	264	5.7	149	2.8
Oct 17	1.5	0.3	0.9	7.0	2.2	26.6	54.1	43.7	7.9	0.5	1.3	11.1	20.1	22.3	191	4.7	99	1.6
Oct 30	1.6	0.3	0.9	7.2	1.8	27.8	45.4	45.6	8.0	0.5	2.2	8.5	21.9	18.3	261	9.6	98	1.6
Nov 27	1.4	0.4	1.1	8.6	2.5	25.6	34.9	53.2	7.8	0.6	2.1	5.4	21.4	24.0	242	4.7	107	2.3
Dec 11	1.8	0.3	1.1	5.1	0.9	38.4	59.9	1.3	7.7	0.6	2.0	8.1	22.8	37.5	267	6.8	134	2.2
Mean	1.5	0.3	0.9	6.4	1.7	28.3	49.8	54.6	6.9	0.6	2.0	8.1	22.8	37.5	267	2.8	134	2.2
S.D.	0.2	0.1	0.3	1.4	0.7	4.9	0.1	7.7	0.8	0.1	0.6	2.9	4.8	20.1	55	2.4	27.4	0.4

Quality of finished compost, Guelph Pilot Areas. Composted for nine weeks prior to sampling in 1990.

2.5 Processing of Recyclables

As outlined in Section 2.2 the quality of recyclables was high for both three-stream and two-stream separated materials (Tables 18 and 19). The two-stream bin system recovered 98% of recyclables of which 96% were sufficiently clean to market, resulting in a net of 94% potential marketablity for this stream. In the three-stream bin system 80% of the recyclables were recovered and 99% of these were sufficiently clean to market, giving a potential marketability of 79% for this stream [40].

The sorting habits of the residential public appear to be sufficiently reliable for the design of new waste management programs. Unfortunately these sorting habits have recently been observed to be deteriorating, probably due to the lack of ongoing promotion, new residents moving into the neighbourhood and/or the reduction in intensive education [5]. The degree of difficulty associated with the processing of the Dry fraction, *i.e.* separation of recyclables, is critical to the success of either a two or three-stream system. Two detailed experiments to test Dry fraction separation are described below.

Ballistic Separator

During October 1990 about 10 tonnes of Dry material from Area C was taken to Pinellas County, Florida where a Recycle America facility operates a ballistic separator similar to the type being suggested for Guelph. Table 41 shows the success of the sorting trial. The machine broke over 90% of the glass and, after three extensive sorts (far more time than could be allocated in a full-scale operation), only 50% of the recoverable recyclables were retrieved. The ballistic separator, common in European waste processing plants, has upwardly inclined, rotating paddles which cause flat and light materials to move up the slope while heavy spherical materials tend to roll down the slope. The tested machine is adjustable and with customized modifications would undoubtedly perform better. The main problems of the machine were glass breakage and an apparent inability to deal with the volumes of paper. The 'fluffed up' newspapers it produced led to very high paper loads on the sorting belts.

Pilot Sorting Trials

Sorting trials of Pilot collected Dry materials have taken place sporadically since May 1991. Dry material collected from Areas A, B, C or D is taken weekly to a temporary sorting facility, where a variable speed (18 m/min ±50%) 110 cm by 13 m sorting belt and up to ten sorting stations are used to compare the sorting efficiencies of two-stream or three-stream sorted wastes. Six weeks of sorting trials

Table 41

	Heavy		Light		Total		
	Mass (kg)	Percent	Mass (kg)	Percent	Mass (kg)	Percent	Expected Percent(1)
Paper							
Newsprint	263	9	1957	37.4	2221	27.0	30
Glossy							9
Fine			100	1.9	100	1.2	3
Boxboard	24	0.8			24	0.3	5
Mixed(2)			312	6.0	312	3.8	5
Corr. Cardboard	272	9.1	91	1.7	363	4.4	5
Plastic							
Film	8	0.3	64	1.2	72	0.9	3
Containers	54	1.8			54	0.7	2
Foam	8	0.3			8	0.1	< 1
PET	9	0.3			9	0.1	< 1
Other	195	6.5			195	2.4	1
Metal							
Fe	336	11.3			336	4.1	5
Al	45	1.5			45	0.6	2
Glass							
Clear and Col.	109	3.7			109	1.3	12
Non-Container							< 1
Ceramic							< 1
Multi-Mat. Pkg.							2
Wood							2
Textiles			9	0.2	9	0.1	2
Inert							< 1
Rubber							< 1
Leather							< 1
Hazardous							2
Residue(3)	463	15.5	1265	24.2	1727	21.0	4
Brini			907	17.3	907	11.0	
Light Frac(3)			526	10.1	526	6.4	
Compactor(3)	673	22.6			673	8.2	
Floor Residue(3)	526	17.6			526	6.4	
Total	2985	36.3	5231	63.7	8216		

Effectiveness of ballistic separator on Guelph Pilot Area C Dry waste. 43% recyclables recovered, 84% possible. Notes: (1) Expected composition from pilot area sorting trials; (2) Mixed paper re-sorted and found to contain 43% newsprint, 3% fine, 10% mixed and 44% residue; (3) Materials not sorted and thus considered refuse.

(May 9 to June 12, 1991) on Dry materials from Areas A, C, D and E, with sorting at three speeds, 12, 18 and 24 m/min, encountered problems obtaining a uniform feed rate and breaking open the bags. This experiment is currently undergoing revisions. Early results of the sorting trials indicate that increasing belt speeds from 12 to 24 m/min produces little discernable difference in sorting efficiencies and suggest a suitable belt speed of 24 m/min. At this speed the percent of missed recyclables were: Area A – 8.9%, Area C – 9.3%, Area D – 16.9% and Area E – 10.4%. Higher rates in Areas D and E are a result of the extra effort required to break the bags (assumed to be an automated process in the full-scale operation).

An important observation from these results is the significant impact of newspapers on any processing system. Not only are newspapers the most commonly missed item, usually more than twice the combined amount of corrugated cardboard, boxboard, fine paper and film plastic, but also newspaper makes up a large proportion of collected materials (43% in Area A and 23% in Area C).

Table 42 shows the results of five Dry sorting trials run from December 1991 to February 1992. Aggregate time, expressed as kilogram per person per hour, is presented for an individual to sort a given quantity of recyclables by hand or magnet. The Pilot sorting system, very similar to the process envisaged for full-scale operation, gives sort times about 25% to 100% better for three-stream materials (Area A) than two- stream materials (Area C). The figures presented in Table 42, although useful for comparison purposes, are not truly indicative of expected full-scale operations. Pilot Dry wastes are separated in three sort procedures. Table 42 presents the figures for the first sort, where paper fibre, plastic film, and food and beverage containers are removed. These materials, sorted from all Pilot areas, are combined in their respective classes for further sorting. Thus only the first sorting operation, shown in shown in Table 42, is useful for comparing processing in terms of two and three-stream systems.

The fibre and film from Areas A and C, and occasionally D and E, undergo a second sort on the same sorting belt. The third separation is the sorting of containers. There is also an occasional fourth sorting for glass, wood and fibre from bulky materials removed in the first sorting. Sorting efficiencies for the second and third sort are typically about half that of the first sort, ranging from approximately 13 kg to 100 kg per person per hour.

An important observation is the difference in cross-contamination between Areas A and C, recorded in Trials 3,4 and 5, with two to three times more contamination observed in the two-stream Dry material. The precise definition of ‘contamination’ is not known, however these numbers represent a serious quality difference. Sorting efficiencies appear to be most significantly impacted by the larger total amounts of material to be processed for two-stream areas (more material ‘along for the ride’), hence the higher rate of contamination observed in

Table 42

	Mass (kg)		Volume (m^3)		Sort Efficiency (kg/person/hr)	
	Area A	Area C	Area A	Area C	Area A	Area C
11 Dec–18 Dec						
Fibre/Film	1,662	2,060			258	229
Glass	241	225	1.08	1.08	139	92
Containers:						
Picked	96	81	2.16	1.8	78	50
Magnet	191	94	1.08	0.36		
Bulky	220	390				
15 Jan–21 Jan						
Fibre/Film	805	1,018			284	119
Glass	183	170	0.81	2.08	183	123
Containers:						
Picked	45	74	1.38	1.35	103	25
Magnet	170	170				
Bulky	122	538				
22 Jan–29 Jan						
Fibre/Film	1,549	1,469			311	167
Glass	315	258	1.35	1.08	222	101
Containers:						
Picked	66	61	2.25	1.92	90	52
Magnet	250	215				
Bulky	250	510				
29 Jan–5 Feb						
Fibre/Film	1,243	1,406			272	197
Glass	248	239	1.08	0.95	191	128
Containers:						
Picked	47	66	1.71	1.8	72	43
Magnet	180	200				
Bulky	141	590	1.44			
5 Feb–10 Feb						
Fibre/Film	1,221	1,391			256	165
Glass	265	255	1.17	1.17	185	102
Containers:						
Picked	44	50	1.62		94	56
Magnet	170	210				
Bulky	180	770				

Dry sorting trials (bins) 1991-92: Three stream Area A *vs* Two Stream Area C. Cross-contamination Area A: 7, 7, 7.6% and Area C: 15.5, 15.5, 22.3% in trials 3, 4 and 5 respectively.

two-stream areas will reduce overall sorting efficiencies. The degree of efficiency reduction is not known but, for this study, a conservative 25% is assumed.

2.6 Waste Collection Practices

In 1991, an average year, approximately 45,000 loads of waste were collected and landfilled in Guelph. About 70% of the total waste stream in Guelph is collected by the private sector. The remainder, mostly residential waste collected by municipal crews, required about 4000 loads to be taken to landfill in 1991, representing less than 10% of the landfill waste loads but often receiving a much greater proportion of attention. Any new waste management system must address the overall waste stream, including the materials not collected by municipal crews. Single family residential waste separation and collection has been extensively piloted in the Guelph study and proposed changes to these collection practices can be made with relative ease, but other areas of waste collection require greater caution.

Residents in apartment buildings and townhouses put their garbage out for collection in a variety of ways. Most apartment buildings over three stories have garbage chutes which usually exit directly into a garbage container, part of a compactor in about one third of the buildings. Waste compactors usually have an attached 19 m^3 to 31 m^3 'roll-off' container collected by specialized private waste collection vehicles, which leave an empty container and haul the entire full container to be emptied at the disposal site. Apartments without waste compactors most often have 2 m^3 to 6 m^3 'front-end' wheeled containers which are placed outside for collection by a custodian on pre-arranged day(s) to be emptied by a front loading private waste collection vehicle. The same empty containers are then wheeled back inside. Many apartment buildings, and most townhouses, have a specific garbage room, or front-end waste containers on the property, to which residents take their wastes directly. In a few buildings (less than 10%) residents put garbage out, at specified locations, in plastic bags, similar to single-family residences.

Businesses generally dispose of their garbage through private waste haulers. Depending on the amount of waste generated this is collected either with front-end bins ranging in size from 1 m^3 to 9 m^3, or with roll-off bins, including those attached to compactors, ranging in size from 8 m^3 to 38 m^3. The type of bins and frequency of collection are customized to meet the specific needs of a business. One of the most important determinants of waste bin size and collection frequency is available space. Space limitations are a common concern for waste generators, in addition to budget limitations, and odour potential. Private waste haulers collect the majority (est. 80-90%) of business wastes, but some smaller businesses, such as landscaping and construction firms, deliver their wastes directly in their own vehicles. Most retail locations have waste collected by private haulers, except for the Central Business District (CBD) whose waste is collected twice per week by municipal crews. The majority of all recyclables in Guelph are currently collected by the City's contractor.

At present any developer must submit new building plans to the Guelph Planning Department. Twinned garbage chutes and larger areas for waste receptacles have already appeared on new plans. Due to space limitations and collection costs the private sector much prefers two-stream separation over a three-stream system.

3 Secondary Considerations

3.1 Environmental Impacts

The average waste collection vehicle burns 65 to 120 litres of fuel per day. With an estimated 75 collection vehicles in Guelph this represents an approximate daily fuel requirement of 7500 litres, or some 2,062,500 litres of fuel annually. This value does not include smaller vehicles which annually deliver an additional 20,000 loads of waste to the Eastview Road Landfill. Total fuel requirements for waste collection in Guelph are estimated to be 3,000,000 to 4,000,000 litres per year. Waste collection also requires considerable resource allocation for such items as waste containers and vehicles, and for building construction such as garbage rooms and chutes, thus accurately estimating the total resource requirements is difficult. Using the assumption that monetary costs closely reflect resource consumption costs, *i.e.* environmental degradation, the cost estimates of Section 2.3 provide the following:

Pre-Collection Costs	
Residential (30,000 @$17.50)	525,000
Non-Residential (45,000 @$35.00)	1,575,000
Collection Costs	
Fuel Requirements (3,500,000 litres @$0.50/l)	1,750,000
Residential (30,000 @$15.00)	450,000
Non-Residential (45,000 @$10.00)	450,000
	$4,750,000

This environmental impact is equivalent to a cost of $4,750,000 for Guelph, primarily for fuel and vehicle requirements for collection, and building and waste container requirements prior to collection. For comparison this cost is about one third the total waste disposal costs for Guelph. Therefore, in this analysis, waste collection would have about one third the environmental impact of waste disposal. The result of these actions is generally some form of pollution, or resource extraction consequence, the most noteworthy local impact being air emissions from collection vehicles and land requirements for waste facilities.

Generally, the greatest perceived environmental impact associated with waste management occurs during waste disposal or processing, such as incinerator emissions and air emissions and leachate from landfills, which also cause public nuisances such as odour and dust. Regular municipal waste is calculated to release a total of 400 m^3 of gas per tonne of buried garbage, roughly equal quantities of methane and carbon dioxide [60], gases which contribute to the 'greenhouse effect'. Methane is about ten times more contributory to global climate change than CO_2 [30] and, because it is also the source of landfill odour problems, it is often vented and burned at active landfills, altering it to CO_2. It is possible to recover energy by burning landfill gases. Removing and processing separately putrescibles and recyclable paper fibres will have an overall impact on landfill gas production, but the specific effects are not completely known. Aerobic composting produces CO_2, however composting an equal quantity of organics anaerobically, the process which occurs in a landfill, releases methane to the atmosphere, which is much more environmentally damaging. The impact of methane can be significantly reduced if it is collected and used as a fuel, replacing other fossil fuels, however, considering overall impacts, aerobic composting should provide a net atmospheric benefit.

Removing recyclable waste paper fibres will also reduce the environmental impact of landfills, since less methane and CO_2 will be released to the atmosphere and leachate quality will be improved. The impact of landfill leachate is assumed to be more severe for older non-lined and non-monitored landfills, which are more prone to leak than newer landfills. The absence of modern leachate collection systems makes treatment difficult. The new landfill proposed in this study would have an extensive leachate collection and treatment system and the site is located on soils with natural leachate attenuating properties. The future quality of the leachate requiring treatment is not known, as the impact of removing putrescibles and paper fibers is not known. A simple model could be developed to project leachate characteristics.

The most significant environmental benefit of removing the compostable and recyclable fraction from the landfill is not the improved air emissions or leachate quality, but rather the related benefits of reducing resource consumption. Tables 43 and 44 show the estimated pollution to be generated by a mass-burn incinerator, similar in size and design to one that would be proposed for Guelph.

Even the installation of state-of-the-art pollution control equipment at such an incinerator will have limitations. Emissions from an incinerator are largely a function of waste composition entering the facility. Controlling air emissions usually comes at the expense of ash toxicity [24, 37]. Also some researchers argue that incinerator scrubbers cause more CO_2 to be released than they remove [15], supposedly a result of the general operating and production requirements of scrubbers. A mass-burn incinerator for Guelph would release annually 500 tonnes of air-borne pollutants and produce 20,000 to 30,000 tonnes of ash. The fly ash, about 10% of the total, is technically a hazardous waste due to heavy metal contamination (as defined by Ontario Regulation 309), so, if this ash cannot be co-disposed with the bottom ash, a significant disposal cost will be incurred (approximately $200 per tonne). One of the most onerous regulatory requirements for incinerators in

Table 43

Constituent (mg/l)	Residue	
	With Fly Ash	Without Fly Ash
Silver	< 1	< 1
Aluminum	2.1	1.5
Barium	< 20	< 20
Cadmium	0.97	< 0.2
Nickel	0.41	0.46
Arsenic	< 2	< 1
Mercury	< 0.04	< 0.04
Selenium	< 0.2	< 0.2
Chromium	< 1	< 1
Copper	< 0.02	0.2
Iron	9.2	0.1
Manganese	4.7	5
Zinc	< 100	< 100
Conductivity (μmho/cm)	813	849
Chlorides	92	62
Sulphates	260	160
DOD	30	28
TOC	8.7	5.7
TO Halogens	0.035	0.065
pH	11	10.8
Alkalinity (mg/kg)	7,900	12,000

Estimated toxicity of incinerator ash. From [56].

Table 44

Pollutant	Basis of Emission	Emission Rate	
		Daily[(3)]	Annual[(4)]
	g/tonne	kg/hr	tonne/yr
Particulates (g/dscf@12%CO_2)	0.04	5.3	37.3
HCl	3,400	45.8	322
SO_2	2,000	27.2	192.4
NO_x (as NO_2)	1,500	20.4	144.3
CO	490	6.7	47.1
VOC (as CH_4)	60	0.75	5.3
Fluorides	50	0.68	4.8
Zn	47	0.63	4.5
Pb	30	0.39	2.7
H_2SO_4	20	0.19	1.34
	mg/tonne	g/hr	kg/yr
Fe	2,500	34	250
Hg	1,200	16	110
Ti	850	13	90
Cd	600	7.7	55
Mn	280	3.9	27
Cr	190	2.6	18
As	85	1.3	90
Ni	60	0.77	5.5
PAH	20	0.27	1.9
Be	5.5	0.009	.55
Co	2.6	0.035	.25
TCDD	$\sim 10^{-3}$	$\sim 10^{-5}$	$\sim 10^{-4}$

Estimated incinerator emissions. From [56]. Incinerator equipped with dry scrubbers and baghouse pollution control equipment. Daily rate based on maximum throughput of 325 tonnes per day. Annual rate based on nominal rating of 260 tonnes per day or 90,000 tonnes per year.

the U.S. is mercury, which occurs in 'button' batteries and ubiquitously in general MSW, seafood and household sweepings. Meeting mercury guidelines is difficult for both air emissions and ash quality.

Composting, recycling and incineration, the three main types of waste processing considered in this study, all have significant environmental impact. Although incineration, as discussed above, has the largest potential impact, especially when considered as a disposal option (mass burning), recycling can also have a significant effect. For example process sludges from paper recycling can be highly contaminated and strict vigilance is required to ensure that the recycling process is carried out in an environmentally acceptable, and properly regulated, manner. Process waste, which may be significant, must be adequately dealt with, however, with respect to overall global environmental degradation, recycling has considerable benefits (Table 45).

Table 45

	Manufactured Material			
	Aluminum	Steel	Paper	Glass
Percent Reduction Of:				
Energy Use	90-97	47-74	23-74	4-32
Air Pollution	95	85	74	20
Water Pollution	97	76	35	
Mining Wastes	-	97	-	80
Water Use	-	40	58	50

Environmental benefits derived from substituting secondary materials for virgin resources. From [1].

Composting can also produce contaminants that are difficult to deal with, the emissions which contribute to global warming, as discussed above, and, more significantly, compost leachate, which, because of its very high organic content, is potentially damaging to receiving bodies of water. Compost can also generate offensive odours and, if not properly processed, can transmit plant and animal pathogens. As with recycling, the most effective way to reduce the potential environmental damage from composting is through proper processing. Compost is usually a net water user, so, if properly processed, it should require water, instead of generating leachate. Ensuring proper composting temperatures and air supply is the most effective way to eliminate odours and pathogen transmission.

3.2 Energy Savings

Municipal solid waste (MSW) represents a significant energy source. The wastes generated annually in Guelph (excluding demolition material) represent an equivalent energy value of 2.09×10^8 kJ, or 36,400 tonnes of coal. An incinerator operating at 50% efficiency could generate approximately $4,275,000 in electricity sales annually from this waste. Table 46 outlines the energy value of the combustible components of MSW, many of which are seen to be of a high energy value, most notably paper and plastic products. Removing food and yard wastes, which

Table 46

	Moisture (Percent)	Energy (MJ/kg)
Paper		
Newsprint	20	17.4
Fine Paper	18	17.0
Magazines	13	12.3
Mixed Paper	19	15.8
Boxboard	23	17.0
Kraft	23	16.7
Corr. Cardboard	12	17.0
Tissues	41	15.1
Plastic		37.2
Polyolefin	23	
Polystyrene	11	
Food	66	6.0
Fruit/Veg		4.2
Meat/Fat		23.3
Yard Waste	60	11.6
Wood	10	17.0
Diapers	61	~9.8
Textiles	20	16.0
Tires	-	23.3

Average moisture content and energy value for selected combustibles in the waste stream. From Ontario Waste Composition Study [32].

are high in moisture and low in energy value, and non-combustible metals and inerts, from the waste stream, increases the average energy value of the remaining material to approximately 19,750 kJ/kg. This material can be considered a fuel, comparable to coal with an energy value of 26,750 kJ/kg.

Sometimes more energy can be saved by recycling an item in the waste stream, rather than through incinerating that same material. Manufacturing one kilogram of paper requires 27,400 kJ of energy and recycling that paper would save some 50%, or 13,700 kJ, of energy over production from virgin resources [39]. Incinerating that same paper would yield 7,900 kJ of useable energy (assuming 50% efficiency), therefore, from a net energy requirement, recycling is 1.7 times more efficient than incineration. Detailed life cycle analysis has recently been used to demonstrate that such calculations may be incorrect, however, and some authors [44] have shown that recycling of paper is actually more energy consuming than incinerating it after one cycle. The use of recycled paper in the manufacturing process increases the need for fossil fuels due to the absence of tree debris for burning, thus recyling paper may be considered to trade trees for fossil fuel.

Although a detailed life cycle analsis is required for accurately measuring energy requirements, recycling combustibles is often 1.5 to 2 times more energy efficient than incineration. For some materials, especially those with an energy value over 21,000 kJ/kg, and those that are not easily recycled, incineration is definitely a practical disposal option. The arbitrary value of 21,000 kJ/kg differentiates between material requiring incineration for disposal, as opposed to material being used as a fuel. At this level items such as tires and plastics, for example, would merit consideration as a fuel source. For some materials, for instance items that require considerable cleaning or constituent separation, such as tires and some plastics, the recycling process may definitely be energy intensive, requiring more energy to recycle than can be recovered through incineration.

One of the most serious constraints affecting incineration is the related emissions, and the ability of incineration to act as a disincentive to recycling. Due to the heterogeneity of the feed material, the clean incineration of MSW is more complicated than incineration of a single fuel type. The synergistic effects of MSW combustion are not well- known, leading to more complex pollution control requirements. Much concern has been raised that some wastes, such as PVC plastics, fluorescent tubes, batteries, printed matter, and paints, make a disproportionately high contribution to incinerator emissions [34], but the cost and energy required to remove these items from the waste stream can diminish the benefits of MSW incineration.

3.3 Local and Global Environmental Threats

Pollution and land development are the most significant local actions that damage the local environment, and these must be considered from a waste management perspective. For purposes of this study, pollution is defined as waste material placed in the air, water or soil, but the three media are interrelated, which enables waste materials to change states and move freely between air, water and soil.

Air pollution, in the form of either gaseous or particulate matter, results from industrial activity, automobiles, and other forms of combustion; waste management is generally more concerned with the release of detrimental gases. Air quality in Guelph is generally good, although in summer it can be significantly degraded for relatively short periods of time, as a result of low-level ozone and associated smog, primarily caused by vehicles. Accurate data does not exist to evaluate the assimilative potential of the local atmosphere, therefore, to minimize any potential human health impacts, or environmental degradation, every effort must be made to reduce air emissions. This study does not adequately investigate the relative impacts of air emissions, for instance dioxins from an incinerator compared to vehicular emissions from waste hauling, to allow defensible comparisons of waste management systems based on air emissions. But it is clear that a proposed waste management system must minimize air pollution.

Water pollution occurs when water bodies are used to remove waste materials. The two largest sources of water pollution in the Guelph area are probably sanitary and storm sewer outfalls, and urban and agricultural run-off, most of which eventually reaches the Speed River. River quality, degraded from this effluent to a degree which is difficult to quantify, has been observed to appear to be improving over the past 15 years. Sanitary sewers have traditionally been used for more than simply removing human wastes, with industries and householders often pouring liquid wastes down the drain, but sewage treatment plants are designed to treat human waste and are not able to neutralize these more insidious pollutants. Although tertiary treatment ensures maximum river protection the receiving water body still deteriorates, even with stringent sewer use by-laws.

Groundwater pollution is of particular concern to Guelph, since the municipal water supply in Guelph is exclusively from these sources. Groundwater pollution can result from similar contaminants as surface water contamination, however groundwater supplies are extremely difficult to clean once contaminated and can generally withstand less contamination than surface water. Any proposed waste management system must therefore minimize potential impacts on receiving water bodies with particular emphasis being placed on the protection of groundwater supplies.

Soil pollution traditionally occurs when wastes are dumped on, or in, the ground, for example the disposal of coal tar waste in Guelph. Such pollution is of most concern when individuals can come in contact with the soil or the pollutants are threatening to change state and become air or water pollution. When evaluating waste management systems, this report is concerned about soil pollution, particularly as it relates to landfilling and incinerator ash disposal.

The other area of potential local environmental impact in Guelph is land development. Guelph is in an area of Southern Ontario that is experiencing growth pressures, which results in the development of land, transferring it from natural or agricultural use to residential or commercial use. As land becomes more developed its environmental benefit is usually reduced, for example, a wooded area can support a larger number of plant and animal species and be more effective at ameliorating the effects of flooding and drought, than a similar area of residential or commercial land. Much of Southern Ontario is rapidly losing farmland to development, adding to the problem of already lost wetlands and forested areas. The waste management systems evaluated in this report are compared as to their land use impact and an attempt is made to minimize land requirements and impacts on neighbouring areas.

Global environmental problems are usually a result of the cumulative impact of millions, sometimes billions, of people carrying out some action that is damaging to the planet, for example the burning of fossil fuels. A brief description of five of the major global environmental problems that are expected to affect Guelph is given below.

Economic and Social Instability: As the world's environmental problems continue to increase in severity their local impact on Guelph will become more pronounced. Environmental refugees, fleeing from floods, famine, and military hostilities over resources, are expected to increase, and many of these will approach Canada as a suitable home. As the global economic structure reorganizes itself, it is unrealistic to expect that this will have no impact on Guelph. It is likely that the relative monetary wealth of residents and governments will decline. These anticipated global economic and social instabilities may lead to a very volatile political atmosphere, for traditionally when people are faced with deteriorating standards of living conflicts often arise [20].

Atmospheric Change: The concentration of carbon dioxide in the earth's atmosphere has increased from a pre-industrial revolution level of 225 ppm to a current level of 355 ppm and this concentration is expected to continue increasing to a level in excess of 600 ppm before 2030, with a predicted corresponding global temperature increase of up to 6°C [30]. Carbon dioxide is the main contributor to the 'greenhouse effect' and the concentrations of other contributing gases, such as methane, and CFCs, are also increasing. The resulting changes to the earth's climate are the subject of much debate. Significant long term climate changes are expected to occur in Guelph, but the severity and pattern that these changes will take is not known. It is expected that droughts will be more common and storms more frequent and severe.

Thinning Ozone Layer: Chlorofluorocarbons (CFCs), released during their use as refrigerants, propellants, and cleaners, have been depleting the earth's protective ozone, the stratospheric ozone which reduces the amount of the sun's ultra-violet radiation that reaches the surface of the earth. Increased levels of UV-B are expected to bring about an increase in the incidences of skin cancer, impair the human immune system and interfere with many of the earth's natural ecosystems. CFCs are being phased out through international agreements, however due to the delay involved with CFCs reaching the upper atmosphere and the large amounts of CFCs still in use, the problem of ozone depletion will continue well into the next century. Ozone thinning has already been reported over Southern Ontario [63].

Loss of Genetic Diversity: There are an estimated 5,000,000 to 30,000,000 plant and animal species on earth, but this number is being reduced by some 100 to 200 species per day [53, 30]. Damage resulting from the loss of genetic diversity is difficult to quantify. As it applies to humankind the loss represents a lost opportunity for possible cures to diseases, and other beneficial product development. Loss of species, occurring most rapidly in tropical rainforest areas, where, as with most of the world, it is being brought about mainly by loss of habitat, also reduces the planet's ability to adapt to large-scale changes.

Global Population: Probably the most serious environmental problem is the growth of the human polulation, estimated to be 5.5 billion today. This population is considered to be greater than that which can be sustained by the planet, and yet the world's population continues to increase by 2% annually [30]. Each person is responsible for some amount of environmental degradation, the individual rate being far greater in developed countries. This damage magnified on a global scale appears to be beyond the assimilative capacity of the planet.

Global Pollution: Waste, the by-products of human activity, is polluting the earth's air, water, and soil. Symptoms such as smog, acid rain, dying lakes, and leaking landfills are becoming all too common. Around the world it is becoming apparent that the environment cannot accommodate the volumes and types of wastes being generated. Problems associated with pollution appear in numerous and varied forms. Human and ecosystem health is often affected. A common difficulty encountered when addressing global pollution is identifying single generators. Often the problems are created due to the cumulative and synergistic effect of numerous generators.

A major aim of a waste management system is to enhance the environment by effectively responding to these local and global environmental threats. As outlined above though, our shared environmental challenges are extremely complex and broad based. Linkages between a local waste management program and a threatened planet are often difficult to see, so, to allow useful environmental comparisons between waste management systems, a number of goals and objectives need to be set. For purposes of this study specific environmental goals are as follows.

1. Promote awareness about environmental problems and effective solutions, both locally and globally, including using the waste management issue as a means to highlight the connections between our environmental and social problems.

2. Reduce resource consumption, particularly fossil fuels, which also includes the promotion of more efficient resource use technologies.

3. Minimize the total emission of pollutants from the system.

4. Maximize the amount of useful commodities derived from the waste stream.

5. Promote overall waste reduction and corresponding resource consumption.

6. Have minimal land requirements.

7. Maximize the diversion of hazardous wastes and provide corresponding education to reduce their use.

8. Proceed in the most cost effective manner possible.

3.4 The Politics of Waste

The world is now facing a ‘garbage crisis’ brought about by trends: (1) the quantity of waste produced together with the increasing difficulty of waste disposal; and (2) the overall rise in environmental awareness. Landfilling has traditionally been the most common form of waste disposal. Low temperature incineration and, more recently, high temperature incineration have also played a significant role. Recycling and composting have always been exercised, at least in a limited fashion, most commonly limited to single separated waste sources such as manure and in-house industrial scrap. As land becomes more scarce the development of landfill facilities is more difficult and more land-use conflicts arise, leading to higher development costs and a more protracted approvals process. In Europe and North America the public has become politically sensitized to the issue of waste.

A relatively recent phenomenon to emerge is the NIMBY syndrome (‘Not In My Backyard’) when local residents, facing land use changes, have become increasingly influential in directing public policy, both with positive and negative implications. Agitated residents can protract the siting and approvals process for much needed waste management facilities, increasing costs and delaying programs. However, these same residents have provided an extremely useful function in increasing overall awareness of the issues and forcing waste management officials to develop more environmentally acceptable solutions. Many critics argue that the rise in NIMBY is a reflection of selfishness and parochial attitudes. This may be a component of the public mood, but it is probably not the main cause of NIMBY. The relative amounts of private land ownership have remained constant over the last 50 years while NIMBY has increased dramatically. The main causes of the NIMBY attitude are likely to be a more knowledgeable, aware and distrustful public, which has become more empowered through revisions to the political process. Past actions by planning officials, including perceived and actual errors, have led to an anxious and wary public. Many people feel that past programs were developed without public input, leading to more technical and non socially interactive policies, an attitude which has largely influenced the creation of current environmental legislation. In Canada this legislation often controls government programs, the private sector being exempt from much of it.

The impact of the rise in environmental awareness and of NIMBY is observed in Guelph. In 1982 the City of Guelph, after being approached by the County of Wellington, undertook a Waste Management Master Plan (WMMP) with an original budget estimate of $72,000 and a projected time frame of 12 months. The actual cost will be at least $4 million with a required time frame of 10 years. Little public input was observed until actual waste disposal sites were identified, when an agitated public closely scrutinised the process, bringing about considerable delays. In spite of the difficulties created the overall process was useful in enhancing general public awareness on the issue of waste management, making new approaches possible, such as Blue Boxes and Wet/Dry separation, while moving away from incineration.

This politically oriented phenonemon has been similar in most North American jurisdictions. The public throughout Canada has become sensitized to environmental issues and responds to perceived environmental threats by searching for meaningful environmental responses. Waste management is often the number one environmental issue in Canada, where environmental issues have been rated with increasing importance, reaching the peak in 1989 when the environment was rated as the number one issue facing Canada (18% rating). This concern has since been overshadowed by other issues: 9% rated the environment as the number one issue in 1990, declining to 4% in 1991, fifth after economy, government deficits, national unity, and taxes [73].

As evidenced by attendance at waste management public meetings environmental concerns are still significant, however the public appears to be interested in addressing environmental issues, such as waste management, in a more holistic and fiscally responsible manner. Public awareness in environmental issues may also be increasing in sophistication and many people are starting to make the connections between wide ranging environmental and social problems. This attitude will take time to develop, and, in spite of the present tendency to demand short-term, isolated responses, the public is undoubtedly demanding waste management solutions. These are often directed at specific components of the waste stream, for example disposable diapers, implementing beverage container deposits and boycotting fast food restaurants with polystyrene containers, however such responses are often ill-informed or even incorrect.

The public identification of specific waste items usually leads to an immediate response by the manufacturer and such biased responses have largely influenced the development of waste management programs in Ontario. Two illustrative examples are OMMRI's response to deposit requests and Procter and Gamble's response to the disposable diaper issue. OMMRI (Ontario Multi Material Recycling Incorporated) was formed in 1986 in response to the Ontario Government's desire to re-introduce soft drink container deposits. OMMRI successfully deflected, or reduced, the demand for deposits, by advocating a more comprehensive approach with the Blue Box as the main component. By granting one third of Blue Box program start-up costs, municipalities were led by OMMRI into beginning Blue Box recycling programs, but municipalities, with Provincial assistance, are still responsible for over 99% of the ongoing waste management costs. Soft drink containers represent less than 1% of the waste stream, yet an industry association, acting solely on behalf of the interests of soft drink sales, was able, through effective lobbying and participatory involvement, to influence the shape of Ontario's waste management program. OMMRI deserves credit in that it is one of the very few industry groups that has taken any responsibility for its packaging and it should be noted that implementation of soft drink container deposits would not have diverted as much waste as is currently being processed through Blue Boxes.

Disposable diapers are another item in the waste stream that appears to have the potential to disproportionately impact the development of waste management programs. Not wanting to see bans or taxes, manufacturers are responding to public criticism of their products by working with municipalities in developing new programs that can easily accommodate disposable diapers. Procter and Gamble Inc. has issued grants to municipalities (e.g. St. Cloud MN and Guelph) to ensure that new composting programs can accommodate diapers. This is not a criticism of manufacturer involvement in waste management issues; on the contrary, more involvement is required from industry. However, as a cautionary note, waste management authorities should ensure that a relatively small component of the waste stream does not unduly influence the development of programs designed to address the entire waste stream.

Currently there is growing dissatisfaction with the Provincial Blue Box recycling program, mainly as a result of the high collection and processing costs.

Municipalities are paying most of these costs and in these times of economic constraint are evaluating more cost effective alternatives. There is considerable pressure, from various sources, to discontinue the Blue Box program [29, 28].

The issue of waste management illustrates the nuances of Provincial/Municipal relations in Ontario. Municipalities currently have the legislated responsibility of waste collection and disposal but the Province of Ontario regulates and approves new, and operating, waste disposal facilities such as landfills and incinerators and provides significant funding for these facilities. Provincial waste management targets and guidelines, for example a goal of 50% waste diversion by 2000, have been set in response to pressure, the construction of new incinerators has been denied, and mandatory commercial/industrial waste audits [36] have been proposed by the Province.

The politics of waste management has been the driving force of program development and the political scope will continue to broaden as waste management takes on a more comprehensive approach. However the path of least political resistance is often not the most cost effective or environmentally correct action. The best response to these shortcomings is improved public education for an informed public will usually desire the most suitable waste management program.

3.5 Waste Trends

As outlined in Section 2.1 the per capita waste generation rates in Guelph have declined by approximately 45% since 1983, however, due to population increases, this study projects a 50% increase in waste quantities over the 25 year planning period, based on 1991 tonnages. Projecting future waste trends is largely a projection of future economic activity, as per capita waste generation rates often mirror economic activity, an indicator of changes in construction activity and wholesale/retail sales.

Much attention is now being focused on waste reduction. Industry has been making steady strides to reduce packaging, mainly as a cost saving measure, the cost of packaging representing about 10% of the current food and beverage bill. Reducing these costs is often achievable by reducing the total amount of packaging, thereby using fewer resources and producing less waste. Packaging plays a significant role in retailing, promoting products and providing convenience, often leading to what is perceived as 'excess packaging': single serving packages are usually manufactured for convenience; blister packs and paper backing, on such items as toys, assist in retailing; and products such as perfume are largely sold by the package. Consumer concern is reducing excess packaging and in some cases the reduced package size is becoming a selling feature. The impact that reductions in packaging will have on the overall waste stream is not certain.

Another trend that appears to be having an effect on per capita waste quantities is a slow movement away from mercantile values by some members of society. More emphasis is being placed on activities, rather than the accumulation of possessions, a trend which is expected to increase, leading to less waste generation.

Another important trend that affects future waste plans is changes to waste composition. Table 10 presents the current composition of Guelph's waste stream. Some predicted changes in composition over the next 25 years are: a decline in newsprint as newspapers use thinner paper (est. 25%), an increase in fine paper as computer use increases (est. 20%), a decrease in mixed and glossy paper (est. 10%), a decrease in corrugated cardboard as fewer large items are purchased (est. 10%), a decrease in container glass which will be substituted by plastic (est. 40%), an increase in plastics as they are substituted for heavier, more energy-consumptive products (est. 50%), an increase in ceramics and composites as they replace more resource-consumptive items (est. 60%), and a decrease in horticultural waste (est. 25%) as gardening changes occur, backyard composting increases and lawn watering restrictions are implemented.

3.6 Experience in Other Communities

When reviewing world waste management it becomes apparent that these programs are very reflective of local conditions. For example, Japan with limited land space, and perhaps less public environmental concern, uses incineration more than any other industrialized nation, however the Japanese public can be counted on to make numerous, and sophisticated, source separations [65]. The United States appears to currently have less reliance on personal waste separation and many programs have been developed accordingly. Europe has a wide range of programs, influenced by limited landfill space, a supportive public (less reluctant to be regulated), and a high overall environmental awareness. Canada is currently wrestling with identifying the best way to proceed and pilot projects are underway from Victoria to Halifax. Again it appears that there will be no one 'right way', but rather a variety of programs according to the local needs of individual communities. Following are brief summaries of a few representative waste management programs.

Lamsterland, Netherlands: This community with a population of 12,000, living almost exclusively in single-family dwellings, adopted a four-stream separation program in early 1991. Each household is given two 240 litre, two compartment wheeled bins and on alternating weeks one bin is wheeled to a 'cluster site', designated by a mark on the curb. An automatically rear loading collection vehicle, divided horizontally into two halves, empties the grouped bins at the cluster sites. The bins are divided into: week one, one compartment of paper and one compartment of trash; and week two, one compartment of organics for composting and one compartment for plastics, metal and aseptic packaging. All four compartments are 120 litres in size. Separate collections for household hazardous waste (HHW), bulky horticultural waste and general bulky waste such as furniture, are also provided. There is also a deposit on glass bottles. The first six months saw virtually 100% participation and an estimated 75% diversion rate from landfill. Few problems, apart from cleaning and jamming bins, have been experienced. Residents have not found keeping putrescible wastes for a two week period to be unduly onerous [6].

Toyohashi, Japan: The residents of this community of 320,000 are asked to deliver their separated wastes to designated locations at designated times. There are five residential waste streams: combustible, non-combustible, bulky, recyclables (glass and metal) and hazardous waste; and three office waste streams: combustibles, non-combustibles, and organics or rubbish. Material is delivered to a site containing a 300 tonne per day incinerator and a 130 tonne per day composting plant for mixed garbage, night soil, and animal waste, producing poor quality compost. A small fraction of the waste stream is sent to recycling markets [62].

Dade County, Florida: In 1978 Agripost Industries opened a 700 tonne per day composting facility near Miami, taking mixed waste from residential areas, processing it through a hammermill (with minimal separation), and composting it in aerated windrows in an enclosed building. Table 33 shows the typical compost quality. This program required little, or no separation from residents. For a variety of reasons the facility was forced to close on May 23, 1991, primarily due to objections from neighbouring residents (especially due to odours), financial difficulties and a poor product. The practice of composting mixed un-sorted MSW is being carried out in several other U.S. communities, for example St. Cloud, Minnesota, and these facilities are experiencing many of the same difficulties that plagued the Agripost operations.

Greve, Chianti, Italy: The community of Greve in the Chianti Region of Italy produces approximately 200 tonnes of residential waste per day. In 1989 construction began on a waste processing plant, to produce refuse derived fuel (RDF), which will be incinerated in the first European fluidized bed incinerator. A small portion of the generated steam will be used by the adjacent cement plant, but the majority will be used to produce some 6.7 MW of electricity, to be sold to the local electric utility. The cement plant is planning to use some of the incinerator ash as feed stock for its operations. There is little emphasis on recycling or waste separation [19].

Gloucester County, New Jersey: In January 1990, a 500 tonne per day incinerator began operation in Gloucester Co., New Jersey, producing 13 MW of electricity. New Jersey has the most stringent regulations on incinerator emissions in the U.S. and pollution control equipment consists of dry scrubbers and fabric filter baghouses. There are strict notification guidelines for emission exceedance, as well as strict levels on ash contamination (which is monofilled), and stack emissions. In a six month study it was found that trying to meet, or exceed, one specific emission requirement often came at the expense of another. For example efforts were made to increase operating oxygen content, however this increased total CO_2 emissions. Currently there is little removal of recyclable materials prior to delivery to the incinerator [24].

Helsinki, Finland: The Helsinki metropolitan area, consisting of four cities with a total population of approximately 820,000, has an average per capita waste generation of 490 kg/year. The one shared landfill site is nearing capacity and four alternative waste management options have been evaluated: sanitary landfill, decentralized waste treatment, centralized waste treatment (mainly incineration), and recycling and materials recovery (involving curbside sorting and composting). The Helsinki office of waste management has recommended a future program that involves extensive recycling and composting (based on source separation) and controlled incineration of the residue. A goal of 50% recycling, composting, and material reuse is felt to be achievable [2].

Cologne, Germany: Cologne, Germany provides perhaps one of the best examples for consideration in designing a waste management system for Guelph. The City has recently carried out an extensive study to determine the best system to adopt. Currently 98% of the City's annual 973,000 tonnes of waste is landfilled, however the area is starting to face landfill space restrictions. Backyard composting has been encouraged and officials estimate that 7% of the waste stream can be diverted through backyard composting. In addition to backyard composting two new waste management systems have been evaluated: (1) A two bin system, one for compostable organics, the other for trash. Paper, glass and metals for recycling are delivered to a dense network of drop off locations; and (2) A more complex three bin system in which 310,000 core area households would have the two bin system as outlined in (1), a requirement thought to be necessary because of the limited storage space for a third bin in this area, which is almost exclusively multi-unit dwellings. The 140,000 outlying households would have a three bin system, one bin for recyclables, a second for trash and a third bin for compostables. The difference in diversion for the two systems was estimated to be less than 2% (three bin superior to two) and thus the extra expense of a three bin system was felt to be unwarranted. Only 34.5% of Cologne's waste stream is generated from residential dwellings and officials were attempting to develop a system that addressed the total waste stream. Therefore the two bin system was recommended for all residential areas, since it would allow more attention to be directed towards reducing the non-residential waste stream, enabling greater overall waste diversion. Eight waste disposal options were studied. The recommended option involved extensive recycling and composting, with incineration of 232,000 tonnes of residue waste annually (approximately 25% of total), but this was was qualified in that, if sufficient landfill space were available, the 232,000 tonnes of residue would be better landfilled than incinerated [25].

There are at least 50 waste diversion pilot programs underway in Canada, being used to evaluated the next 'best' step, or as the early stages of a larger program. Such programs are aimed at providing a comfort level to local residents and officials as to how best to proceed, by ensuring the customization of any new program to suit local conditions. These programs have illustrated one significant fact: the absence of one optimum system. Many different systems can attain the same desired goals and officials must now decide which is best for their specific community. The following examples illustrate this fact.

Mississauga, Ontario: Mississauga has had 1200 households separating organics and recyclables for over two years, with various two-stream and three-stream, bin and bag, scenarios studied. The various organic streams are to be composted separately. The main goal of this pilot program was to evaluate various residential collection scenarios. (The City of Mississauga is responsible for residential waste collection only, and the Region of Peel, of which Mississaugua is a member, has the legislated authority for waste disposal.)

Region of Hamilton-Wentworth: The Region of Hamilton-Wentworth is exploring the practicality of composting non-sorted MSW [61], against strong criticism from many Ontario waste management officials who feel all organics should be separated prior to composting. The Region of Hamilton-Wentworth is responsible for waste disposal within the Region; it is not responsible for collection. The Region can use limited bans and preferential pricing to encourage desired waste streaming. However the investigation of mixed MSW composting is an immediate step that the Region has the authority to implement. The full-scale implementation is likely to be delayed since it is assumed that the compost produced would not meet Provincial compost guidelines.

Hastings County, Ontario: Centre and South Hastings has been investigating an expanded Blue Box program, launched in September, 1990, and serving 32,000 households (mainly single-family homes). Items for collection include: Blue Box glass bottles and jars, rigid plastic containers, and food and beverage cans; bagged newspapers and inserts placed next to the Blue Box; flattened and separately bagged boxboard and rinsed milk cartons placed next to the Blue Box; and flattened and tied bundles (not to exceed $75 \times 75 \times 22$ cm) of corrugated cardboard also placed next to the Blue Box. The program was largely funded and supported by OMMRI with a goal of evaluating potential residential waste diversion while maintaining the Blue Box. All recyclable materials are collected with a single vehicle and a separate vehicle collects garbage. Residents have been very supportive of the program. Participating households divert approximately 150 kg per year [58].

Other illustrative Canadian pilot programs are underway in Powell River, Victoria, and Vancouver, British Columbia; Edmonton and Riley, Alberta; Toronto, Halton Region, Richmond Hill, Ottawa, Chatham, Durham Region, Waterloo Region, Dryden, and Niagara Falls, Ontario; Trois Rivieres and Quebec City, Quebec; St. John, New Brunswick; Halifax and Lunenburg, Nova Scotia; and St. Johns, Newfoundland. This is not a complete list but does give an indication of the widespread research that is now being directed towards waste management in Canada.

4 The Recommended Waste Management System

4.1 Basis for Test System Comparison

This study compares five basic waste management systems for Guelph, as outlined in Section 1.2, with increasing levels of generator source separation. The first system, one garbage stream only, is provided for illustrative purposes only. Also the two-stream garbage and compostables system is unlikely to be a serious possibility, since the public would be reluctant to stop household recycling. These five systems are compared and rated in three equally weighted areas as described below.

Economic Rating

To rate the five waste management systems on an economic basis a total estimated annual cost is calculated for each of them, including all associated costs, such as waste preparation costs. These costs are significant, especially for non-residential generators, since waste preparation is usually the most expensive component of a waste management system. An estimate is made for the cumulative waste management costs for the over 5,000 businesses in Guelph and the impact of various separation procedures on this community.

The costs, calculated on the basis of Section 2.3, are presented in the following manner:

1. *Residential preparation* which includes mainly household waste containers and building requirements such as garbage chutes. These costs represent approximately 7% of total costs and are paid for by residents when purchasing containers (*e.g.* garbage bags) or home purchase/rental costs. This amount is estimated to be less than 0.05% of the total operating cost of a typical household.

2. *Non-residential preparation* which includes labour costs of housekeeping staff and building/land requirements. These costs represent approximately 35% of the total costs and are borne directly by businesses at an estimated level of 1% to 5% of business operating costs.

3. *Residential collection* costs for vehicle and labour requirements. Through property taxes the Corporation of the City of Guelph indirectly pays about 70% of these costs for single-family residential waste collection. The remain-

ing 30% is paid to private waste haulers by multi-unit residents, usually through rent.

4. *Non-residential collection*, the charges businesses incur for waste removal, either paid to a private waste hauler or to support in-house collection staff and/or vehicles. These costs make up about 15% of the total and about 2% of the business operating budget.

5. *Capital processing* costs to cover the construction of waste processing facilities are based on an amortization period of 20 years at 8% interest. They can be as much as 6% of the total and are paid by the City through indirect taxes and tipping fees.

6. *Operating processing* costs, the per tonnage costs associated with processing recyclables and compostables, are the highest at 18% of the total in the two stream Wet/Dry system. These costs are paid through tipping fees.

7. *Sale of products* is based on the market values of recyclable materials, given in Table 31. This revenue offsets operating costs of the processing facilities, however it is never expected to exceed 3% of total system costs.

8. *Disposal costs*, not expected to exceed 15% of total system costs, are given for both landfilling and incineration, although the total annual cost estimate is based on the exclusive use of cheaper landfilling. These costs are paid directly by waste generators through tipping fees.

To establish total costs in these categories an annual waste generation rate of 90,000 tonnes is assumed, using 1991 data (see Table 32), a figure which includes 30,000 tonnes residential and 45,000 tonnes non-residential waste generated within the City of Guelph limits, and also 15,000 tonnes demolition waste. Preparation and collection costs are calculated using the per tonne rates given in Table 29. Processing and disposal costs are calculated using the rates of Table 30. Table 47 gives the estimated costs for each of the five test systems and the economic rating assigned for comparison. This is calculated on a scale of 0 to 50, as a measure of the cost in excess of the minimal cost for the baseline system of garbage only, which is rated at 50. The most expensive system has a rating of 0 and the others are arranged on a linear scale.

Waste Diversion

The Governments of Canada and Ontario have set waste diversion targets of 50%, although on what this target is based is not clear, nor is the timetable

Table 47

	Estimated annual cost ($million)				
	1 Stream	2 Stream			3 Stream
	Garbage	G & Rec.	G & Comp.	Wet/Dry	G C & Rec.
Preparation					
Residential	0.75	1.05	1.05	1.05	1.35
Non-Residential	4.50	6.30	6.30	6.30	8.10
Collection					
Residential	2.03	3.08	2.76	2.76	3.63
Non-Residential	2.25	2.93	2.93	2.93	4.05
Processing					
Capital	-	0.08	0.60	1.20	1.10
Operating	-	1.28	0.66	3.68	2.64
Demolition	0.23	0.23	0.23	0.23	0.23
Disposal					
Landfill	2.70	2.22	2.37	1.23	1.38
Subtotal	9.53	17.17	16.90	19.38	22.48
Less:					
Sale of Recyclables	-	0.32	-	0.62	0.58
Total	9.5	16.9	16.9	18.8	21.9
Rating(0 to 50)	50	20	20	13	0

Economic rating of five test systems.

for implementation [23, 52]. In response to various government objectives and in consideration of the aims outlined in Section 1.1 the recommended system will attempt to maximize waste diversion as far as possible. Table 48 shows diversion estimates for the five potential systems; those for Systems 1, 2 and 3 are based on general assumptions, whereas the estimates for Systems 4 and 5 are based on extensive data generated in the Guelph Pilot Study. Table 23 implies

Table 48

	Material diversion (10^3 tonnes/yr)				
	1 Stream	2 Stream			3 Stream
	Garbage	G & Rec.	G & Comp.	Wet/Dry	G C & Rec.
Compost(1)	-	-	11.4(8)	18.1(10)	15.2(12)
Recyclables					
Paper	-	9.2(6)	-	20.7(11)	19.5(13)
Glass	-	1.9(7)	-	2.2(11)	2.0(13)
Metal	-	1.1(7)	-	1.3(11)	1.2(13)
Plastic	-	1.3(6)	-	2.2(11)	2.0(13)
Other(2)	-	2.5	-	4.5	4.0
Total Diverted(3)	-	16.0	10.3(9)	47.2	42.4
Percent Diverted(4)	-	18	11	52	47
Rating (0 to 50)(5)	0	11	7	33	30

Material diversion rating of five test systems. Notes: (1) Compost of sufficient quality to meet Ontario guidelines; (2) Includes tires, textiles, scrap metal, wood and items diverted for repair and/or re-use; (3) Total diverted reflects 10% disposal residue of composting process; (4) Compared to total waste stream of 90,000 tonnes, inclusive of 15,000 tonnes demolition waste; (5) Based on percentage diversion rate compared to theoretical maximum diversion rate of 80%; (6) 50% of available news, fine paper, corrugated cardboard and plastic containers and film; (7) 75% of available glass containers; (8) 60% of available 19,000 tonnes; (9) Value could be increased by approx. 10,000 tonnes through current recycling program; (10) 95% of available 19,000 tonnes; (11) 85% of available news, glossy, fine paper, boxboard, corrugated cardboard, plastic containers and film, metal cans and glass containers; (12) 80% of available 19,000 tonnes; (13) Value could be increased by approx. 2,000 tonnes through legislation and financial incentives.

a theoretical maximum diversion rate of 71% and, as discussed in Section 2.2, this figure could be further increased to about 80% by establishing new markets for diverted materials. The waste diversion rating given in Table 48, used for test system comparison, is calculated on a scale of 0 to 50, as a measure of the percentage diversion compared to this theoretical maximum diversion rate of 80%. Of course, by establishing a diversion program for demolition waste this figure could be increased for each of the systems considered.

Environmental and Political Factors

The test systems are comparatively analyzed for five environmental considerations and three additional political factors, each on a scale of 1 to 10. These eight values are totalled and converted so as to provide a measure on a scale of 0 to 50, thus providing equal weighting with the economic and waste diversion characteristics. The values chosen are arbitrary, however, despite their subjectivity, they are a useful tool for comparison purposes.

1. *Conservation of resources* is influenced by the quantity of recyclables diverted, the amount of compost produced and also by the resource requirement for collection and processing.

2. *Local impacts* were evaluated for each system based on potential land requirements, nuisance potential and other considerations.

3. *Avoidance of pollution* is closely related to the conservation of resources, however most potential pollution will occur either through energy use or problems with residue disposal.

4. *Positive societal changes* means the potential impact that a system can have with respect to producing environmentally beneficial changes, which is largely a function of the educational value of a particular waste management system.

5. *Impact on new waste management alternatives* is assessed for each of the five systems, which are evaluated for their influence on new waste management initiatives, such as new product design, product and packaging bans and waste reduction efforts.

6. *Flexibility* describes the ability of a system to adapt to future changes, such as loss or gain of recycling markets, problems with compost quality, budget constraints, disposal restrictions and legislative changes.

7. *Public implementation* measures the ease with which the public can carry out the requested source separations.

8. *Political implementation* is the expected political reaction to a system, anticipated from local, Provincial, and Federal politicians and their respective civil servants, non-government organizations and industry.

Table 49 contains detailed scores for the five test systems in each of these categories.

Table 49

	Economic and Political Rating				
	1 Stream	2 Stream			3 Stream
	Garbage	G & Rec.	G & Comp.	Wet/Dry	G C & Rec.
Resource Conservation	0	7	6	10	10
Local Impacts	8	6	4	3	0
Avoid Pollution	0	7	6	10	9
Positive Societal Changes	0	3	4	10	10
New Waste Management Alternatives	0	6	6	9	10
Flexibility	0	6	5	10	10
Public Implementation	5	8	6	6	5
Political Implementation	0	6	5	8	10
Total (0 to 80)	18	49	42	63	64
Rating (0 to 50)	11	31	26	39	40

Environmental and political rating of five test systems.

Overall Ratings of Five Test Systems

Table 50 presents the overall numerical ratings for the five test systems.

(1) One-Stream Garbage

This baseline system is estimated to cost $9.5 million annually. No waste diversion is assumed for this ‘do nothing’ test system, however, through the addition of simple drop-off centres for recyclables and/or compostables, waste diversion could be greatly improved with little additional cost. There are no significant environmental benefits to one stream garbage, although local impacts are minimized, except for the increased landfill requirements. This system provides no flexibility and

Table 50

	Test System Rating				
	1 Stream	2 Stream			3 Stream
	Garbage	G & Rec.	G & Comp.	Wet/Dry	G C & Rec.
Economic	50	20	20	13	0
Waste Diversion	0	11	7	33	30
Environmental and Political	11	31	26	39	40
Total (0 to 150)	61	62	53	85	70
Percent Ideal$^{(1)}$	41	41	35	57	47

Overall comparison of five test systems. Note: (1) Defined as percentage score with respect to maximum attainable on this rating system, representing no increase in cost over baseline system, maximum theoretical diversion of 80% and ideal environmental and political factors.

is an unacceptable option, both politically and publicly. Implementation is easy because no source separation is required.

(2) Two-Stream Garbage/Recyclables

This system is similar to the standard Blue Box Recycling Program currently operating in Guelph. The additional annual cost for operating this system is $7.4 million. It is assumed that current Guelph diversion rates could be improved by 50%, to 16,000 tonnes of recyclables, giving an estimated diversion rate of 18% and a rating of 11 out of 50. The system presents a substantial environmental improvement over one-stream garbage, notably in the areas of resource conservation and pollution, due to the large quantities of diverted recyclables, however, with respect to local impacts and impact on new waste management alternatives, the system is less satisfactory, since substantial improvements can be obtained with a relatively small increase in effort (System 4). The positive societal changes category is given a low score because this system is not likely to encourage continued behaviour changes, as discussed in Section 2.2. The scores for flexibility and political ease of implementation reflect some inherent growth limitations with this system, which is considered to be a 'first step'. Implementation is easy, since it is the existing system.

(3) Two-Stream Garbage/Compostables

The cost increase over the baseline system is identical to that for two-stream garbage and recyclables, in spite of a lower diversion rate of 11%, representing an estimated annual waste diversion of 10,300 tonnes, with a rating of 7 out of 50. This system is similar in environmental potential to two-stream garbage and recyclables, but, the score is slightly less since fewer materials are diverted and composting is expected to impact the local area somewhat more. Some resistance should be anticipated if residential collection of recyclables is stopped and there is also little flexibility, since recyclables are not being diverted.

(4) Two-Stream Wet/Dry

The Wet/Dry system provides significant improvement in several areas, at an increase in annual cost of $9.3 million over the baseline garbage system, only about 11% more expensive than the other two-stream systems considered. Of the five systems evaluated this provides the greatest diversion potential, about 47,000 tonnes per year, giving a 52% diversion rate, and a score of 33 out of 50, based on extensive tests in the Pilot Area. The Wet/Dry system receives the highest environmental score because of the impressive resource conservation potential, public support and limited requirements with respect to land and resources needed for building modification *etc.* This system should be relatively easy to implement, particularly in multi-family residential areas, and very flexible, but, as observed in the surveys, political problems may arise since Wet/Dry appears to build less on the Blue Box Program. Also many interest groups have an interest in retaining the Blue Box. A Wet/Dry Program would require extensive public education, increasing the implementation difficulty.

(5) Three-Stream Garbage/Recyclables/Compostables

The three-stream system is the most expensive option to operate, with an annual cost of $12.4 million in excess of the baseline system, about 16% more expensive than the two-stream Wet/Dry system. Three-stream separation was also extensively tested in the residential areas of the Pilot Program and was found to be highly effective. An estimated 42,000 tonnes annually could be diverted, giving a diversion rate of 47%, about 5% less than two-stream Wet/Dry, and a rating of 29 out of 50. The environmental benefit of three-stream, and the associated political factors, are roughly the same as for Wet/Dry, except for a greater requirement for local building modifications. One of the main benefits of three-stream is that it would require less start up education and could be phased in. Two-stream Wet/Dry requires a virtual community-wide commitment.

4.2 System Selection

The current Guelph Blue Box program is diverting about 9000 tonnes of recyclables (about 10% of the total) at a cost of $180 per tonne and backyard composting is diverting an additional 1500 tonnes of material at minimal cost, but this existing program is not meeting the aims set out in this study. Based on the criteria given above, either two-stream Wet/Dry or the three-stream system could be recommended, since either can achieve about a 50% waste diversion rate (excluding the possibility of a separate demolition waste diversion program). However the following clear advantages of two-stream Wet/Dry make it the superior choice:

- diverts about 10% more material
- costs about 15% less
- more adaptable to changing recycling markets
- implemented more easily, both in multi-unit residences and non-residential areas
- provides greater consumer behaviour changes
- can be collected from single-family residences weekly with a single vehicle
- found to be more convenient by residents

Disadvantages of the two-stream Wet/Dry over three-stream system are:

- places less emphasis on recycling
- more difficult to process recyclables
- more difficult to process Wet waste
- encourages less public pressure to reduce use of non- compostable or non-recyclable products
- hazardous wastes pose a greater threat
- less benefit (requirement) for residential drop-off locations
- less continuity with the present Blue Box system (maybe a benefit)
- requires more initial public education

- more difficult to 'phase in'
- harder to implement a generator pay program where costs reflect true disposal costs (*e.g.* cheaper to compost than to landfill)
- could be confusing to the public since waste separations are based on sorting/processing requirements rather than the current, seemingly more logical, recyclable *vs* waste

Hybrid systems are possible: alternating weekly collections, setting up a dense network of drop-off locations, perhaps limited deposits, could provide significant cost savings, with minimal disruption to any adopted system. When comparing the five systems such variations were not considered therefore it may be possible to improve on the recommended system in this way. At this time it is not suggested that putrescible wastes be collected less frequently than once a week, although horticultural wastes could be collected less frequently than weekly. It would be especially beneficial to use drop-offs (or backyard composting) for such yard waste, due to the significant seasonal fluctuations. Putrescible wastes from large generators, such as restaurants, will require more frequent collection, possibly even daily. Most residents would not be willing to solely deliver their putrescible wastes to a drop-off location, although this facility may prove beneficial for occasional residential use.

Drop-off facilities for recyclables merit serious consideration, since these materials can be stored and transported relatively easily, as confirmed by the 50 tonnes received per month at the current drop-off centre on Gordon Street, Guelph. With only minor preparation requirements such containers serve a large population for minimal cost. Residents, especially businesses, would likely have to face punitive charges, as opposed to actual costs, in order to deliver recyclables to a drop-off location. Waste management costs are typically less than 1 to 3% (sometimes much less) of a household or business total budget, therefore it is likely that household (business) collection will be preferred over the slight cost savings associated with delivery. It is possible that recycling drop-off locations could develop similar to community mailboxes. Such recycling centres are already in place for many multi-unit residences. The question of drop-offs could be posed to the public, but based on the survey results (Section 2.2) most people would wish to have waste materials collected 'at the door'.

Alternating weekly collection is only of value to single-family residences, but, because such households generate only about 25% of the waste stream, it is important to ensure that they do not dictate the development of the overall system. The advantage of having the same waste separation system at home and work (or school) is not known, however having the same sorting habits necessary for all wastes would seem to be beneficial. Considering the reluctance of waste haulers, businesses, and apartment building owners and superintendents outlined in Section 2.6, it is unlikely that a three-stream program would have as much long term success, or commitment, as would a two-stream system. Therefore if attempting to have the same system community wide, two-stream separation again appears to have more potential.

It is possible that the increased sorting difficulties with the Dry waste could hinder the development of a two-stream system, but this can be minimized by careful planning. Following is a discussion on the specific components of the recommended system, which take into account the findings of Chapters 2 and 3, and are designed to minimize any potential problems associated with two-stream separation while maximizing the benefits.

4.3 Implementation

Required Facilities

The operating costs of the recommended system are presented in Table 47 and total about $18.8 million annually, based on 1991 values. Table 54 shows a total capital cost of about $56 million, including a Wet/Dry processing facility (Table 51), a collection system (Table 52), promotion and advertising, and a sanitary landfill (Table 53).

Due to economies of scale, and easier transportation routing, attempts should be made to process the Wet and Dry materials at the same site. The design of the waste processing facilities, for both recyclables and compostables, would change little for either two-stream or three- stream separation and the facility recommended in this study could accommodate materials from either two-stream or three-stream systems, or both simultaneously, adding less than 10% to the capital costs [11]. It is important to ensure that the processing facility can accommodate either two-stream or three-stream material, since this provides a significant contribution to the overall flexibility of the system. Design changes to give this greater processing flexibility are: incorporation of a transfer station, variable-speed sorting belts and possibly slightly larger processing equipment which enable the third garbage stream to be directly transferred, processing equipment to handle material streams that have a large fraction of recyclables (*e.g.* not overloading a magnetic separator if changing to three-stream) and changing sorting conditions to suit incoming waste streams.

Worker health and safety is an important consideration when designing any waste management system. However, since there is virtually no difference in working conditions between two-stream and three-stream processing plants, the

Table 51

	Cost $1,000
Administration Building	550
Dry Stream Receiving/Processing	
Building	4,000
Equipment	7,000
Wet Stream Receiving	
Building	650
Equipment	1,250
Wet Stream Processing/Composting	
Building	2,750
Equipment	1,750
Biofilter System	300
Weighscale	350
HHW Facility	300
Site Works and Services	2,250
Mobile Equipment	675
Engineering and Construction Supervision	3,250
Geotechnical and Testing Costs	55
Land Costs	1,000
Contingencies	2,500
Total	28,630

Estimated capital costs of recommended system processing facility. Based on Guelph WMMP [11].

Table 52

	Cost $1,000
Corporation of Guelph	
Bins (48,000 @ $70 ea.)	3,360
New Vehicles (3 @ $110,000 ea.)	330
Changes to Existing Fleet	100
Private Waste Haulers	
Additional Containers (500 @ $1,000 ea.)	500
Changes to Vehicles	400
New Vehicles (5 @ $150,000 ea.)	750
Residential Alterations	
Building Modifications (est.)	1,500
New Containers (est.)	300
Non-Residential Alterations	
Building Modifications (est.)	4,000
New Containers (est.)	750
Total	11,240

Estimated capital costs of recommended collection system.

Table 53

	Cost $1,000
Land Acquisition (legal fees and purchase price of 90 hectares)	4,000
Roads and Services	2,500
Buildings (incl. weighscales)	1,750
Buffering (fences, berms, and vegetation)	750
Leachate Treatment	2,500
Surface Water Controls	500
Public Drop-Off Facilities	100
Heavy Equipment	1,750
Engineering	1,500
Contingency	1,000
Total	15,350

Estimated capital costs of recommended system landfill. Based on Guelph WMMP [11].

Table 54

	Cost ($1,000)
Processing Facility	28,630
Collection System	11,240
Advertising (First Year)	200
Education and Promotion (Including Labour)	300
Landfill	15,350
Total Capital Cost	55,720

Summary of estimated capital costs for recommended system.

same precautions are needed for either system.

The other major waste facility required is a sanitary landfill site. This facility would need to accommodate 25 years of waste from Guelph and Wellington County. The site is not assumed to be within Guelph City limits but would be as close as possible since Guelph generates about 80% of the wastes within Wellington County. The site would have to meet numerous constraints, most notably hydrogeological and land use impacts. The required landfill should be able to accommodate baled refuse, as well as loose. There may be cost savings and environmental benefits if the process residue from the Wet/Dry plant is baled at the facility prior to disposal. From the City of Guelph the landfill will receive sewage sludge (likely composted) and non-processable wastes such as fiberglass and demolition material, in addition to process residue. The Wet/Dry system will generate waste to be landfilled, at the rate of 42,800 tonnes per year (see Table 48), which, over the 25 year study period, represents about 1,100,000 tonnes of process residue.

Phased Implementation

Phasing implementation of a two-stream system could reduce the likelihood of potential problems. As the experience of the McDonalds Restaurant and recent sorting difficulties highlight, some uncertainties still exist with the material separation required for a two-stream system (Section 2.2 and 2.4). Table 55 outlines a phased implementation program that would see the system fully operational by 1996.

This timetable assumes that construction on the Wet/Dry processing plant begins in September, 1993 and is completed within 20 months (including commissioning). Once a date has been set for plant start-up, working backwards, the timetable can be finalized. Some flexibility will obviously be necessary, but much complementary work needs to be carried out during the relatively short construction period.

Immediately after starting plant construction, changes to the Municipal building code should be brought forward. The revised building code must ensure that new buildings have sufficient space to accommodate two separate waste streams, especially important in multi-unit residences and large commercial/industrial buildings. Most new construction in Guelph has already made provisions for these requirements. Local waste haulers should be informed of the projected start-up date when it is known and a Council resolution could stipulate that, effective on a specified date, private waste haulers will be required to bring wastes separated into either Wet or Dry fractions. Giving the waste haulers as much notice as possible will allow them to make necessary vehicle changes and work with their

Table 55

	1993				1994												1995											
	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
Processing Plant Construction	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X								
Building Code Changes	X	X	X	X																								
Public Notice					X	X	X	X	X	X	X	X																
Hazardous Waste Notice									X	X	X	X	X	X	X	X												
Commercial/Business																	X	X	X	X	X	X	X	X	X	X	X	X
Multi-Unit Residences																					X	X	X	X	X	X	X	X
Single-Family Residences																												
Expand Blue Box																	X	X	X	X								
Blue Box Material Mixed																					X	X	X	X				
Wet/Dry Separation																									X	X	X	X
Direct Billing																	X	X	X	X	X	X	X	X	X	X	X	X

Schedule of system implementation.

larger waste generators to develop separation programs.

After about four months of construction, when a start date is better known, local businesses should be notified in writing that they will be required to separate their wastes into two streams, effective two months prior to plant start-up. A two month overlap will allow for transitional problems without unduly upsetting businesses who would, for a short period, be separating wastes just to be disposed of. For two months after plant opening, recyclables could still be collected separately from businesses. This will permit actual plant sorting trials, and revisions, on both two-stream and three-stream Dry material (similar to the current mixed recycling stream).

Immediately upon start-up, compost should be produced, and extensively tested, especially for heavy metals. Two months of compost data would be available, as well as complete Dry sorting trials, prior to initiating the residential separation program, allowing for modifications if the early results warranted. After two months of full-scale plant operation it would still not be too late to bring in a three-stream separation system for residential areas. This however is assumed to be an unlikely requirement for which no extensive plans should be made, although the possibility should not be ruled out.

Eight to twelve months prior to plant opening the hazardous waste program should begin (see Section 4.3) and the full-scale program should be in place three months prior to Wet/Dry start-up, which requires early completion of the hazardous waste facility, assumed to be at the same location as the Wet/Dry processing facility.

On start-up, once the two months of operating data is available, the present recycling collection should be discontinued and multi-unit residences should be included in the system, most likely by being asked to perform two-stream separation. Staggering the implementation of the system start-up is a prudent measure. Two-stream separation is especially attractive in multi-unit residences and commercial/industrial settings, so, by starting these establishments first, more options remain available. If required, single-family households could be use a three-stream program, although this would create educational and operational difficulties.

During commissioning trials of the plant the Blue Box recyclables should be collected in a one compartment truck, thus providing a material stream similar to the three-stream recyclable stream. Sorting trials, continuing for at least three months after plant opening, will provide a useful insight into full-scale operation. After this time sufficient operating experience would be available to proceed with a successful two- stream system for all waste generators.

Four months prior to plant start-up, hopefully the first of the year, direct billing for waste collection from single-family residences should begin. This billing system should mesh with truck revisions and the proposed Wet/Dry charges outlined in the following section.

Pricing Structure

Showing residents the actual costs of waste management can provide a useful educational tool (Section 2.2 and 3.4). The cost of collection and disposal of single-family residential waste is currently included in general property taxes. Residents see the percentage of tax allocation to waste management once a year on annual tax statements, but notifying residents more often could reinforce the expense involved with waste management. Although it would require slightly more effort, a benefit would likely result if residents could be charged monthly for waste disposal, perhaps most easily by incorporating it in the current utility bill for electricity, water, and sewerage.

Initially each waste management bill could be a fixed monthly fee, based on a percentage of total property taxes, however this could change as soon as it is possible to determine the amount of waste for each waste generator. Technology is available to enable direct billing, per household, based on the *mass* of waste produced Section 2.5. Residents facing waste volume charges would be much more inclined to compact wastes, making them more difficult to process. The feasibility of installing truck scales and micro-processors should be investigated, and, if adopted, such a system should be installed on municipal collection vehicles, preferably prior to Wet/Dry collection. Single family waste billing based on use is a similar concept to other utility charges, and is, in fact, the current practice in non-residential areas.

Within the annual operating budget, costs should be established for the following services: (1) residential waste collection by municipal crews; (2) landfill disposal; (3) mixed Dry processing; (4) Wet processing; and (5) processing specific sorted, clean, recyclables. All processing costs should be net of any possible revenue and a preferential pricing policy should be established for the delivery of properly sorted, saleable items. The processing facility should be designed to accommodate delivery of sorted materials by allowing a partial processing by-pass, although it is likely that these materials would require some final processing, such as baling, prior to shipment to market. Providing business operators and homeowners the opportunity to save money by performing more waste separations than required by law, would be another useful educational tool. Such a preferential pricing structure encourages the continuance of efficient current recycling programs, such as for office paper and corrugated cardboard recycling.

A variable pricing structure which reflects published monthly waste management costs is another powerful economic tool for enhancing the overall system. These costs should be the actual costs being incurred by the City, varying with recycling markets, labour costs and disposal fees. Such a scheme is quite cumbersome to adopt but it would allow public monitoring of the success of the program, which could provide significant benefits.

Education

The sorting habits of the Pilot Area residents declined towards the end of the Project (Section 2.2), which is believed to be a consequence of a reduced information and education program. Extensive public education will be required with the new system, both before implementation and ongoing [46].

One of the inherent shortcomings of a two-stream Wet/Dry program is that participants are not making seemingly logical separations, such as recyclable *vs* non-recyclable. Keeping residents informed about what is being recycled, why other materials are not, and what they can do to further assist the operation of the system would reduce some of the pressures manufacturers are facing over product packaging and design.

The specific aim of an education program is to inform residents how to make the proper separations, both at home and at work. The overall aim should be to educate residents about the issue of waste management, including 'up-stream' related impacts, with an emphasis on 'resource management' rather than waste management (Section 3.1). Schools are an obvious place to direct educational efforts. It is also likely that each of the 3000 to 5000 businesses will require an initial visit to explain the system, and at least one follow-up visit. As demonstrated by the Pilot Project, personal contact provided significant benefit and it is recommended that this should be attempted for all 93,000 residents of Guelph. For residences a 'start up crew' can train local volunteers to act as neighbourhood representatives, similar to the 'bag people' of Pilot Areas D and E.

During the first nine months of program operation (3 months exclusively business followed by 6 months residences and businesses) a help phone line should be staffed from 6:00 am to 11:00 pm, for answering questions and arranging personal visits. The processing facility should also be available for tours and it is highly recommended that every school child in the City should visit the facility within the first year of operation. Numerous other education programs are possible: newsletters, videos, radio spots, promotional items and programs similar to the Blue Box advertising campaign. A first year budget of $500,000, including labour, is estimated for the education program.

The recommended system in this study is extremely aggressive and requires many dramatic changes to the current system. It would be naive to think that societal changes of this magnitude would not have some opposition, however an educated public is an extremely valuable ally. Opposition can be minimized by explaining the reasons for selecting a particular waste management system.

Waste Collection

One of the most significant advantages of a two-stream system is the possibility to collect residential wastes with a single vehicle, while three- stream would require two vehicles or alternate week collection. Work is underway within Guelph to develop an appropriate two- compartment garbage truck for residential collection. Assuming a bin program is adopted, the first option is to retrofit current municipal vehicles with a bin lifter, which would still require two passes but would be phased out by replacement with two-compartment vehicles.

The best method of placing waste at the curb has been studied. As shown in Sections 2.2 and 2.5, either bins or bags would be workable, so a vehicle accommodating either would be preferable. Residents could be provided with bins and billed over a one to two year period, or, they could buy translucent green and blue bags at local stores. Garbage pails and opaque garbage bags should not be used by residents. If a bag/bin collection vehicle is not possible, bin collection would probably be more effective. Pilot Area residents had a slight preference for bins, which also present a greater visual impact when placed outside for collection.

Commercial waste haulers are also looking at two-compartment vehicle designs up to twice as large as residential garbage trucks. Most of these have an overhead container (1.5 to 6 m^3) lift mechanism, making the design of a two-compartment commercial collection vehicle more difficult than the residential equivalent. Roll-off bin collection is well suited for adaptation to two-stream collection.

The area of public waste receptacles needs considerable attention. A Wet/Dry system requires all garbage containers to be 'twinned', which is difficult due to space limitations. A distinctive Wet colour (green) and Dry colour (blue), as well as logos, will prove helpful for public identification.

To fundamentally alter the way every individual deals with waste is a monumental task and it is most critical that an easy, and available, method is adopted for separating and placing garbage out for collection (Sections 2.2, 2.5, 2.6 and 3.6).

Hazardous Wastes

Development of an effective hazardous waste diversion program is crucial to the success of the recommended system. The current programs operating in Ontario are not adequate. Hazardous waste in either the Wet or Dry streams has the potential to disrupt the system by subjecting workers to unsafe conditions or affecting the compost quality. The processing plant has provisions for a hazardous waste building, sized to accommodate all residential HHW and small quantity generators (as defined by Ont. Reg. 309).

The Pilot Study showed that residential collection of HHW will be required (Section 2.2), which is expensive to operate (est. $150,000 per year). The overall hazardous waste program will cost an estimated $1.5 million per year [11]. Some revisions to current Provincial regulations may also be required. Small quantity hazardous waste generators will have to deliver, or have collected for a fee, small amounts of materials such as dry cleaning solvents, paints, solvents and photographic chemicals. Larger industrial generators would continue to dispose of their hazardous wastes through licensed haulers.

Some hazardous wastes should have specific programs developed for them, such as delivering batteries to selected retail locations from where they may be collected by municipal crews. Special attention is also needed for medical wastes, especially syringes. With the assistance of medical, dental and pharmacist associations a virtually 100% effective collection program needs to be developed for used needles, especially important in residential areas where less control is possible.

4.4 System Components

The critical consideration for development of a waste management system is to ensure that components are properly sized and that they act together in a co-ordinated manner. Based on the information in Chapter 2, a brief description of the main components of the recommended system follows. Careful planning is important to attain maximum flexibility, especially so because the waste stream is expected to significantly change over the 25 year planning period (Section 3.4). Also system components can interfere with each other if they are improperly sized, for example an incinerator can act as a disincentive to recycling if it requires too large a fraction of combustible material for efficient operation. There are also outside influences on system components, such as the goal of enhanced economic activity versus long-term waste reduction.

Waste Reduction

Effectively there are two levels of waste reduction: (1) product and packaging re-design to use fewer resources; and (2) reducing the flowthrough of materials in the economy, *i.e.* buying less of everything.

On the first level, more attention is now being devoted by manufacturers to make disposal of products and packaging easier. Municipalities and individual waste generators are also exploring ways to easily reduce waste generation. Organizations such as OMMRI and the National Packaging Coalition are involved in this form of waste reduction [26, 17, 42].

The second level of waste reduction is much more difficult to achieve, since, in essence, it is in direct opposition to our current economic system which measures economic health by the amount of resources consumed and their eventual disposal. It is unrealistic to expect the business community to actively encourage consumers to buy fewer products and Government will certainly not encourage this form of waste reduction, as shown by the current attempts to extract the economy from the present recession.

Nevertheless overall waste reduction is the most important goal of any waste management system, in spite of its complexity and the considerable education and time required to achieve it. The central theme of this waste management system is to encourage movement in this direction and attempt to quicken the pace.

Recycling

The recommended system is largely dependent on recycling, as over one-third of the waste stream is expected to be recycled (Sections 2.1 and 2.5), which will require markets for about 850,000 tonnes of material during the study period. Clearly the environmental impact of this recycling will be significant, however the net impact should be beneficial (Section 3.1). Recycling should not be viewed as a waste management panacea but rather the least objectionable of a number of disposal options.

The area of greatest concern in recycling this amount of material is ensuring markets for the paper products, which represent two-thirds of all materials recycled in this system. Canada is largely a nation of primary resource extraction, especially forestry products, so a shift to secondary resource use will impose financial and social hardships. Reluctance is already being expressed by forestry companies. The paper products that require the most attention are newspapers and corrugated cardboard for which guaranteed markets must be established, undoubtably requiring some form of Federal and/or Provincial assistance. Fine paper has a relatively strong market which is expected to continue. Boxboard, mixed paper and glossy paper markets are still weak. Recycling markets for products other than paper are fluctuating and require attention, however they are probably not as critical as paper markets since there is a relatively small demand and they are generally more diverse.

An important consideration regarding recycling is the false sense of security it imparts to the public. It is argued by some that the success of recycling programs alleviates consumptive consciences, as highlighted by the study described in Section 2.2 [46].

Composting

About 20,000 tonnes of organic material will be composted annually, producing about 10,000 tonnes of finished compost (Section 2.4). This study recommends that this organic material be separated at source and collected/processed separately to ensure high quality compost meeting the Ontario Compost Guidelines [22]. Although the economic value of the compost is assumed to be zero, no marketing difficulties are anticipated with high quality compost.

The composting method must be a high-rate aerobic process to ensure proper pathogen destruction, especially important due to the wide range of organic waste generators accomodated. Operating temperatures should exceed 55°C for three consecutive days [38].

The two-stream separation process recommended for most, or all, of the waste stream is expected to cause some difficulty with plastic contamination and equipment will be required to open bags and remove plastics as well as screen the finished product. The Pilot study has shown that the infeed organic material is suitable for composting (Section 2.4), confirmed by a detailed study on composting the Pilot Area source separated organics [72].

Landfill

The primary disposal option in this study is landfilling (Section 2.1), for both process residue and non-processable wastes. A detailed design of the proposed site is presented in the WMMP. The new landfill, with a 25 year design capacity, will replace the exhausted Guelph Eastview Road Sanitary Landfill Site and will also serve areas within Wellington County outside of Guelph.

Locating a landfill site is an acrimonious process since it involves a controversial change in land use (Section 3.4). The proposed facility is to be located on hydrogeologically acceptable lands with an identified leachate collection and treatment facility and extensive monitoring program. The expected leachate from such a site should be less objectionable than that from other landfills, since most organics will have been removed for composting, although the extent of this improvement is not known. The facility should be designed to accommodate baled refuse since it may be preferable to bale the processing plant residue prior to shipment. Composted sewage sludge from Guelph is also expected and industrial process waste, particularly fiberglass.

Since this will be a new site with limited putrescible organics a study could be undertaken to assess the feasibility of making the site a 'bio-reactor'. Traditionally landfills attempt to entomb wastes, keeping moisture and air away from the garbage, greatly extending the required monitoring period for the closed site. On the contrary, enhancing conditions for bio-degradation would reduce the time required to return the site to useful land use.

When assessing the overall environmental impact of a landfill site a significant benefit can be obtained by extending the life of the site. Although it may not be politically palatable, the practicality of operating the site for more that the twenty five year planning period should be considered.

Demolition Waste

About 15,000 tonnes of demolition waste is generated annually in Guelph and this has been characterized in a detailed study [48]. A separate sub-program needs to be developed to address this specific waste stream which amounts to some 500,000 tonnes over the 25 year planning period (Table 9). Of all of the distinct waste streams, demolition waste is the most influenced by economic activity, the rate of new building construction and old building demolition directly mirroring local economic activity.

Table 56 shows the composition of demolition waste, about 30 to 40% of which is generated by building construction. The largest single component of this waste stream is inert material, such as bricks and concrete, for which an inert disposal

Table 56

	Quantity (10^3 tonnes)	Percent
Wood	2.4	16
Plaster	1.5	10
Inert	3.0	20
Shingles	1.5	10
Metal	2.4	16
Other	4.2	28
Total	15.0	100

Composition of demolition waste, City of Guelph.

site is recommended by the WMMP. A single distinct site may not be necessary if this material is truly inert (as defined by Ontario Regulation 309), for clean inert material, or clean fill, could be taken to land reclamation sites such as the numerous pits and quarries near Guelph. Directing the construction industry to take inert materials to these alternative disposal sites will require safeguards to be implemented: the inert materials disposal site should be staffed to ensure that received materials are in fact inert; the site could also have some rudimentary monitoring and contamination attenuation facilities. A private pit or quarry, near or in Guelph, would be the most logical place to create this site, since such locations need clean fill for their restoration.

The wood from demolition operations should be chipped and composted at the central processing facility where possible. Plaster and drywall should either be recycled or taken to the landfill, because gypsum based products are not inert and release H_2S gas as they decompose. Metals and roofing shingles from demolition sites should be recycled as far as possible and the remainder landfilled. The 'other' stream of demolition waste is probably not well suited for sorting operations at the processing facility, since it is very dusty and also most of this is multi-material items such as plastered and painted wood and drywall, and coated wiring.

Construction firms are now required to obtain a demolition permit prior to carrying out demolition work on a building, providing an attractive method for placing minor control parameters on wrecking firms and individuals. To the mutual benefit both of the demolition firm and the municipality, prior to issuing a demolition permit for a building in excess of 100 m^2, the site should be visited by a municipal employee to determine the best method of waste separation and removal.

New building construction and renovations is a significant contributor to this waste stream. Building a 100 m^2 house generates about 1.5 tonnes of waste [4] which is relatively easy to separate into distinct streams, with about 75% off-cut wood, drywall, roofing shingles, PVC piping and electrical wire, and the remainder primarily corrugated cardboard. All of these materials should be diverted from landfill or incineration. Local builders have already expressed an interest in this [4], but the public abuse of drop-off bins and the variety of builders working in new subdivisions are major obstacles. Providing new home builders with a waste collection service may be a practical option, allowing a builder either to deliver separated materials to the processing centre at a reduced rate, or to have the separated materials collected at the construction site for a fee. Collecting materials from all building sites within a new housing area should provide significant savings. It is probably better to contract the collection service to private waste haulers, who would be supervised by the municipality.

Incineration

This study does not recommend the construction of an Energy From Waste (EFW) disposal facility, for which the cost of construction and operation is greater than the expected revenue from sale of energy (Section 3.2). With relatively large areas available for garbage burial (landfilling), at less cost, it is unlikely that incineration will become a practical solution.

There are, however, specific waste items that probably should be burned for energy recovery prior to disposal. To satisfy this the processing facility will have the ability to divert process residue of high energy value (more than 21 MJ/kg), considered to be a low-grade fuel similar to coal. A significant environmental benefit has been described for producing electricity and/or steam from this material, rather than straight landfilling (Section 3.2 and 3.6). This process 'fuel' should be burned at facilities that are expressly designed for EFW energy generation and the material would have sufficient energy value to warrant shipment to proper facilities. Materials such as non-recyclable tires and RDF (refuse derived fuel) may be sold as fuel to proper users, for instance Ontario Hydro, who should be encouraged to investigate the feasibility of using this material.

5 Conclusions and Recommendations

5.1 Conclusions

Either a two-stream Wet/Dry or three-stream waste separation system can achieve the objectives outlined in this study. Despite the additional operating constraints of a two-stream system, it is concluded that, with proper safeguards, two-stream Wet/Dry separation should form the basis of the future waste management program for Guelph. Comparisons between the two systems are sensitive to interprative considerations, however two-stream Wet/Dry has the potential to divert larger amounts of waste for less cost than three-stream separation.

In addition the following can be concluded from the investigations carried out in this study:

1. Over 95% of environmental damage is caused by a product prior to its becoming municipal solid waste. Environmental benefits from waste management are most effectively achieved by using waste as a tool to reduce overall resource consumption.

2. Reducing resource consumption by waste reduction and recycling are the cornerstones of sustainable development.

3. Diversion of waste from disposal is more of a social and environmental solution than a technical, or 'engineered', solution. The technical constraints are generally provided by collection systems, materials handling issues, emission controls and materials substitution (*e.g.* recycling markets), whereas the social challenges are societal education, shifts in attitude, and economic restructuring, issues which require much broader input and a longer time frame for resolution.

4. The current system of Blue Boxes, expanded recycling and backyard composting is diverting 10,000 tonnes of waste per year in Guelph, at a cost in excess of $2,000,000. This system does not meet the objectives of this study which identifies an effective system to supersede the Blue Box program.

5. Per capita waste generation rates have been declining in Guelph since the peak year of 1985 and the rate, more than a 45% waste reduction from 1985, is expected to continue its decline by perhaps an additional 50% by 2017.

6. Newspaper is the single item in the waste stream that has the largest potential for waste diversion.

7. The citizens of Guelph are anxious to enter into more aggressive waste management activities, but seem willing to do so only if the new system is cost effective (a 10% increase appears to be the limit) and simple to participate in.

8. Preparation or pre-collection costs, often ignored, give the largest fraction of waste management cost, up to 40% of the total.

9. True costing is a useful tool to allow proper consideration of economic externalities as they effect the seemingly unrelated environmental and social costs. However the current costs of waste management in Ontario, particularly landfilling, are likely artificially high, even after considering all of the related costs.

10. Preliminary indications show that there is virtually no difference between the compost quality from two-stream or three-stream separation, in spite of the intuitive assumption that three-stream compost should be better.

11. Non-source-separated organics and composted sewage sludge are not likely to meet the Ontario Compost Guidelines, among the most stringent in the world, particularly for mercury, and strict separation controls will be necessary.

12. Over the 25 year planning period the City of Guelph could divert some 850,000 tonnes of recyclables through the recommended system, however it is not certain if markets will remain in place for these materials.

13. Current municipal hazardous waste diversion programs are neither adequate nor cost effective, necessitating changes to enable the safe and reliable operation of new waste management systems.

14. Mechanical separation of Dry material, particularly ballistic separation, has only limited applicability to the waste stream.

15. For a small component of the waste stream, incineration is certainly beneficial for the environment, when compared to landfilling and alternative energy production. Further study through life-cycle analysis is required to determine the overall impact of general material use and disposal. Caution is needed when planning for waste incineration since it has the potential to act as a disincentive to other waste management options, due to the high cost of incinerator construction and operation, and the influence of economies of scale.

16. The individual interests of industrial groups have skewed the development of the current waste management program in Guelph and other communities, and have the potential to do so again in the future.

17. Single-family dwellings have had a disproportionately large influence on the development of local waste management programs, considering that they generate less than 25% of the overall waste stream.

5.2 Recommendations

A number of recommendations, based on the findings of this study, are made:

1. The recommended waste management system for the City of Guelph is a two-stream Wet/Dry waste separation system, however adoption of this system requires considerable caution and flexibility to ensure that possible problems with materials processing are minimized. Some limited areas may not be suitable for a two-stream system.

2. A residential waste collection and disposal fee, based on amount (mass) and type, of waste generated, should be evaluated and, if practical, replace the current tax-based system.

3. When the full scale Wet/Dry program is implemented, differential material fees should be in place to reflect the cost savings obtained by having generators, or haulers, separate wastes prior to delivery to the processing plant.

4. Effective immediately the cost of waste collection and disposal should be presented to residents separately from other municipal charges, perhaps by including it on the monthly utility bill.

5. Changes to building codes and other municipal constraints should be made now to guarantee that all future buildings have sufficient room to accommodate at least two-stream waste separation.

6. To provide flexibility the Wet/Dry processing plant should be designed for processing either two-stream or three-stream waste materials, or some combination.

7. Considerations should be made to bale process residue prior to landfilling.

8. The Wet/Dry program should be phased in over a period of 24 months. Flexibility should be incorporated so that if, during this time, three-stream waste separation appears more practical for certain areas, a system change could be made. Single-family residential dwellings should be incorporated last.

9. Considerable attention should be devoted to an education program for implementing a Wet/Dry system, a campaign that will probably require ten times the resources required by the Blue Box campaign. Every home and business may require at least one personal visit.

10. A comprehensive hazardous waste program should be implemented as soon as possible, well before start-up of the new system, with a requirement for significant increases in the amount, and type, of waste currently being diverted.

11. Incineration of parts of the process residue by large energy users (*e.g.* Ontario Hydro, cement factories) should not be dismissed, because some material may be considered as a fuel and treated accordingly. This RDF would have to be sent to an existing central incineration facility.

12. The emphasis on *waste* management should be changed to *resource* management, both before and after an item becomes waste.

13. Encouragement of backyard composting should continue.

14. Collection of grass clippings and watering of lawns should be phased out.

15. Inter-governmental and broad-based programs to expand and strengthen recycling markets are needed, with particular emphasis being placed on the pulp and paper industry since over 60% of the projected recyclables are paper fibres.

16. Newspaper is a waste product that needs serious and immediate attention since newsprint will be the largest recycled commodity. Assistance should be sought from newsprint producers, newspaper companies and governments to develop a long term program to ensure marketability of this material and to reduce material use by employing thinner paper and finer print, as is the case in Europe.

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