CRC FOR WASTE MANAGEMENT AND POLLUTION CONTROL LIMITED A.C.N. 055 584 819

REPORT

ASSESSMENT OF FOOD DISPOSAL OPTIONS IN MULTI-UNIT DWELLINGS IN SYDNEY

Prepared for:
In-Sink-Erator

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1 Acknowledgments

In undertaking this study, the investigators received support and assistance from numerous people and organisations that provided information and data.

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The study was overseen by a steering committee which consisted of representatives from the NSW Environmental Protection Authority (EPA), Sydney Water, the NSW Waste Boards, Nature Conservation Council, Local Government and Shires Association and In-Sink-Erator. The project definition and methodology, together with the wording in this report, were developed in consultation with the committee, however this report does not necessarily represent the endorsed view of any of these organisations.

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3 Executive Summary

Food Waste Processor (FWP) units are mainly used to dispose of waste generated in the kitchen during the preparation of food. Their use is limited by legislation to domestic and existing hospital use only (in NSW). The highest per capita installation of FWP units appears to be in apartment blocks.

In-Sink-Erator has approached the Cooperative Research Centre for Waste Management and Pollution Control (CRC for Waste Management & Pollution Control Limited) to investigate the environmental, technical, economic and social impacts of their product. In-Sink-Erator is the leading supplier of residential, sewer-based food waste disposal systems.

The research was undertaken as five separate but interlinked studies examining the technical/operational, environmental, economic, social acceptance and microbial risk impacts of FWPs. The In-Sink-Erator unit was taken as representative of FWP units.

The study was restricted to the Waverley Local Government (Council) Area in the eastern suburbs of Sydney. Within the limitations provided in the specific reports, the results are believed to be representative of this area.

The procedures for this study are believed to be generic for analysis of these types of impacts. Such procedures should be able to be transferred to other situations, for FWP use in both multi – unit and other dwellings.

The results may not be transferable or applied to other areas without using new or verified data sets. The general conclusions are expected to follow those reported here for similar situations, but care must be taken to verify and document the basis on which the assumptions are based.

The following FWP scenarios were adopted:

- The current situation. Available data indicate that 3% to 5% of households in the Waverley area have FWP units. A value of 5% has been adopted for this investigation.
- The future situation. Using the market penetrations of 15%, 25% and 50%, the 50% market penetration in this study is considered to be an extreme case. It was assumed that all FWPs are used every day for each of the adopted market penetrations - an extreme situation.

The five studies and their results are outlined below.

Sub-investigation 1: Operational Impacts of the Food Waste Disposal System.

The aims of the analysis of the operational impacts investigation were:

- To determine current and anticipated future loads on the sewerage system from the use of FWP units; and
- To determine the positive and negative macro environmental impacts from the use of FWP units in terms of impacts on:

  (a) the occurrence of sewage overflows;
  (b) the sewage treatment process;
  (c) biosolids reuse;
  (d) the marine environment in disposal of uncaptured portion of food wastes; and
  (e) energy consumption required in sewage transport, treatment and biosolids processing.

- To provide data to evaluate capital and operating costs of the food disposal options.

Data was both generated through a laboratory investigation using a FWP unit and also obtained from In-Sink-Erator, Sydney Water and other relevant sources. The specific water usage used in this investigation for each FWP unit was 6.2 Liters per household per day or 2.95 Liters per person per day. These values are higher than the values obtained from the laboratory investigation, midway between other referenced studies and lower than those used in overseas investigations.

Several assumptions were made for this investigation in consultation with the steering committee:

- All of the FWPs were assumed to operate together every day for each of the adopted market penetrations.
- The current market penetration was assumed to be 5%.
- It was assumed that the latest available local data as used in this study will not change in the future.
- Pollutant load increases of less than 10% for all pollutants at Bondi STP were considered to be within the design and operational capabilities of the plant and would not result in operational problems or need capital upgrades.
- Sewage quality into Bondi STP was assumed to be the same as in the Waverley-Bondi Eastern Slopes Intercepting Sewer.
- The results from the laboratory investigation were assumed to be representative of the Waverley Catchment.

There were major differences in concentrations and loads of pollutants in FWP effluent between this investigation and those used by other investigators. In particular, the mean NFR,

BOD_5 and COD concentration from this investigation differed by up to three times when compared to literature values.

Only this study and two others are based on local monitoring data. The others are based on monitoring sewers for small differences of irregular flows. Results from the other investigations cited in this report are based on generic literature values or theoretical calculations.

The overall results of the operational impacts of the food waste disposal study show:

- increases in sewage flows from FWPs at any of the adopted market penetrations are very small;
- FWPs contribute less than 0.1% flow to the Instantaneous Maximum Flow in the sewer at a market penetration of 50%;
- impact on the sewage treatment process from the hydraulic loading attributable to FWPs is small. Even for 50 % market penetration, FWPs would only contribute an extra 0.5% to the Mean Average Daily Flows which are attributable to the area studied through the sewage treatment plant;
- impacts from additional pollutant loads on the sewage treatment process as a result of FWP usage is also small: a market penetration of up to 15% should not cause operational problems in terms of BOD_5, Oil and Grease and NFR. (It should be noted that the mean annual effluent concentration for Oil and Grease at Bondi STP was closer to the EPA licence limit than for the other pollutants for 1999. An increase of 10% Oil and Grease could increase effluent concentrations by about 2 mg/L, resulting in a mean average effluent concentration of about 25 mg/L, if the rate of chemical dosing for the chemically assisted sedimentation process is not varied. This slightly increased effluent concentration is about 15% less than the EPA licence limit of 30 mg/L.)
- FWPs would not adversely affect sludge digesters, dewatering centrifuges and biosolids trucking movements up to a market penetration of 25%;
- FWPs at any market penetration studied are unlikely to affect biosolids reuse, the marine environment or energy consumption.
- The use of FWPs would result in additional hydrogen sulphide generation within the sewerage system and while this is associated with corrosion and odour problems, it is not possible to quantify the effects or to estimate an upper FWP market penetration that could be sustained by the existing system.

Sub-investigation 2. Environmental Profiles of the Food Disposal Options

The aim of investigating the environmental profiles of food waste disposal options was to assess FWPs on the holistic basis of the ISO14040 standards using *Life Cycle Assessment* (LCA) and compare them to home composting, co-disposal of food with municipal waste and centralised composting of food and garden waste.

The functional unit ("fu") adopted for the LCA was the average amount of food waste produced by a household for disposal in one year, 182 kg (wet).

The LCA was based on several assumptions made in consultation with the Steering Committee:

- The beneficial use of by-products, such as compost and biosolids (avoided products), was not part of the study.
- The FWPs are operated correctly and require no maintenance over a 12 year lifespan.
- The home composting unit is made of polyethylene that lasts for 12 years.
- Home composting is correctly operated, and food waste degrades under aerobic conditions.
- A Centralised Composting system for food and garden waste was assumed to run in parallel with the existing MSW system, at a capacity of 50,000 tpa.

The disposal of food waste with municipal waste is common practice. No major assumptions were made concerning the collection of waste. The amount of recovered energy is uncertain should the biogas generated be used for energy recovery. This was treated by a sensitivity analysis.

The LCA gave the following results for the impact categories studied:

- Home composting had the smallest environmental impacts in all impact categories studied;
- The FWP unit ranked second in terms of energy consumption, global warming potential and acidification, but fourth in terms of human, aquatic and terrestrial toxicity potential and eutrophication;
- Co-disposal received the second highest ranking in the categories of toxicity potential and eutrophication potential, ranked only slightly behind FWP for energy consumption and acidification and had the lowest ranking for global warming potential; and
- Centralised composting had a relatively poor environmental performance due to its energy intense collection activities, ranking fourth for energy and acidification and third in the remaining categories.

Normalization of the results to an emission per capita basis (without weightings), showed eutrophication from the FWP to have the largest relative potential impact for all the food waste disposal options (of the impact categories considered), followed by centralized composting. Co-disposal made significant contributions only to global warming and eutrophication potential. The energy consumption and acidification potential of all food waste disposal options were smaller relative to the annual average per capita impact.

Sub-investigation 3: Cost Comparison of the Food Disposal Options.

The results of this study show home composting is the least expensive option for the residents of multi-unit dwellings, while the FWP is the most expensive. The cost to the resident of co-disposal and centralized composting are in between these two extremes, with centralized composting being marginally the cheaper.

From a system-cost point of view, FWD appears again to be the most expensive option, and this cost increases beyond the 25% market penetration level in the study area as additional capital expenditure may be required at the sewage treatment plant.

The Codisposal system option would not necessitate additional capital investment (within limitations imposed by the existing landfill capacity) as this is the waste management option presently in place, whereas implementation of the Centralised Composting system option would necessitate capital expenditure since such a system suitable for food wastes does not exist within the Sydney area.

Sub-investigation 4 Additional Health Risks of the Food Disposal Options.

The aims of this part of the investigation were to evaluate:

- Microbial risks associated with sewer overflows caused by FWP units;
- Relative microbial risks between the four processing options; and
- Risks associated with disease vectors.

A formal quantitative microbial risk assessment (QMRA) approach was undertaken at a screening level to compare risk between the various options under consideration. To compare pathogen risks, each of the four possible pathogen groups was represented by an index organism; *viz*: a virus (rotavirus), a bacterium (*Salmonella typhimurium*), a parasitic protozoan (*Giardia lamblia*) and a helminth (*Ascaris lumbricoides*).

Overall the study identified that:

- Risks from overflows from raw sewage would be unacceptable, however, FWP units may only marginally increase the rate of sewer overflows during periods when the sewer is already flowing at 100% (such as during storm events);
- Domestic composting, without the addition of pet faecal wastes or meat products, was predicted to result in acceptably low infection rates for all the pathogen groups;
- Commercial composting (including human faecal wastes) appeared satisfactory from the point of view of no significant pathogen risks;
- Overall vector-based diseases were not considered significantly different due to the operation of FWP units and on-site domestic composting in approved containers.

Sub-investigation 5: Social Impacts of the Food Disposal Options.

The relative merits (social factors) of the four food waste disposal options in multi-unit dwellings within the study area were compared through two focus group discussions. The options were assessed across four criteria: consumer choice, accessibility of the option, space requirements, and consumer uptake.

Disposal of food with municipal waste (the dominant current practice) was judged as being the least satisfactory of all the options. Individual garden composting, while environmentally ideal, was judged to be impractical for multi-unit dwellings.

FWPs and the separate food waste collection with centralised composting were evaluated as being much more appropriate (across the four criteria) than the mixing of food and other waste. This assessment, however, was provisional on the availability of a level of treatment that would enable re-use of the waste material.

Overall conclusions.

Up to a market penetration of about 15 % of households, the use of FWP in multi-unit dwellings would have small impacts on the sewage treatment and transport systems. Beyond this figure there are increasing impacts, and at 50% market usage some may become significant.

The study indicates that Home Composting is the least expensive option for the residents of multi-unit dwellings, while the FWP is the most expensive. The cost to the resident of Co-disposal and Centralised Composting are in between these two extremes, with that of Centralised Composting being marginally the cheaper.

For the householder, FWP appears to be the most expensive option. Overall, costs increases beyond the 25% market penetration level in the study area may be incurred as additional capital expenditure may be required at the sewage treatment plant.

The Co-disposal system option would not necessitate additional capital investment (within limitations imposed by the existing landfill capacity) as this is the waste management option presently in place, whereas implementation of the Centralised Composting system option would necessitate capital expenditure since such a system suitable for food wastes does not exist within the Sydney area

From an environmental viewpoint well controlled and managed home composting is the most favoured option across all impact categories. FWP ranks approximately equal second across three categories but fourth across four categories of impact potential.

None of the options, when correctly operated, posed a significant additional risk to health.

While the focus groups preferred FWP or centralised composting for food disposal in multi-unit dwellings, for convenience and perceived health benefits, they are sensitive to the impact arising from the disposal of the waste materials. Thus FWP and Centralised Composting would appear to have a high acceptance rate if the biosolids or compost are reused in a way that has acceptable minimal impacts on the environment.

For up to 15% market penetration in the study area, the use of FWP in multi-unit dwellings would be expected to have a small impacts on the sewage treatment system. If their adoption and use became more widespread, there would appear to be a need for additional investment in the sewage treatment system, however this is unlikely to be in the near future given the presently low market penetration of these units. Environmentally, correctly implemented Home Composting is the preferred option, however this may not be acceptable to residents of multi-unit dwellings for whom the FWP offers a practical, but much more expensive, alternative. The environmental cost of adopting this alternative would present a trade-off: The Energy, Global Warming and Acidification impacts are less than or equal to those of the Co-disposal or Centralised Composting options, however the Toxicity and Eutrophication impacts are higher.

4 Background

Food Waste Processor (FWP) units are mainly used to dispose of waste generated in the kitchen during the preparation of food. Their use is limited by legislation to domestic and existing hospital use only (in NSW). The highest per capita installation of FWP units appears to be in apartment blocks.

In-Sink-Erator has approached the Cooperative Research Centre for Waste Management and Pollution Control (CRC for Waste Management & Pollution Control Limited) to investigate the environmental, technical, economic and social impacts of their product. In-Sink-Erator is the leading supplier of residential, sewer-based food waste disposal systems.

The research was undertaken as five separate but interlinked studies examining the technical/operational, environmental, economic, social acceptance and microbial risk impacts of FWPs. The In-Sink-Erator unit was taken as representative of FWP units.

This research assessed the environmental, technical, economic and social impacts in in-sink food waste disposal units. The main objectives were to:

(a) *To establish and quantify:*

- *The positive and negative environmental impacts*
- *The infrastructure provision and operating costs*

resulting from current and possible future use of in-sink food disposal units in multi dwelling developments to assess the impacts on the water and wastewater management system, as well as impacts avoided in the solid waste management system, in "likely" and "worst case" scenarios, depending on disposer market penetration.

(b) To compare the benefits and disadvantages of the FWP with the following food waste management options:

- *Individual garden composting,*
- *Disposal of food with municipal waste (Co-disposal),*
- *Separate organic waste collection with centralised composting*.

5 Aims of the Investigation

The specific aims of the investigation were to:

- determine current and anticipated future loads on the sewerage system and sewage treatment system from the use of FWP units;

- determine the positive and negative macro environmental impacts from the use of FWP units in terms of impacts on:
  - the occurrence of sewage overflows;
  - the sewage treatment process;

- biosolids reuse;
- the marine environment in disposal of uncaptured portion of food wastes;
- energy consumption required in sewage transport, treatment and biosolids processing.

- determine loads diverted from municipal solid waste collection as a result of using FWP units and the associated environmental and economic consequences;
- determine environmental profiles of the food disposal options;
- evaluate capital and operating costs of the food disposal options;
- evaluate the social implications of the food disposal options;
- compare the overall benefits and disadvantages of the food disposal options.

6 Report Structure

The aims of this study were addressed through five separate sub-investigations, the results of which form the basis for the overall comparison of the benefits and disadvantages of the food disposal options.

These sub-investigations were:

- An operational analysis approach to assess impacts on the sewerage system of FWP units;
- A Life Cycle Assessment approach to compare the environmental impacts of the disposal system options;
- A cost comparison of the disposal system options;
- A microbial risk assessment (MRA) conducted to estimate additional health risks;
- A broad assessment of the social aspects of each food waste disposal option through focus groups;

Following a literature review, the sub-investigations are presented in detail in the following sections 8 to 12 of this report and then the overall comparison of the food disposal options is presented through the conclusions in section 13.

7 Literature Review

A review of the available literature revealed the following references which describe earlier investigations to evaluate impacts of FWPs on sewerage systems:

Sinclair Knight (April 1990) undertook a study for Sydney using market penetrations of 5% to 100%. The authors concluded that FWPs would have a minimal effect on the volumes of sewage flow and could result in significant increases in pollutant loads in Sydney sewerage systems, although impacts would be dependent on the extent to which FWPs were used. At the estimated market penetration rate at the time of the study (10%), FWPs were concluded to have a minimal effect on the sewerage system. The results from this investigation were based on generic literature values, not on local sampling data.

Griffith University (August 1994) collected kitchen organic waste from 10 households in the Ashmore suburb of Gold Coast City, ground the waste through a FWP unit and analysed the resultant wastewater. Impacts on the Ashmore sewerage system (75,000 households) were evaluated assuming 100% market penetration of FWPs.

The results indicated that the incremental increase in the sewage hydraulic load would be negligible, increases in solids and BOD_5 loads would be less than 20% and nutrient loads would increase by less than 5%. Furthermore, STP aeration tanks would have to be increased in size by about 16%, based on the most pessimistic circumstance that STPs were at full load capacity. It was concluded that FWPs do not present an unmanageable load on the existing sewage treatment facilities. FWP market penetration in the area at the time of the study was approximately 20%, however this was not considered by the investigators.

de Koning, J and van der Graaf, JHJM (1996) investigated impacts of FWPs on the Dutch sewerage system using the theoretical chemical composition of food waste. Food composition data were obtained from investigations undertaken in different countries. It was concluded that impacts of FWPs on sewer systems and wastewater treatment plants was minimal and that adverse effects were negligible at a FWP market penetration of 10%.

NYC (Late 1990s) monitored sewers for 21 months at three study locations to determine impacts of FWPs. The data were used to predict impacts on sewers to the year 2035 assuming a worst case scenario of 1% increase in the number of households using FWPs annually. This rate of increase would mean that more than one third of households in New York City would have FWPs installed by the year 2035, a market penetration which was considered to be unlikely.

The results indicated that although FWP units may cause increases in Suspended Solids and Oil & Grease in the sewerage system, incremental increases in sewer maintenance costs, water consumption and STP operating costs would be minimal. It was recommended that a ban on the introduction of FWPs in combined sewer areas of New York City should be lifted.

There is a scarcity of published literature on Life Cycle Assessment (LCA) for food waste processors (FWP), whereas more LCA studies are available for municipal solid waste (MSW). Four studies have been found which address the environmental impacts of FWP units.

The most relevant work was carried out by Diggelman & Ham (1998). Basically, this study compares food waste management in the MSW system (default system) with the FWP system. Five alternative options are compared in the United States: 1) FWP and on-site systems, 2) FWP and municipal wastewater systems, 3) MSW collection and composting, 4) MSW collection and Waste-to-Energy and 5) MSW collection and landfill. Life Cycle Inventories (LCI) were provided for each option, and they included the production and operation of capital equipment. The five systems were ranked for twelve inventory indicators: land use, total system materials, water, total system energy, total system costs, air emissions, acid gases, greenhouse gases, wastewater, waterborne waste, solid wastes and system food waste byproducts (sludge, septage, compost, ash, landfill residues). The five systems were ranked simply from high to low impacts for each inventory indicator.

Waste Board (2000) and Partl *et* al (1999) have investigated alternative kitchen organics collection systems in the greater Sydney region. The two collection systems studied were 1) regular kerbside collection system of garden organics with kitchen waste and 2) domestic in-sink disposal of kitchen organics. However, these studies provide only a qualitative assessment of environmental impacts and a quantitative evaluation of associated costs.

Hardin *et al* (1999) analysed three disposal options for putrescible (kitchen and garden) waste, ie. kerbside collection and landfill, home composting/worm farming and disposal with FWP. According to the authors, the environmental impacts from the three options were difficult to assess, and as a consequence, the study does not quantify environmental impacts, although it provides a qualitative assessment for the Brisbane area.

None of the previous studies quantify environmental impacts in terms of impact categories for FWP and the alternative waste treatment options in the greater Sydney region. A comparative, quantitative LCA of the four options (ie. FWP, MSW and landfill, home composting and centralised composting) is not available. The LCA investigation performed in this study goes beyond the LCI study from Diggelman & Ham (1998) by addressing the environmental indicators and impact categories of energy consumption, Global Warming, Human- and Eco-toxicity, Acidification and Eutrophication Potential qualitatively and odour qualitatively. Moreover, the potential environmental impacts are based on Sydney specific conditions.

8 Investigation of Operational Impacts

Sub-investigation 1

Operational Impacts of the Food Waste Disposal System.

Sub-Investigation 1 - Contents

1 Introduction

1.1 Operation of Food Waste Processor Units

Food Waste Processor (FWP) units are mainly used to dispose of waste generated in the kitchen during the preparation of food. Their use is limited by legislation to domestic and existing hospital use only (pers comm, Sydney Water). The highest per capita installation of FWP units appears to be in blocks of apartments (pers comm, In-Sink-Erator).

FWP units increase the contribution of flow and pollutants to the sewerage system because of the food wastes that are passed through them using tap water. They contribute to the following factors:

- Increased flows in the sewerage reticulation system during dry and wet weather periods. These increased flows may exceed the capacity of the sewerage system and result in overflows of raw sewage.

- Increased flows to downstream sewage treatment plants that may decrease treatment efficiencies and result in sewage bypasses.

- Increased discharges of pollutants from sewage treatment plants to receiving waters.

- Increased quantities of biosolids, possibly with higher levels of pollutants, that may affect their reuse. Sydney Water currently reuses over 97% of biosolids from the sewage treatment plants that they operate.

1.2 Objectives of Investigation

The objectives of the sewerage analysis component of the investigation are as follows:

1.2.1 To determine current and anticipated future loads on the sewerage system from the use of FWP units.

1.2.2 To determine the positive and negative macro environmental impacts from the use of FWP units in terms of impacts on:

(a) the occurrence of sewage overflows;
(b) the sewage treatment process;
(c) biosolids reuse;
(d) the marine environment in disposal of uncaptured portion of food wastes; and
(e) energy consumption required in sewage transport, treatment and biosolids processing.

1.2.3 To evaluate capital and operating costs of the food disposal options. This evaluation is presented in the "Cost Analysis" section.

2 Methodology

This investigation was undertaken using the following types of information:

1. Information and data provided by In-Sink-Erator, Sydney Water and other relevant sources.

2. The results of a laboratory investigation using an In-Sink-Erator FWP unit to determine typical water usage, energy usage and quality of food waste effluent from the In-Sink-Erator unit.

   An In-Sink-Erator FWP unit was set up in a sink with flowing cold tap water in the CRC for Waste Management and Pollution Control laboratory at the University of New South Wales using the same types and diameter of plumbing that are used in domestic kitchens.

   Kitchen food waste consisting of vegetable, fruit, meat and other food wastes was collected from six households over a two week period. The households consisted of three of Australian background, two of European background and one of Indian background. The ages of adults in the households ranged from twenty years to more than fifty years. Four of the households had one or two children whereas no children lived at the other two households.

   The waste was stored in a freezer until it was used. It was removed from the freezer six hours prior to its use, thawed, mixed thoroughly and divided into three batches of equal sizes. The three batches were passed through the In-Sink-Erator FWP unit in quick succession. The FWP effluent from each batch was collected separately in 25 litre plastic containers. Each batch was vigorously stirred while three samples were obtained for analysis. The samples were analysed by Australian Laboratory Services Pty Ltd, which is a NATA approved laboratory, for several physical and chemical constituents. Samples were stored and analysed according to APHA "Standard Methods for the Examination of Water and Wastewater".

   This investigation was undertaken at the end of March 2000 and the results were received from Australian Laboratory Services on 4 April 2000.

   The operating and analytical results are included as Appendix 1 and summarised in Tables 4.1 and 4.4.

The investigation was undertaken for part of the Waverley Local Government Area. The following FWP scenarios were adopted:

- Current situation. The available data indicates that 3 to 5% of households in the Waverley area have FWP units (pers comm, In-Sink-Erator). A value of 5% has been adopted for this investigation. This value is considerably less than the 10% that has previously been cited for Sydney (eg Sinclair Knight, April 1990). The current value is lower because of the larger population in Sydney and declining sales of FWP units.

- Future situation using the following market penetrations for increased FWP usage: 15%, 25% and 50%.

  The choice of market penetrations of up to 50% in this study is considered to cover all possible market penetration scenarios. This study also assumes that all of the FWPs will be used every day for each of the adopted market penetrations. This may not be the case as people are not at home all of the time and do not eat all meals at home.

3 Description of Waverley Sewerage System

3.1 Waverley Local Government Area

The Waverley Local Government Area (Waverley LGA) extends northwards from Waverley Cemetery at Bronte Beach to Christison Park, Vaucluse. The western boundary extends from Vaucluse along Old South Road and Oxford street to Centennial Park and then along the eastern boundary of Centennial Park to Darley Street. The southern boundary runs almost due west to the coast immediately to the south of Waverley Cemetery (refer Figure 3.1).

The Department of Urban Affairs and Planning (DUAP) has estimated that the resident population in the Waverley LGA in 1998 was 64,706 (information provided by Colin Goldsworthy, Sydney Water). DUAP has forecast a growth of 100 dwellings per year from 1999/2000 to 2003/2004.

Waverley LGA is served by a total of six sewerage systems which are part of the South-East BOOS system (refer Figure 3.1). The southern area of the Waverley LGA was chosen as the study area for this investigation because it is the only part of the Waverley LGA which is served by a dedicated sewerage reticulation system, it does not serve other areas. Sydney Water refers to this area as Waverley Catchment.

Waverley Catchment has a population of 24,900 living in 11,954 residential dwellings. The dwellings consist of separate houses (13%), townhouses (13%), flats and apartments (68%) and other types (6%). The numbers of persons per dwelling varies from 2.9 for separate houses to 1.9 for flats and apartments. The average numbers of persons per dwelling is 2.1.

3.2 Sewerage Reticulation Systems

Waverley LGA is served by several sewerage reticulation systems. They are (refer Figure 3.2):

- Diamond Bay North Outfall;
- Diamond Bay South Outfall;
- Waverley-Bondi Eastern Slopes Intercepting Sewer;
- Rose Bay Submain (south of Old South Head Road);
- Waverley-Woollahra Submain (South of Oxford Street); and
- BOOS (east of Old South Head Road).

The Waverley Catchment study area is serviced by the Waverley-Bondi Eastern Slopes Intercepting Sewer. Sewage from Waverley Catchment is conveyed northwards along the Waverley-Bondi Eastern Slopes Intercepting Sewer to the BOOS Sewer Main and then eastwards to Bondi Sewage Treatment Plant (STP).

Flow data for 1999 from the gauging station on the Waverley-Bondi Eastern Slopes Intercepting Sewer, located at the corner of Glenayr Avenue and Beach Road immediately before the sewer joins the BOOS, is shown in Table 3.1.

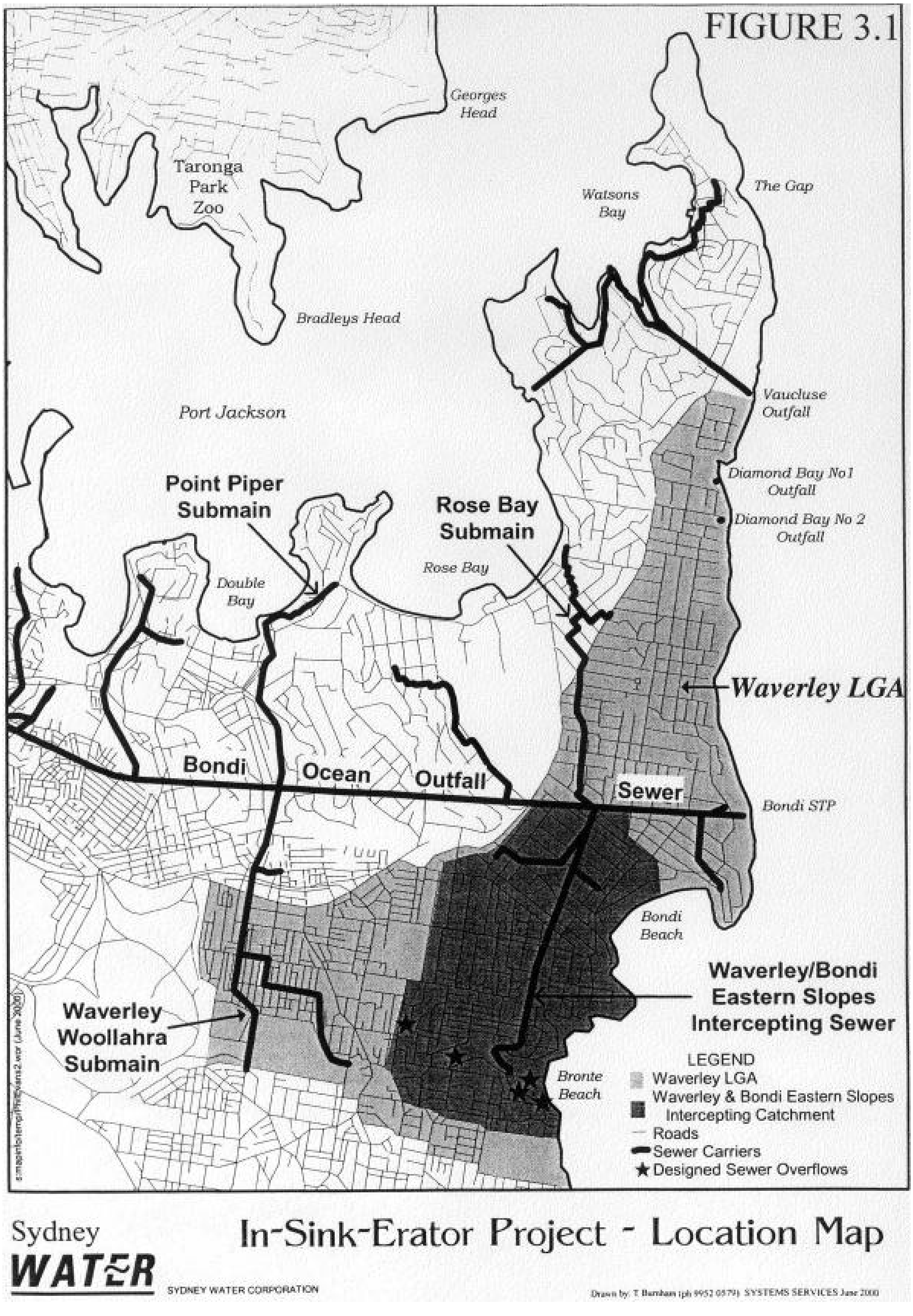
FIGURE 3.1
Georges Head
Taronga Park Zoo
Watsons Bay
The Gap
Bradleys Head
Vaucluse Outfall
Port Jackson
Diamond Bay No1 Outfall
Diamond Bay No 2 Outfall
Point Piper Submain
Rose Bay Submain
Rose Bay
Double Bay
Waverley LGA
Bondi Ocean Outfall Sewer
Bondi STP
Bondi Beach
Waverley/Bondi Eastern Slopes Intercepting Sewer
Waverley Woollahra Submain
Bronte Beach
LEGEND
Waverley LGA
Waverley & Bondi Eastern Slopes Intercepting Catchment
Roads
Sewer Carriers
Designed Sewer Overflows
Sydney WATER
SYDNEY WATER CORPORATION
In-Sink-Erator Project - Location Map

TABLE 3.1 Flow Data from the Waverley-Bondi Eastern Slopes Intercepting Sewer

Flow Parameter	Unit	Value
Mean Average Daily Flow	ML/d	7.314
Minimum Average Daily Flow	ML/d	3.552
Maximum Average Daily Flow	ML/d	13.776
Instantaneous Maximum Flow	L/s	618

There are five reticulation nodes and no design overflow structures along the Waverley-Bondi Eastern Slopes Intercepting Sewer. Furthermore, this sewerage system does not have any silt or grit traps.

3.3 Bondi Sewage Treatment Plant

The current treatment process at Bondi STP consists of (Sydney Water, November 1998):

- Six influent bar screens (780 ML/d total capacity);
- Grit removal through six constant velocity grit removal tanks (700 ML/d total capacity);
- Four influent 5mm fine drum screens (520 ML/d total capacity);
- Four rectangular primary sedimentation tanks with partial chemically assisted settling (520 ML/d total capacity. The effluent channel is limited to 420 ML/d);
- Effluent pumping to the ocean through a deep ocean outfall (700 ML/d capacity); and
- Three anaerobic sludge digesters.

All flows up to 700 ML/d receive coarse screening and grit removal. Flows up to 420 ML/d also receive fine screening and primary sedimentation.

Flows of treated effluent up to 700 ML/d from Bondi STP can be discharged to the Tasman Ocean though a deep ocean outfall that extends two kilometres offshore. Flows in excess of 700 ML/d are discharged through a cliff face outfall after coarse screening (Sydney Water, June 1998).

The EPA licence for Bondi STP permits the discharge of a total of up to 451 ML/d of treated effluent from the deep ocean and shoreline ocean outfalls.

Influent flow data (Sydney Water, April 1999) and raw sewage quality data for 1999 provided by Sydney Water (as annual averages, refer Appendix 2) for Bondi STP are summarised in Table 3.2). Considerably lower concentrations of pollutants have been measured in influent flows to Bondi STP during wet weather (Sydney Water, June 1998). Corresponding EPA licence limits (as 50 percentile concentration limits) are also included in this table.

TABLE 3.2 Influent Data for Bondi STP

Parameter	Unit	Measured	Licence
Average Dry Weather Flow (ADWF)	ML/d	129	451
Maximum Flow	ML/d	352	451
Peak Wet Weather Flow (PWWF)	ML/d	700	451
Suspended Solids (NFR)	mg/L	197	200
Biochemical Oxygen Demand (BOD_5)	mg/L	173	
Chemical Oxygen Demand (COD)	mg/L	380	
Oil & Grease (O&G)	mg/L	38.0	30
Total Kjeldahl Nitrogen (TKN)	mg/L	36.6	
Total Phosphorus (TP)	mg/L	5.8	
Suspended Solids removal efficiency	%	51	

4 Results of Investigation

The results of this investigation are presented according to the objectives listed in Section 1.2.

4.1 Current and Anticipated Future Loads on the Sewerage System from the Use of FWP Units

4.1.1 Hydraulic Loads

The operating results from the laboratory investigation, including water usage, are shown in Table 4.1. All the parameters were measured with the exception of the Power Used as kilowatt-hours (kWh), which was calculated from the measured Power Used (as Amps.)

TABLE 4.1 Results from Laboratory Investigation

Parameter	Units	Batch 1	Batch 2	Batch 3
Weight of food waste	kg	1.5	1.8	2.0
Time for FWP usage	Seconds	115	110	144
Water usage	Litres	16.2	19.7	21.4
Water usage	Litres/kg food waste	10.9	11.2	10.8
Power used	Amps	4.2	4.2	4.1
Power used (calculated)	kWh	0.032	0.031	0.039

The following values were used in this investigation:

- Water usage by a FWP unit: 12.4 L/kg of food waste (Hartmann, 2000). This value was calculated from the University of Wisconsin study (Diggelman and Ham, 1998).

  Therefore, the specific water usage by a FWP unit adopted in this investigation was 6.2 L/household/d or 2.95 L/person/d assuming an average numbers of persons per dwelling of 2.1.

  It should be noted that a water usage of 12.4 L/kg food waste was used in this investigation instead of the slightly lower value from the FWP laboratory investigation (about 11 L/kg food waste, refer Table 4.1) in order to provide more conservative estimates of impacts.

- Generation of food waste: 182 kg/household/year, as wet weight, ie 0.5 kg/household/d or 0.24 kg/person/d. This figure applies to Sydney (BIEC, 1997, CCWB, 2000).

The above results can be compared with those reported by other investigators, as shown in Table 4.2. Reported food waste generation rates are also included in this table.

TABLE 4.2 Water Usage Rates and Food Waste Generation by FWP Units Reported by Other Investigators

Source	Water Usage by FWP Units		Food Waste Generation
	(per household)	(per person)	(per person)
de Koning & van der Graaf, 1996 (Note 1)	10.7 L/d	4.5 L/d (2.37 pers/hh)	0.12 kg/d (wet)
Diggelman & Ham, 1998	10 L/d		
Griffith University, 1994	4.23L/d		
NYC, late 1990s		3.8 L/d	
Sinclair Knight, April 1990		4.5 L/d	
Strutz, 1998 (Note 2)			0.29 lb/d (wet) (0.13 kg/d)

Note 1. The estimate of water usage was considered to be possibly high by the authors.
Note 2. 75% of the total food waste generated was stated as being processed through FWP units, ie 0.21 lb/d (0.10 kg/d).

Comparison of the above adopted water usage values with the data in Table 4.2 indicates that considerably less water was used in operating FWP units in this study than reported for overseas studies. However, the water usage values adopted in this investigation are about 50% larger than the value reported by Griffith University and 50% less than the value in the Sinclair Knight report.

There are also differences between Sydney and other locations in generation of food wastes. Sydney inhabitants appear to produce about twice as much food waste as those in the Netherlands and parts of the USA.

Hydraulic loads from the use of FWP units were calculated using the above adopted water usage and the number of residential dwellings in the Waverley Catchment (11,954 residential dwellings, refer Section 3.1). They are shown in Table 4.3.

TABLE 4.3 Current and Future Hydraulic Loads from FWP Units

Market penetration	Hydraulic Load (ML/d)
Current-5%	0.004
Future-15%	0.011
Future-25%	0.019
Future-50%	0.037

4.1.2 Pollutant Loads

Analytical results from the laboratory investigation are shown in table 4.4 (refer Section 2 for description of methodology).

TABLE 4.4 Analytical Results for Laboratory Investigation

Constituent	Units	Sample					
		1a	**2a**	**3a**	**1b**	**2b**	**3b**
Settleable Solids (Note 1)	mg/L			3,520			3,890
Suspended Solids	mg/L	2,910	6,150	7,730	3,070	8,490	5,940
Chemical Oxygen Demand	mg/L	8,520	17,600	17,800	10,400	14,900	29,100
Nitrite & Nitrate (as N)	mg/L	17	25	19	17	21	19
Total Kjeldahl Nitrogen (as N)	mg/L	137	285	292	144	398	289
Total Nitrogen (as N)	mg/L	154	310	311	161	419	308
Total Phosphorus (as P)	mg/L	25	74	49	27	94	49
		1c	**2c**	**3c**			
Settleable Solids (Note 1)	mg/L			2,570			
Suspended Solids	mg/L	2,680	7,150	8,390			
Chemical Oxygen Demand	mg/L	7,680	21,100	18,400			
Nitrite & Nitrate (as N)	mg/L	17	24	20			
Total Kjeldahl Nitrogen (as N)	mg/L	137	351	675			
Total Nitrogen (as N)	mg/L	154	375	695			
Total Phosphorus (as P)	mg/L	25	113	58			
Wet sieve test results:							
% solids retained by 5.6 mm sieve	-			5.7			
% solids retained by 2.8 mm sieve	-			0.8			
% solids retained by 1.0 mm sieve	-			2.2			
% solids passing less than 1.0 mm sieve	-			91			

Note 1. Settleable solids analyses were undertaken on the composited batches.

The results in Table 4.4 show large variations for each constituent between samples and batches. This variability occurred as a result of differences in food wastes in the relatively small sample size, stirring of batches and sampling between batches. Arithmetic means and standard deviations were calculated using all the data for each constituent in order to obtain representative data to be used for this investigation. The statistical results are shown in Table 4.5. Biochemical Oxygen Demand (BOD_5) concentrations were calculated from the COD results by assuming a COD/BOD_5 ratio of 1.45 in FWP effluent (de Koning & van der Graaf, 1996).

TABLE 4.5 Pollutant Concentrations Used in this Investigation

Constituent	Units	No of Samples	Mean	Std Dev	Minimum	Maximum
Settleable Solids	mg/L	3	3,327	681	2,570	3890
Suspended Solids	mg/L	9	5,834	2,376	2,680	8490
Chemical Oxygen Demand	mg/L	9	16,167	6,770	7,680	29,100
Biochemical Oxygen Demand (1)	mg/L	9	11,150	4,669	5,297	20,069
Nitrite & Nitrate (as N)	mg/L	9	20	3	17	25
Total Kjeldahl Nitrogen (as N)	mg/L	9	301	170	137	675
Total Nitrogen (as N)	mg/L	9	321	171	154	695
Total Phosphorus (as P)	mg/L	9	57	31	25	113

Note 1. Calculated by using a COD/BOD_5 ratio of 1.45 in FWP effluent (de Koning & van der Graaf, 1996).

Analyses for Oil and Grease (O&G) were not undertaken because discussions with Australian Laboratory Services indicated that the analytical methods used would be unlikely to provide true measures of the total Oils and Greases in food waste effluent from the FWP unit.

The only investigations that discussed Oil & Grease contributions from the operation of FWP units were from Sydney (Sinclair Knight, April 1990) and a recent study undertaken in New York City (NYC, late 1990s). Sinclair Knight (April 1990) used a range of 2.7 to 7.7 g/capita/day O&G from the operation of residential FWP units. These values were obtained from the literature. NYC (late 1990s) measured a mean value of 2.66 g/person/day from three residential areas. This value agrees with the lower value assumed by Sinclair Knight (April 1990). However, the investigation described in this report uses the Sinclair Knight (April 1990) range of values, ie 2.7 to 7.7 g/capita/day, to provide conservative estimates because Oil & Grease measurements were not undertaken.

Comparison of the data in Tables 4.5 and 4.6 show that there are major differences between the results from this investigation and those calculated from the data presented by other investigators.

TABLE 4.6 Quality of FWP Effluent Reported by Other Investigators

Source	Units	NFR	BOD_5	COD	O&G
de Koning & van der Graaf, 1996	mg/L	10,667	11,648	16,889	
Griffith University, 1994	mg/L	10,369	7,524	-	
NYC, late 1990s	mg/L	5,634	8,078	12,128	707
Sinclair Knight, April 1990	mg/L	6,356	4,000	-	600-1700

There are large differences in pollutant concentrations used by various investigators. Concentrations of NFR (reported as Suspended Solids by Australian Laboratory Services) in FWP effluent as used by investigators in the Netherlands (de Koning & van der Graaf, 1996) and Australia (Griffith University, 1994) are about twice as high as the mean value shown in Table 4.5. However, the NFR values used by NYC (late 1990s) and Sinclair Knight (April 1990) are similar to the mean value measured in this investigation. The COD and BOD_5 concentrations used in the Netherlands by de Koning & van der Graaf (1996) were similar to the mean value measured in this investigation. However, concentrations of these pollutants calculated from the other investigations are considerably lower than the mean value used in this investigation. The lowest value (4,000 mg/L) was that calculated from the Sinclair Knight (April 1990) report.

It should be noted that this investigation, the Griffith University (Griffith University, 1994) investigation and the New York City investigation (NYC, late 1990s) are based on experimental data. However, the New York City study monitored sewers, which is considered to be unreliable because of the small and irregular slugs of FWP effluent which would likely occur compared to normal sewage flows. The results from the other investigations cited in this report are based on generic literature values or, in the case of de Koning & van der Graaf (1996), on theoretical calculations.

Pollutant loads from the use of FWP units were calculated using the mean values presented in Section 4.1.2 and are shown in Table 4.7.

TABLE 4.7 Current and Future Pollutant Loads from FWP Units

Market Penetration	Pollutant Load (kg/d)					
	NFR	BOD_5	COD	TKN	TP	O&G
Current-5%	22	41	60	1.1	0.2	3.4-9.6
Future-15%	65	124	180	3.4	0.6	6.7-19
Future-25%	108	207	300	5.6	1.1	17-48
Future-50%	216	413	599	11	2.1	34-96

4.2 Impacts from the Use of FWP Units on the Occurrence of Sewage Overflows

Sewage overflows during wet weather are mainly caused by excess infiltration and inflows of rainwater into sewerage systems, although loss of pipe capacity due to siltation and blockages can also be a factor.

The Sewage Overflows Licensing Project Environmental Impact Statement for the BOOS System (Sydney water, June 1998) states that environmental impacts from overflows from the BOOS, including discharges from Bondi STP, are localised and not major in extent. For example, the BOOS has been estimated to contribute only 2% of nutrients to Port Jackson, compared to about 50% from the Northern Suburbs Ocean Outfall Sewer (NSOOS) and the Southern and Western Suburbs Ocean Outfall Sewer (SWSOOS).

The Impact Statement (Sydney Water, June 1998) that the Waverley-Bondi Eastern Slopes Intercepting Sewer has a low likelihood of infiltration, low rainfall ingress, low leakage severity and low frequency of chokes. There are five reticulation nodes and no design overflow structures along the Waverley-Bondi Eastern Slopes Intercepting Sewer, although there are five design overflow structures located within the southern reticulation area. Modelling has shown that the reticulation nodes are only ranked 14th out of 16 in the BOOS System and 61st when compared to Sydney wide reticulation overflows. During the ten year modelling period (January 1985 to December 1994), the overflow volume from the reticulation nodes was predicted to be 143 ML, which represented 3% of the total overflow volume from the BOOS System.

The Waverley-Bondi Eastern Slopes Intercepting Sewer does not significantly affect water quality at Bondi and Bronte Beaches, which are considered to be sensitive areas. Furthermore, no bypasses of partially treated sewage from Bondi STP occurred from 1993 to 1998. Sewer modelling has predicted that only one bypass of 8.9 ML with a duration of 5.5 hours would occur during the ten year period that was modelled (Sydney water, June 1998).

The percent contributions of flows from FWP units on the Waverley-Bondi Eastern Slopes Intercepting Sewer as a function of the Instantaneous Maximum Flow in the sewer (618 L/s, refer Table 3.1) are shown in Table 4.8. FWP flows are provided in Table 4.3.

TABLE 4.8 Percent Flow Contribution of FWP Units on the Waverley-Bondi Eastern Slopes Intercepting Sewer

Market penetration	% Flow Contribution (Instantaneous Max Flow)
Current-5%	0.007
Future-15%	0.02
Future-25%	0.04
Future-50%	0.07

These results reinforce the conclusion that flows contributed by FWP units in the Waverley Catchment study area for any of the adopted market penetration levels would be very small compared to wet weather flows that flow in the Waverley-Bondi Eastern Slopes Intercepting Sewer. Even for 50% market penetration, FWP units would only contribute an extra 0.07% flow to the Instantaneous Maximum Flow in the sewer.

In principal, any additional flows would result in sewage overflows if the sewer is flowing at full or very nearly full capacity. Therefore, additional flows from the operation of FWPs could result in wet weather sewage overflows. However, flows from FWP units are extremely small compared with the increase in sewage flows that can result during wet weather. For example, at 50% market penetration FWP units would contribute 0.037 ML/d compared to the difference between Mean and Maximum Average Daily Flows of about 6.5 ML/d (refer Table 3.1).

Furthermore, the very small increases in overflows from FWP units would be offset by the reduced sewage flows that have been occurring since 1990/91 and will continue to occur for the next ten to twenty years as a result of the Demand Management Strategy implemented by Sydney Water.

Water quality data are not available for the Waverley-Bondi Eastern Slopes Intercepting Sewer. Calculations using NFR data from the BOOS (refer Table 3.2) indicate that even for 50% market penetration, FWPs would only contribute an additional 15% to the NFR load in the Waverley-Bondi Eastern Slopes Intercepting Sewer. Furthermore, the wet sieve analysis results (refer Table 4.4) show that 91% of the solids in FWP effluent are less than 1 mm in size. Ground kitchen food waste has a density approximately equal to water and easily remains suspended in moving sewage (de Koning & van der Graaf, 1996). Therefore, the relatively low additional load of particles of this small size would be unlikely to clog or become deposited in sewers or plumbing pipes.

This conclusion agrees with those from the Netherlands, which has flat sewer systems (de Koning & van der Graaf, 1996), and Sweden (Nilsson et al, 1990). Nilsson et al (1990) also stated that there was "no blockage of indoor installations", ie house service lines. Furthermore, the In-Sink-Erator FWP operating instructions clearly specify that cold water should be used to flush food through FWP units and that hot water should not be used. De Koning & van der Graaf (1996) state that the concern that grease and fats will clog sewers is not valid because the use of cold water causes grease and fat in food wastes to congeal and become attached to other ground food waste particles. Investigations in New York City have also shown that no observable deposits of solids were observed in combined sewers in areas where FWPs are used (NYC, late 1990s).

There does not appear to be any sound evidence in the literature to suggest that FWPs cause clogging or deposits of solids in pipes. Some investigators have stated that ground bones from

FWP units have a beneficial effect in scouring pipes and enhancing their self-cleansing capabilities (eg de Koning & van der Graaf, 1996).

4.3 Impacts from the Use of FWP Units on the Sewage Treatment Process

It was not considered relevant to estimate the impacts of FWPs in the Waverley Catchment area on Bondi STP as it currently exists, because this would only assess impacts of FWPs in a relatively small part of the catchment served by Bondi STP. For the purposes of this investigation, Bondi STP was scaled-down so that only the capacity corresponding to the treated sewage from the Waverley-Bondi Eastern Slopes Intercepting Sewer was considered.

Bondi STP was scaled-down by assuming that it only treated a flow of 7.314 ML/d, ie the Mean Average Daily Flow from the Waverley-Bondi Eastern Slopes Intercepting Sewer (refer Table 3.1), instead of the current design ADWF of 129 ML/d.

4.3.1 Hydraulic Impacts

The percent contributions of flows from FWP units on the scaled-down Bondi STP are shown in Table 4.9 (refer Table 4.3 for FWP flow data). Data reported in other investigations are also included in this table.

TABLE 4.9 Percent Flow Contributions of FWP Units on Scaled-down Bondi STP

Market Penetration	% Flow Contribution	
	Bondi STP	Other Systems
This Investigation		
Current-5%	0.05	
Future-15%	0.15	
Future-25%	0.25	
Future-50%	0.50	
Current design flow at scaled-down Bondi STP	7.3 ML/d	
Other Investigations		
de Koning & van der Graaf, 1996		
100% penetration		1.35
Griffith University, 1994		
20% penetration-current		0.09
100% penetration		0.4
Sinclair Knight, April 1990 (Note 1)		
5% penetration	0.03	
50% penetration	0.26	

Note 1. Data from Sinclair Knight (April 1990) apply to the entire BOOS System and assume a 26% residential contribution towards total flows in the BOOS whereas data presented for this investigation are for the Waverley-Bondi Eastern Slopes Intercepting Sewer which mainly transports sewage from residences.

The results from this investigation show that flows contributed by FWP units in the Waverley Catchment study area for any of the adopted market penetration levels would be very small compared to the Mean Average Daily Flow treated at the scaled-down Bondi STP. Even for 50%

market penetration, FWP units would only contribute an extra 0.037 ML/d to the scaled-down Bondi STP. This value corresponds to a 0.5% increase in the Mean Average Daily Flow at the scaled-down treatment plant. This value would decrease to 0.03% if the full capacity of Bondi STP was considered.

These small flow increases could in principle cause hydraulic capacities of the existing sewage treatment units and the allowable volume of treated sewage from Bondi STP discharged to the ocean (451 ML/day, EPA Licence) at Bondi STP to be exceeded. However, the flow increases caused by the operation of FWP units are extremely small compared to the increase caused by wet weather (refer Table 3.2).

Influent ADWFs at Bondi STP have decreased by about 15% since 1990/91 as a result of the Demand Management Strategy implemented by Sydney Water (Sydney Water, November 1998). It is possible that influent ADWFs would decrease by an additional 20% during the next ten to twenty years if the Demand Management Strategy continues. This flow decrease would result in corresponding increases in the percent contributions of FWP flows to flows at Bondi STP. However, the resulting percent contributions would still be extremely low and would not result in adverse impacts on the operations of Bondi STP.

Data from this investigation can be compared to data from other cited investigations, as shown in Table 4.9. Although there are differences in the hydraulic impacts of FWPs between this and the other investigations, they can be largely explained by differences in the adopted market penetrations of FWP units, water usages by FWP units and the adopted flows in the sewers. For example, the percent contributions of flows from FWP units are larger for this investigation than for the Sinclair Knight investigation even though the unit water usage for FWPs adopted for this investigation are about 50% less than the value used by Sinclair Knight because of the difference in domestic contributions between this investigation and Sinclair Knight (April 1990). Despite these differences, the results from this investigation agree with those from the other investigations in that increases in flows from the use of FWPs at any of the adopted market penetration levels are very small.

4.3.2 Impacts of Pollutants

Pollutant Impacts

The percent contributions of pollutants from FWP units on the scaled-down Bondi STP are shown in Table 4.10 (refer Table 4.7 for FWP pollutant loads).

TABLE 4.10 Percent Pollutant Contributions of FWP Units on Scaled-down Bondi STP

Market Penetration	% Pollutant Contribution at STP					
	NFR	BOD_5	COD	TKN	TP	O&G
This Investigation (at scaled-down Bondi STP)						
Current-5%	2	3	2	0	0	1-3
Future-15%	5	10	6	1	1	2-7
Future-25%	8	16	11	2	2	6-17
Future-50%	15	33	22	4	5	12-35
Current influent sewage loads to scaled-down Bondi STP (kg/d)	1,440	1,265	2,780	270	40	280
Other Investigations						
de Koning & van der Graaf, 1996						
5% penetration	1	4	2	0.6	-	
50% penetration	10	41	22	5	-	
Griffith University, 1994						
20% penetration-current	4	3	-	-	-	
100% penetration	18	16	-	-	-	
NYC, late 1990s						
49.4% penetration (Queens)	7	8	42	55	28	38
Sinclair Knight, April 1990						
5% penetration	1.1	0.6	-	-	-	0.3-2
50% penetration	11	6	-	-	-	3-8

It should be noted that this investigation, the Griffith University (Griffith University, 1994) investigation and the New York City investigation (NYC, late 1990s) are based on experimental data. The results from Sinclair Knight, April (1990) are based on generic literature values whereas de Koning & van der Graaf (1996), used theoretical calculations.

The impacts of pollutants from the operation of FWPs are higher than corresponding hydraulic impacts. Nevertheless, additional loads of pollutants contributed by FWP units would generally be considerably smaller at most of the adopted market penetration levels compared to total loads received at the scaled-down Bondi STP

Effluent data from Bondi STP (refer Appendix 2) indicate that the mean annual concentration for Oil and Grease was closer to the EPA licence limit than for the other pollutants. The mean annual effluent Oil and Grease concentration was 23 mg/L[1] compared to the 50 percentile EPA licence

[1] Recently available data for the 1999 - 2000 financial year indicate the Oil and Grease concentration in the Bondi STP effluent to be 26 mg/l, which is higher than the 1999 calendar year figure of 23mg/l used in this study. Whereas the Oil and Grease attributable to FWPs at a market penetration of 15% would still be unlikely to result in the EPA licence conditions being exceeded, this increased value is cause for concern and may necessitate earlier capital works if the background influent Oil and Grease concentration continues to increase.

limit of 30 mg/L. It is considered that increases of less than 10% in pollutant loads, including Oil and Grease, are within the range of design and operational variance at sewage treatment plants and could be handled at Bondi STP without resulting in operational problems or the need for capital upgrades. An increase of 10% Oil and Grease could increase effluent concentrations by about 2 mg/L, resulting in a mean average effluent concentration of about 25 mg/L, if the rate of chemical dosing for the chemically assisted sedimentation process is not varied. This slightly increased effluent concentration is about 15% less than the EPA licence limit.

The BOD_5 and Oil and Grease results in Table 4.10 indicate that a FWP market penetration of up to 15% should not cause operational problems at Bondi STP. It should be noted that a maximum increase of no more than 7% would be expected for Oil and Grease at this market penetration, which could increase the mean effluent concentration by less than 2 mg/L. Similarly, based on the NFR results, a FWP market penetration of up to 20% would not be expected to cause problems at Bondi STP.

Despite differences in assessment methods and assumptions, the percent contribution of NFR calculated for this investigation is slightly larger than those reported by the other cited investigations. The results for BOD_5, COD and TKN from this investigation agree closely with those from the Netherlands (de Koning & van der Graaf, 1996). However, the percent contributions of BOD_5 and Oil & Grease are considerably larger than those calculated by Griffith University (1994), NYC (late 1990s) and Sinclair Knight (April 1990).

<u>Biosolids Production</u>

Biosolids produced as a result of the operation of FWP units in Waverley Catchment are shown in Table 4.11. These calculations assume 51% removal of suspended solids during primary sedimentation (refer Table 3.2), 28% and 72% fixed and volatile solids in primary sludge, respectively, 50% volatile solids destruction during digestion, 3.5% solids concentration in digested sludge and 28% solids concentration in dewatered sludge. This dewatered solids concentration value was obtained from the dewatering design criteria for the proposed Bondi STP upgrade (Sydney Water, November 1998 and April 1999).

TABLE 4.11 Biosolids Produced by FWPs in Waverley Catchment and Removed at Bondi STP

Market penetration	Sludge after Digestion (Kg/d dry weight)	Dewatered Biosolids (cubic metres)	Dewatered Biosolids % Increase
Current-5%	7	0.03	2
Future-15%	21	0.08	4
Future-25%	35	0.13	6
Future-50%	71	0.25	12

The volumes of dewatered biosolids which would be produced by the operation of FWPs in Waverley Catchment are small. Bondi STP currently produces about 35 cubic metres of dewatered biosolids daily. This quantity would reduce to about 2 cubic metres per day for the scaled-down plant. Therefore, a 50% FWP market penetration would result in about 12% additional biosolids being produced. The same increase in sludge produced from the primary sedimentation tanks would be expected. These increases are considered to be marginally undesirable. It is considered that at all FWP market penetrations studied up to 25%, the performances of sludge digesters, dewatering centrifuges and biosolids trucking movements are not adversely impacted to a measurable extent.

Sulphide production

Sulphide can be a major contributor to odours, corrosion and safety problems in sewerage systems. Sulphide generation is affected by several factors, including the concentration of readily biodegradable organics, sulphate concentration, dissolved oxygen levels, temperature, pH and sewage flow velocities.

Calculations of hydrogen sulphide generation using the Pomeroy equation for gravity sewers undertaken by Sydney Water for this project (refer Appendix 3) indicate that effluent from FWPs at a market penetration of 50% would result in about 30% increase in hydrogen sulphide generation in the Waverley-Bondi Eastern Slopes Intercepting Sewer. This increase would be caused by the increase in BOD_5 concentration assuming that all other factors remain the same. Proportionally lower increases in hydrogen sulphide generation would be expected at lower FWP market penetrations.

The Waverley-Bondi Eastern Slopes Intercepting Sewer is constructed of a combination of brick and concrete sections whereas the section of the BOOS downstream of the confluence with the Waverley-Bondi Eastern Slopes Intercepting Sewer is constructed of brick with much of the lower sections being rendered concrete. The Waverley-Bondi Eastern Slopes Intercepting Sewer is understood to be in good condition. However, the lower section of the BOOS between Mitchell Street and Wairoa Avenue, Bondi, ie downstream of the confluence with the Waverley-Bondi Eastern Slopes Intercepting Sewer, is currently being repaired. The brickwork is being repointed because mortar between the bricks in this section has eroded as a result of damage caused by hydrogen sulphide during the last 100 or so years since the BOOS was constructed. Hence the rate of attack by hydrogen sulphide has not been rapid. The lower concrete- rendered sections of the BOOS have not been damaged because they are submerged by sewage.

The generation and impacts of hydrogen sulphide in sewers is complex and depends on several factors apart from increases in BOD_5. It is not possible to quantify these effects or to estimate an upper FWP penetration rate that should not be exceeded. Nevertheless, it is considered that any increase in hydrogen sulphide generation could lead to corrosion problems, particularly as these problems have been occurring in the past.

4.4 Impacts from the Use of FWP Units on Biosolids Reuse

The contaminant results of biosolids from Bondi STP for the third quarter of 1999 are shown in Appendix 4. Biosolids have a contaminant grading of C according to the draft EPA biosolids guidelines (EPA, October 1995) and can be beneficially used on agricultural and forest areas. Sydney water has advised that all biosolids from Bondi STP are applied to agricultural lands.

It is unlikely that the small additional quantities of biosolids which would be produced by FWPs in Waverley Catchment would affect the current contaminant grading or the current reuse options for biosolids from Bondi STP. This conclusion agrees with the statement in Sinclair Knight (April 1990) that “the characteristics of sludge will not change with the addition of domestic food waste to the sewerage system”.

4.5 Impacts from the Use of FWP Units on the Marine Environment in Disposal of Uncaptured Portion of Food Wastes

The settleable solids results from the laboratory investigation (refer Tables 4.4 and 4.5) demonstrate that FWP solids settle readily under gravity. In fact, several investigators (as cited in Sinclair Knight, April 1990) have stated that the addition of FWP solids enhances settling characteristics of sewage. At least half of the FWP solids would be expected to be removed in the primary sedimentation tanks at Bondi STP.

The pollutant loads that would be expected to escape the treatment process and be discharged to the ocean are shown in Table 4.12, assuming 51% removal of suspended solids during primary sedimentation (refer Table 3.2). The following removal efficiencies were assumed for the other pollutants: BOD_5 and COD – 30%, TKN and Total Phosphorus – 10% (Metcalf & Eddy, 1991) and Oil & Grease – 51%. The uncaptured pollutants at the scaled-down Bondi STP were calculated using annual mean effluent data for 1999 (refer Appendix 2). It should be noted that effluent BOD_5 and COD are not monitored. Percent load increases are shown in parentheses.

TABLE 4.12 Uncaptured Pollutants at Bondi STP

Market Penetration	Pollutant Load (kg/d)					
	NFR	BOD_5	COD	TKN	TP	O&G
Current-5%	11	29	42	1	0.2	1.7-4.7
Future-15%	32 (5)	87	126	3 (1)	0.5 (1)	3.3-9.4 (2-6)
Future-25%	53 (8)	145	210	5 (2)	1 (2)	8.2-24 (5-14)
Future-50%	106 (15)	289	419	10 (4)	2 (5)	16-47 (10-28)
Current uncaptured pollutants at scaled-down Bondi STP	704	-	-	279	40	167

Note: Percent load increases are shown in parentheses.

These data indicate that, with the possible exception of Oil & Grease, there would be less than 10% increase of solids and attached pollutants to the ocean from the scaled-down Bondi STP as a result of the operation of FWP units in the Waverley Catchment area for market penetrations of up to 25%. The data also indicate that very low additional discharges of TKN and Total Phosphorus would be experienced at any of the adopted FWP market penetrations.

If Oil & Grease concentrations in FWP effluent were shown to be particularly high, FWP market penetrations greater than 20% could cause excessively high additional discharges of this pollutant to the ocean assuming that increased discharges of Oil & Grease loads should be kept to 10% or less. Similarly, excessively high increases in BOD_5 discharges would be experienced at market penetrations greater than about 30%.

These comments should be regarded as only being indicative in nature in the absence of water quality modelling results. However, the EPA licence for Bondi STP permits the discharge of a total of up to 451 ML/d of treated effluent from the deep ocean and shoreline ocean outfalls. Furthermore, the discharge of treated effluent through the deep ocean outfall is subject to the following two criteria:

- Ammonia Nitrogen concentrations should be less than 0.6 mg/L as six monthly median values at the edge of the mixing zone (EPA, 1993).
- The outfall should provide dilution of at least 400:1 at the edge of the mixing zone (Sydney Water, January 1996).

The maximum allowable Ammonia Nitrogen concentration at the edge of the mixing zone is the product of the maximum allowable Ammonia Nitrogen concentration values at the edge of the mixing zone (0.6 mg/L) and the dilution ratio (400), ie 240 mg/L.

This value can be compared with the estimated Ammonia Nitrogen concentration in Bondi STP effluent that includes FWP effluent. If it is assumed that the Ammonia Nitrogen concentration in Bondi STP effluent increases by 4% as a result of added effluent from FWPs at 50% market penetration, the mean and maximum Ammonia Nitrogen concentrations in Bondi STP effluent would be 27 and 31 mg/L, respectively (refer Appendix 2 for measured effluent quality data). This assumption for the percentage increase is the same as for TKN (refer Table 4.12). It is considered to be valid because FWP effluent would not contribute a large proportion of the effluent discharged to the ocean and the Ammonia Nitrogen to TKN ratio in raw sewage and treated effluent is almost the same (0.66 and 0.67, respectively). Therefore, there is little change in nitrogen characteristics during treatment.

These estimated Ammonia Nitrogen concentrations in Bondi STP effluent that includes FWP effluent (50% market penetration) are almost an order of magnitude lower than the maximum allowable Ammonia Nitrogen concentration at the edge of the mixing zone. Therefore, effluent from FWPs at any of the adopted market penetrations would have negligible impacts on the discharge of effluent to the ocean from Bondi STP in terms of the EPA discharge criteria.

4.6 Energy Consumption Required in Sewage Transport, Treatment and Biosolids Processing

Petre (1999) states that the energy requirements by Sydney Water for providing sewerage services in the Sydney region during the 1998/99 financial year was 325 kWh per million litres of sewage treated. It is understood that this figure should be increased to 405 kWh per million litres of sewage treated to allow for sewage pumping stations, which are not included in the quoted figure.

Although the above energy requirements are not specific to any sewerage system, they can be used to obtain an estimate of the energy requirements by Sydney Water for treating FWP effluent at the scaled-down Bondi STP.

The energy requirements for transporting and treating effluent from FWPs at 50% market penetration (0.037 ML/d) and at the scaled-down Bondi STP (7.314 ML/d Mean Average Daily Flow) are 15 and 2960 kWh/day, respectively. These values indicate that even at the maximum adopted market penetration of 50%, transport and treatment of FWP effluent would only require an additional 0.5% energy.

Major energy uses at Bondi STP are for pumping primary effluent to achieve the necessary head for discharge through the deep water ocean outfall, odour control and ventilation, biosolids dewatering centrifuges and sludge pumping systems. No energy consumption data are available for these individual processes. However, the results of this investigation indicate that most of the additional energy required to transport and treat FWP effluent at Bondi STP would be required for sludge treatment.

5 Conclusions

This investigation was undertaken for Waverley Catchment, which exists in the Waverley Local Government Area. Waverley Catchment has a population of 24,900 living in 11,954 residential dwellings.

The following FWP scenarios were adopted:
- Current situation (a 5% FWP market penetration was assumed).
- Future situations using market penetrations of 15, 25 and 50%.

The choice of market penetrations of up to 50% is considered to cover all possible market penetration scenarios. This study also assumes that all of the FWPs will be used every day for each of the adopted market penetrations. This may not be the case as people are not at home all of the time and do not eat all meals at home.

Conclusions with respect to the study objectives are as follows:

5.1 Current and Anticipated Future Loads on the Sewerage System from the Use of FWP Units

- The specific water usage by each FWP unit used in this investigation was 6.2 L/household/d or 2.95 L/person/d. These values are conservative because they are higher than the values obtained from the laboratory investigation. However, they are lower than those used in overseas investigations. They are also about 50% larger than the value reported by Griffith University and 50% less than the value in the Sinclair Knight report.

- There were major differences in concentrations and loads of pollutants in FWP effluent between this investigation and those used by other investigators. In particular, the mean NFR, BOD_5 and COD concentration measured in this investigation differed by up to three times when compared to literature values.

- Only this, the Griffith University (Griffith University, 1994) and the New York City investigations (NYC, late 1990s) are based on local experimental data. However, the New York City study monitored sewers, which is considered to be unreliable because of the small and irregular slugs of FWP effluent which would likely occur compared to normal sewage flows. The results from the other investigations cited in this report are based on generic literature values or theoretical calculations.

5.2 The Positive and Negative Macro Environmental Impacts from the Use of FWP Units in Terms of Impacts on:

(a) The Occurrence of Sewage Overflows

- Flows contributed by FWP units in the Waverley Catchment study area for any of the adopted market penetration levels would be very small compared to wet weather flows in the Waverley-Bondi Eastern Slopes Intercepting Sewer. Even for 50% market penetration, FWP units would contribute less than 0.1% flow to the Instantaneous Maximum Flow in the sewer.

In principal, any additional flows would result in sewage overflows if the sewer is flowing at full or very nearly full capacity. Therefore, additional flows from the operation of FWPs could result in wet weather sewage overflows. However, flows from FWP units at any of the adopted market penetrations are extremely small compared with the increase in sewage flows that can result during wet weather.

- There would not be expected to be problems with solids deposition or clogging in the sewer at any of the adopted FWP market penetrations.

- These conclusions agree with those from overseas and other Australian investigations.

(b) The Sewage Treatment Process

<u>Hydraulic Impacts</u>

- Flows contributed by FWP units in the Waverley Catchment study area for any of the adopted market penetration levels would be very small compared to the flow treated at the scaled-down Bondi STP. Even for 50% market penetration, FWP units would only contribute an extra 0.5% to the Mean Average Daily Flow at the scaled-down treatment plant.

  These small flow increases could in principal cause hydraulic capacities of the existing sewage treatment units and the allowable volume of treated sewage from Bondi STP discharged to the ocean (451 ML/day, EPA Licence) at Bondi STP to be exceeded. However, the flow increases caused by the operation of FWP units are extremely small compared to the increase caused by wet weather.

  This conclusion agrees with other investigations.

<u>Impacts of Pollutants</u>

- The impacts of pollutants from the operation of FWPs are higher than the corresponding hydraulic impacts.

- The BOD_5 and Oil and Grease results indicate that a FWP market penetration of up to 15% should not cause operational problems at Bondi STP. Similarly, based on the NFR results, a FWP market penetration of up to 20% is not expected to cause problems. These conclusions assume that increases of less than 10% in pollutant loads are within the range of design and operational variance of sewage treatment plants and could be handled at Bondi STP without resulting in operational problems or the need for capital upgrades.

  Effluent data from Bondi STP (refer Appendix 2) indicate that the mean annual concentration for Oil and Grease was closer to the EPA licence limit than for the other pollutants. An increase of 10% Oil and Grease could increase effluent concentrations by about 2 mg/L, resulting in a mean average effluent concentration of about 25 mg/L, if the rate of chemical dosing for the chemically assisted sedimentation process is not varied. This slightly increased effluent concentration is about 15% less than the EPA licence limit of 30 mg/L.

- A 50% FWP market penetration would result in about 12% additional biosolids being produced. Therefore, a FWP market penetration of up to 25% would not be expected to lead to adverse performance of sludge digesters, dewatering centrifuges and biosolids trucking movements to a measurable extent. This 25% limit is larger than the limiting penetration of 15% which is determined by the BOD_5 and Oil & Grease results, as discussed above.

- Calculations of hydrogen sulphide generation using the Pomeroy equation for gravity sewers undertaken by Sydney Water for this project indicate that effluent from FWPs at a market penetration of 50% would result in about 30% increase in hydrogen sulphide generation in the Waverley-Bondi Eastern Slopes Intercepting Sewer. This increase would be caused by the increase in BOD_5 concentration assuming that all other factors remain the same. Proportionally lower increases in hydrogen sulphide generation would be expected at lower FWP market penetrations.

  The generation and impacts of hydrogen sulphide in sewers is complex and depends on several factors apart from increases in BOD_5. It is not possible to quantify these effects or to estimate an upper FWP penetration rate that should not be exceeded. Nevertheless, it is considered that any increase in hydrogen sulphide generation could lead to corrosion and odour problems, particularly as these problems have been occurring in the past.

(c) Biosolids Reuse

- It is unlikely that the small additional quantities of biosolids which would be produced by FWPs at any of the adopted market penetrations would affect the current contaminant grading or the current reuse options for biosolids from Bondi STP.

(d) Marine Environment in Disposal of Uncaptured Portion of Food Wastes

- Effluent from FWPs at any of the adopted market penetrations would have negligible impacts on the discharge of effluent to the ocean from Bondi STP in terms of the EPA discharge criteria. These criteria are specified in terms of the maximum allowable Ammonia Nitrogen concentration and the minimum dilution ratio at the edge of the mixing zone.

(e) Energy Consumption

- The results indicate that even at the maximum adopted market penetration of 50%, transport and treatment of FWP effluent at Bondi STP would only require an additional 0.5% energy.

6 References

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7 APPENDIX 1 - Results of Laboratory Investigation

AUSTRALIAN LABORATORY SERVICES P/L
A.C.N. 009 936 029

ANALYTICAL REPORT

LABORATORY: ENV SYDNEY
BATCH NUMBER: ES21929
SUB BATCH: 0
No. OF SAMPLES: 12
DATE RECEIVED: 28/03/00
DATE COMPLETED: 06/04/00

CONTACT: SANDEEP CHUGH
CLIENT: .
ADDRESS: CRC FOR WASTE MANAGMENT & POL.

ORDER No.:
SAMPLE TYPE: WATER
PROJECT:

Method	Analysis description	Units	LOR	BATCH 1A	BATCH 2A	BATCH 3A	BATCH 1B
EA-025	Suspended Solids (SS)	mg/L	1	2910	6150	7730	3070
EA-034	Settleable Solids	mg/L	1	----	----	----	----
EK-059A	Nitrite and Nitrate as N	mg/L	0.01	16.7	25.1	19.4	17.2
EK-061A	Total Kjeldahl Nitrogen as N	mg/L	0.1	137	285	292	144
EK-062A	Total Nitrogen as N	mg/L	0.1	154	310	311	161
EK-067A	Phosphorus as P - Total	mg/L	0.01	25.4	73.8	49.1	27.2
EP-026	Chemical Oxygen Demand	mg/L	1	8520	17.6 g/L	17.8 g/L	10.4 g/L

COMMENTS:

TKN & Total phosphorus spike recoveries for sample BATCH 1A not determined due background levels of these analytes. This report supersedes any previous preliminary reports of the same batch number.

• This is the Final Report which supersedes any preliminary reports with this batch number.

• Results apply to sample(s) as submitted by client.

ANALYTICAL REPORT

LABORATORY: ENV SYDNEY
BATCH NUMBER: ES21929
CONTACT: SANDEEP CHUGH
SUB BATCH: 0
CLIENT: .
No. OF SAMPLES: 12
ADDRESS: CRC FOR WASTE MANAGMENT & POL.
DATE RECEIVED: 28/03/00
DATE COMPLETED: 06/04/00

ORDER No.:
SAMPLE TYPE: WATER
PROJECT:

Method	Analysis description	Units	LOR	BATCH 2B	BATCH 3B	BATCH 1C	BATCH 2C
EA-025	Suspended Solids (SS)	mg/L	1	8490	5940	2680	7150
EA-034	Settleable Solids	mg/L	1	----	----	----	----
EK-059A	Nitrite and Nitrate as N	mg/L	0.01	21.1	18.6	17.1	23.9
EK-061A	Total Kjeldahl Nitrogen as N	mg/L	0.1	398	289	137	351
EK-062A	Total Nitrogen as N	mg/L	0.1	419	308	154	375
EK-067A	Phosphorus as P - Total	mg/L	0.01	94.0	48.9	24.8	113
EP-026	Chemical Oxygen Demand	mg/L	1	14.9 g/L	29.1 g/L	7680	21.1 g/L

COMMENTS:

- This is the Final Report which supersedes any preliminary reports with this batch number.
- Results apply to sample(s) as submitted by client.

AUSTRALIAN LABORATORY SERVICES P/L
A.C.N. 009 936 029

ANALYTICAL REPORT

LABORATORY: ENV SYDNEY
BATCH NUMBER: ES21929
SUB BATCH: 0
No. OF SAMPLES: 12
DATE RECEIVED: 28/03/00
DATE COMPLETED: 06/04/00

CONTACT: SANDEEP CHUGH
CLIENT: -
ADDRESS: CRC FOR WASTE MANAGMENT & POL.

ORDER No.:
SAMPLE TYPE: WATER
PROJECT:

Method	Analysis description	Units	LOR	BATCH 3C	1 SETTLEABLE	2 SETTLEABLE	3 SETTLEABLE
EA-025	Suspended Solids (SS)	mg/L	1	8390	----	----	----
EA-034	Settleable Solids	mg/L	1	----	3520	3890	2570
EK-059A	Nitrite and Nitrate as N	mg/L	0.01	19.9	----	----	----
EK-061A	Total Kjeldahl Nitrogen as N	mg/L	0.1	675	----	----	----
EK-062A	Total Nitrogen as N	mg/L	0.1	695	----	----	----
EK-067A	Phosphorus as P - Total	mg/L	0.01	58.3	----	----	----
EP-026	Chemical Oxygen Demand	mg/L	1	18.4 g/L	----	----	----

COMMENTS:

• This is the Final Report which supersedes any preliminary reports with this batch number.

• Results apply to sample(s) as submitted by client.

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Sydney
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Melbourne
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Malaysia
Thailand
Hong Kong

AUSTRALIAN LABORATORY SERVICES P/L
A.C.N. 009 936 029

ANALYTICAL REPORT

LABORATORY: ENV SYDNEY
BATCH NUMBER: ES21929
SUB BATCH: 0
No. OF SAMPLES: 12
DATE RECEIVED: 28/03/00
DATE COMPLETED: 06/04/00

CONTACT: SANDEEP CHUGH
CLIENT: ·
ADDRESS: CRC FOR WASTE MANAGMENT & POL.

ORDER No.: SAMPLE TYPE: QUALITY CONTROL PROJECT:

Method	Analysis description	Units	LOR	BATCH 1A %SPK REC	BATCH 3C CHK	1 SETTLE. CHK	METHOD BLANK 28/03/00
EA-025	Suspended Solids (SS)	mg/L	1	----	----	----	<1
EA-034	Settleable Solids	mg/L	1	----	----	3250	----
EK-059A	Nitrite and Nitrate as N	mg/L	0.01	105 %	----	----	<0.01
EK-061A	Total Kjeldahl Nitrogen as N	mg/L	0.1	Not Det'd	678	----	<0.1
EK-062A	Total Nitrogen as N	mg/L	0.1	----	----	----	----
EK-067A	Phosphorus as P - Total	mg/L	0.01	Not Det'd	60.0	----	<0.01
EP-026	Chemical Oxygen Demand	mg/L	1	----	----	----	<1

COMMENTS:

Results which appear on this report are for laboratory QUALITY CONTROL purposes.

• This is the Final Report which supersedes any preliminary reports with this batch number.

• Results apply to sample(s) as submitted by client.

Multiple Analysis Profile

Test Type I Wet SIV - 6,2.6,1.06 mm (MAP)
Order No 86806 Job No:
Reference
Sample Name 1 WET - 13 ES21929
Sample No. 53058
Date Received 29/03/2000 Total No Pages: 1 of 1
Client: Australian Laboratory Services
Michael Heery
PO Box 63
RYDALMERE NSW 1701

Certified Laboratory Practice
ISO 9002/G25 LIC031 Standards Australia

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Specialists in Soil Chemistry and Agronomy

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Tests are performed under a quality system certified as complying with ISO 9002.
Results & Conclusions assume that sampling is representative. This document shall not be reproduced except in full

SAMPLE	SAMPLE NAME	RESULT	COMMENTS

Wet Sieve Analysis

5.6mm = 5.7%
2.8mm = 0.8%
1mm = 2.2%
<1mm = 91.3%

Checked by Principal.. Consultant....................
Simon Leake Date of Report 06/04/2000 S.Flanagan

Batch No.	Current Uasge (A)	Time (s)	Solid Waste (Kg)	Water Usage (l)	Litres of Water Usage/Kg of Waste
Batch 1	4.2	115	1.487	16.192	10.889
Batch 2	4.2	110	1.762	19.726	11.195
Batch 3	4.1	144	1.984	21.423	10.798

For Each Batch:

The effluent, containing mashed up waste and water, was collected in a 25 l bucket. The effluent was continuously stirred and three (3) random samples were then taken for analysis.

8 APPENDIX 2 - Raw Sewage and Effluent Quality Data for Bondi STP for 1999

Bondi STP

Summary of Raw Sewage Quality for 1999

POLLUTANT	SAMPLES	LOQ	Non Detects	Avg Conc	Std Dev	Min Conc	Max Conc	Units
2-Chloronaphthalene	10	0.0001	10	0.0001	2.66E-12	0.0001	0.0001	mg/L
4,4-DDD	10	0.00001	10	0.00001	2.35E-13	0.00001	0.00001	mg/L
4,4-DDE	10	0.00001	9	0.000015	1.58E-05	0.00001	0.00006	mg/L
4,4-DDT	10	0.00001	10	0.00001	2.35E-13	0.00001	0.00001	mg/L
Acenaphthene	10	0.0001	9	0.00011	3.16E-05	0.0001	0.0002	mg/L
Acenaphthylene	10	0.0001	9	0.0001	2.66E-12	0.0001	0.0001	mg/L
Aldrin	10	0.00001	10	0.00001	2.35E-13	0.00001	0.00001	mg/L
Alkalinity as CaCO3 to pH4.5	10	1	0	154	9.128709	134	164	mg/L
alpha BHC	10	0.00001	10	0.00001	2.35E-13	0.00001	0.00001	mg/L
Ammonia NH3-N	10	0.01	0	24.14	3.415065	18.2	30.1	mg/L
Anthracene	10	0.0001	9	0.00011	3.16E-05	0.0001	0.0002	mg/L
Benzo(a)anthracene	10	0.0001	10	0.0001	2.66E-12	0.0001	0.0001	mg/L
Benzo(a)pyrene	10	0.0001	10	0.0001	2.66E-12	0.0001	0.0001	mg/L
Benzo(b)&(k)fluoranthene	10	0.0001	10	0.0001	2.66E-12	0.0001	0.0001	mg/L
Benzo(b)fluoranthene	10	0.0001	10	0.0001	2.66E-12	0.0001	0.0001	mg/L
Benzo(e)pyrene	10	0.0001	10	0.0001	2.66E-12	0.0001	0.0001	mg/L
Benzo(ghi)perylene	10	0.0001	10	0.0001	2.66E-12	0.0001	0.0001	mg/L
Benzo(k)fluoranthene	10	0.0001	10	0.0001	2.66E-12	0.0001	0.0001	mg/L
beta BHC	10	0.00001	10	0.00001	2.35E-13	0.00001	0.00001	mg/L
BOD5	10	2	0	173.4	84.81378	79	350	mg/L
Chemical Oxygen Demand	10	1	0	380.2	75.10556	307	491	mg/L
Chlorfenvinfos	8	0.0001	8	0.0001	2.38E-12	0.0001	0.0001	mg/L
Chlorfenvinphos (E)	2	0.0001	2	0.0001	0	0.0001	0.0001	mg/L
Chlorfenvinphos (Z)	2	0.0001	2	0.0001	0	0.0001	0.0001	mg/L
Chlorpyrifos (Ethylchlorpyrifos)	2	0.00005	1	0.00014	0.000127	0.00005	0.00023	mg/L
Chlorpyrifos (Ethylchlorpyrifos)	8	0.0001	5	0.000238	0.000192	0.0001	0.0005	mg/L
Chrysene	10	0.0001	10	0.0001	2.66E-12	0.0001	0.0001	mg/L
Coronene	2	0.0001	2	0.0001	0	0.0001	0.0001	mg/L
Coronene	8	0.0005	8	0.0005	0	0.0005	0.0005	mg/L
delta BHC	2	0.00001	2	0.00001	0	0.00001	0.00001	mg/L
Demeton-S-Methyl	10	0.0001	10	0.0001	2.66E-12	0.0001	0.0001	mg/L

Bondi STP

Summary of Raw Sewage Quality for 1999

Diazinon	10	0.0001	3	0.00019	0.00011	0.0001	0.0004	mg/L
Dibenzo(ah)anthracene	9	0.0001	9	0.0001	2.71E-12	0.0001	0.0001	mg/L
Dieldrin	10	0.00001	4	0.000014	5.16E-06	0.00001	0.00002	mg/L
Endrin	10	0.00001	10	0.00001	2.35E-13	0.00001	0.00001	mg/L
Fluoranthene	10	0.0001	9	0.00012	6.32E-05	0.0001	0.0003	mg/L
Fluorene	10	0.0001	10	0.0001	2.66E-12	0.0001	0.0001	mg/L
Guthion (Methyl Azinphos)	10	0.0001	9	0.00012	6.32E-05	0.0001	0.0003	mg/L
Heptachlor	10	0.000005	7	5.6E-06	1.58E-06	0.000005	0.00001	mg/L
Heptachlor Epoxide	10	0.00001	10	0.00001	2.35E-13	0.00001	0.00001	mg/L
Hexachlorobenzene	10	0.00001	10	0.00001	2.35E-13	0.00001	0.00001	mg/L
Indeno-123-CD-pyrene	9	0.0001	9	0.0001	2.71E-12	0.0001	0.0001	mg/L
Lindane (gBHC)	10	0.00001	10	0.00001	2.35E-13	0.00001	0.00001	mg/L
Malathion	10	0.0001	5	0.00025	0.000207	0.0001	0.0007	mg/L
Methoxychlor	10	0.00001	10	0.00001	2.35E-13	0.00001	0.00001	mg/L
Methylene Blue Active Substances	10	0.1	0	6.24	2.927342	2.1	11.1	mg/L
Naphthalene	10	0.0001	2	0.00046	0.000438	0.0001	0.0015	mg/L
Nonylphenolethoxylates	10	0.01	0	0.2044	0.153596	0.018	0.43	mg/L
Oil & Grease using Chloroform	10	5	0	38	8.563488	25	50	mg/L
Palmitic Acid	10	1	2	2.6	1.577621	1	6	mg/L
Perylene	10	0.0001	10	0.0001	2.66E-12	0.0001	0.0001	mg/L
pH Description	10	0.01	0	7.301	0.231106	7.06	7.78	pH units
Phenanthrene	10	0.0001	6	0.00013	6.75E-05	0.0001	0.0003	mg/L
Pyrene	10	0.0001	8	0.00014	9.66E-05	0.0001	0.0004	mg/L
Stearic Acid	10	1	2	1.8	1.032796	1	4	mg/L
Sulphate	10	1	0	70.9	38.88573	43	146	mg/L
Sulphide	10	0.1	2	0.35	0.241523	0.1	0.8	mg/L
Suspended Solid	10	1	0	197.1	24.47879	164	244	mg/L
Total Aluminium	10	0.005	0	0.2896	0.072054	0.2	0.455	mg/L
Total Arsenic	10	0.01	9	0.014	0.012649	0.01	0.05	mg/L
Total Barium	10	0.001	0	0.0377	0.02331	0.026	0.102	mg/L
Total Beryllium	10	0.001	9	0.0089	0.024982	0.001	0.08	mg/L
Total Boron	10	0.01	0	0.093	0.043474	0.04	0.2	mg/L
Total Cadmium	10	0.0001	1	0.00733	0.022021	0.0001	0.07	mg/L
Total Calcium	10	1	0	25.9	6.314885	21	42	mg/L

Bondi STP

Summary of Raw Sewage Quality for 1999

Total Chlordane	10	0.00001	8	0.000011	3.16E-06	0.00001	0.00002	mg/L
Total Chromium	10	0.001	0	0.0133	0.030485	0.002	0.1	mg/L
Total Cobalt	10	0.0001	0	0.0099	0.0292	0.0004	0.093	mg/L
Total Copper	10	0.001	0	0.1249	0.030333	0.085	0.187	mg/L
Total Cyanide	10	0.005	1	0.1006	0.083739	0.005	0.207	mg/L
Total Dissolved Solids	10	1	0	755.4	402.7208	464	1820	mg/L
Total Endosulfan	10	0.00001	10	0.00001	2.35E-13	0.00001	0.00001	mg/L
Total Iron	10	0.1	0	1.63	1.559238	0.4	3.9	mg/L
Total Kjeldahl Nitrogen	10	0.1	0	36.6	6.427026	24.2	46.2	mg/L
Total Lead	10	0.001	0	0.0224	0.028891	0.006	0.079	mg/L
Total Lithium	10	0.001	0	0.0063	0.004244	0.002	0.015	mg/L
Total Magnesium	10	1	0	23.8	15.43301	14	66	mg/L
Total Manganese	10	0.001	0	0.0412	0.023266	0.028	0.105	mg/L
Total Mercury	10	0.0001	7	0.00013	6.75E-05	0.0001	0.0003	mg/L
Total Molybdenum	10	0.001	0	0.0215	0.028668	0.007	0.102	mg/L
Total Nickel	10	0.001	0	0.0134	0.028076	0.002	0.093	mg/L
Total Phosphorus	10	0.01	0	5.824	1.032109	4.24	7.83	mg/L
Total Potassium	10	1	0	18.8	4.638007	14	30	mg/L
Total Selenium	10	0.005	5	0.0124	0.020326	0.005	0.07	mg/L
Total Silver	10	0.001	2	0.0054	0.007427	0.001	0.026	mg/L
Total Sodium	10	1	0	189.5	123.2407	102	519	mg/L
Total Tin	10	0.001	2	0.0016	0.000516	0.001	0.002	mg/L
Total Vanadium	10	0.01	10	0.01	1.96E-10	0.01	0.01	mg/L
Total Zinc	10	0.001	0	0.1128	0.030901	0.086	0.192	mg/L

BONDI STP EFFLUENT
1 JAN 1999 TO 31 DEC 1999

PLANT	SAMPLE	MINIMUM	MEAN	MAXIMU	UNITS	SUBSTANCE
Bondi	13	20.300	25.600	29.700	mg/L	Ammonia Nitrogen
Bondi	365	6.000	22.858	35.000	mg/L	Grease and Oil
Bondi	13	0.010	0.014	0.050	mg/L	Nitrates
Bondi	13	0.010	0.010	0.010	mg/L	Nitrites
Bondi	13	4.490	5.413	7.000	mg/L	Phosphorus (Total)
Bondi	365	56.000	96.279	162.000	mg/L	Suspended Solids (Non-Filterable Residue)
Bondi	13	29.900	38.138	46.400	mg/L	Total Kjeldahl Nitrogen
Bondi	13	0.010	0.014	0.050	mg/L	Total Oxidised Nitrogen (Nitrates & Nitrites)

Sydney WATER

fax message

To	Jeppe Nielsen		
Fax	02 9955 4995	Phone	
From	Phil Evans, Strategy & Product Development Officer-Technical		
Division / Section	WASTEWATER SOURCE CONTROL - CHATSWOOD DX2511W Level 2, Interchange Building, Chatswood NSW		
Fax	(02) 9952 0300	Phone	(02) 9952 0303 or 9952 0500
Date	22 May 2000	Number of pages including cover	1

Message - Bondi STP Suspended Solids Removal Efficiency for 1999

R.E. = (Influent – Effluent)/Influent
Mean = 0.51
10-Percentile = 0.40, 50-Percentile = 0.52, 90-Percentile = 0.61

Influent
Mean = 201mg/L,
10-Percentile = 154mg/L, 50-Percentile = 204mg/L, 90-Percentile = 244mg/L

Effluent
Mean = 96mg/L,
10-Percentile = 78mg/L, 50-percentile = 96mg/L, 90-Percentile = 114mg/L

Regards,

Phil

Phil Evans
Ref: JN22may2k.doc

9 APPENDIX 3 - Calculations of Hydrogen Sulphide Generation Undertaken by Sydney Water

Calculation of Rate of Sulphide Generation

The calculations shown below, show that at 50 % market penetration of WDU's in the Waverley Council area the incremental change in sulphide generation due to the increase in BOD is ~ 30% other factors being the same

Number of properties	11,954
Flow Data Mean Average Daily Weather Flow (Table 3.1 page 3)	7314 kL/d
BOD Influent Data (Table 3.2 page4, In-Sinkerator Report)	**173 mg/L**
Expected BOD contribution from 50% market penetration of Waverley Council (Table 4.6 page 8)	413 kg/day
Expected BOD contribtion in mg/L	56.5 mg/L
Expected increase as a % of total BOD	32.6%
Expected BOD	**229.5 mg/L**

Sewer data

Slope	Waverley Bondi Eastern Slopes		0.22 %
Mean Sewage Velocity		min	0.7 m/s
Mean Sewage Velocity		max	1 m/s
Area	Waverley Bondi Eastern Slopes		0.046 m2
Depth	Waverley Bondi Eastern Slopes		0.23 m
Wetted Perimeter			0.35 m

For Gravity Sewers

Predicted Sulphide generation rate of gravity sewers using the Pomeroy and Parkhurst Formula (from EPA Design Manual "Odour and Corrosion Control in Sanitary and Sewerage Systems and Treatment Plants").

dS/dt = M' * EBOD /R - m [S] (s*u)3/8 /dm, mg/L - hr

In this formula the M' is the sulfide generation by the slime layer and assumes that this is the sole source of sulfide. This assumption is fairly accurate, as sulfide generation within the stream of a gravity sewer is usually negligible.
The second term accounts for losses of sulfide due to oxidation in the streamand emission to the sewer atmosphere.

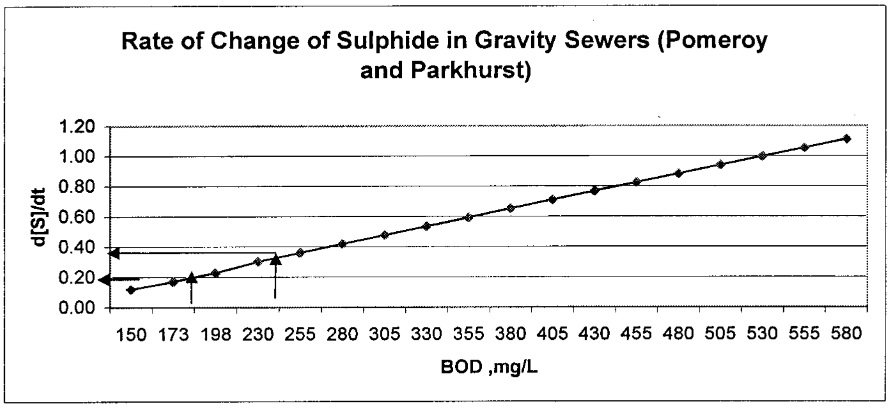
Definitions

M' =	Effective sulfide flux coefficient for sulfide generation by the slime layer in gravity sewers, experimentally determined empirical constant, m/hr
EBOD=	Effective BOD = BOD_5 x 1.07^{T-20}, mg/L
R=	Hydraulic radius, equal to area of flow divided by wetted perimeter (P), m ;where R = Area/perimeter, m
m=	empirical coefficient to account for sulfide losses by oxidation and escape to atmosphere. dimensionless
[S] =	total sulfide conc., mg/L
dm =	mean hydraulic depth, equal to area of flow divided by surface width, (b), m
u=	mean sewage velocity, m/s
s=	slope of energy grade line, m/m

Data

M	0.0003 m/hr	from"Gravity Sanitary Sewer Design and Construction", ASCE, WPCP 1982
T=	20 C	
R	0.13 m	from ARBITER, Sydney Water
m	0.64	from"Gravity Sanitary Sewer Design and Construction", ASCE, WPCP 1982
S	0.4 mg/L	from Year 2000 Sewer Survey, Sydney Water Data
s	0.22 %	from Sydney Water Data , Existing System Performance Report,June 1995, Table A -1
u	0.7 m/s	from Sydney Water Data , Existing System Performance Report,June 1995, Table B -1
dm	0.1 m	from ARBITER, Sydney Water

M	T	BOD	EBOD	R	m	S	s	u	dm	Rate of change of Sulphide ds/dt
0.0003	20	150	150	0.13	0.64	0.4	0.0022	0.7	0.1	0.12
0.0003	**20**	**173**	**173**	**0.13**	**0.64**	**0.4**	**0.0022**	**0.7**	**0.1**	**0.17**
0.0003	20	198	198	0.13	0.64	0.4	0.0022	0.7	0.1	0.23
0.0003	**20**	**230**	**230**	**0.13**	**0.64**	**0.4**	**0.0022**	**0.7**	**0.1**	**0.31**
0.0003	20	255	255	0.13	0.64	0.4	0.0022	0.7	0.1	0.36
0.0003	20	280	280	0.13	0.64	0.4	0.0022	0.7	0.1	0.42
0.0003	20	305	305	0.13	0.64	0.4	0.0022	0.7	0.1	0.48
0.0003	20	330	330	0.13	0.64	0.4	0.0022	0.7	0.1	0.54
0.0003	20	355	355	0.13	0.64	0.4	0.0022	0.7	0.1	0.59
0.0003	20	380	380	0.13	0.64	0.4	0.0022	0.7	0.1	0.65
0.0003	20	405	405	0.13	0.64	0.4	0.0022	0.7	0.1	0.71
0.0003	20	430	430	0.13	0.64	0.4	0.0022	0.7	0.1	0.77
0.0003	20	455	455	0.13	0.64	0.4	0.0022	0.7	0.1	0.82
0.0003	20	480	480	0.13	0.64	0.4	0.0022	0.7	0.1	0.88
0.0003	20	505	505	0.13	0.64	0.4	0.0022	0.7	0.1	0.94
0.0003	20	530	530	0.13	0.64	0.4	0.0022	0.7	0.1	1.00
0.0003	20	555	555	0.13	0.64	0.4	0.0022	0.7	0.1	1.06
0.0003	20	580	580	0.13	0.64	0.4	0.0022	0.7	0.1	1.11


Rate of Change of Sulphide in Gravity Sewers (Pomeroy and Parkhurst)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
d[S]/dt
150 173 198 230 255 280 305 330 355 380 405 430 455 480 505 530 555 580
BOD ,mg/L

10 APPENDIX 4 - Biosolids Quality Data for Bondi STP for 1999

Analytical Samples Summary Report

RESIDUALS MANAGEMENT
BioSoil

Selection Criteria : Specified Period = 1/07/99 to 30/09/99
STP = Bondi, Product = Dewatered (DBN)
Report Profile = Standard

Printed On : 26/10/99 11:09:33

Contaminant	Mean	Std Dev (S)	Mean + 1S	Mean + 2S	Min Value	Max Value	No of Samples
Total Solids %	31.36	1.58	32.93	34.51	28.40	34.60	12
pH (pH units)	7.61	0.20	7.81	8.00	7.20	7.80	12
Conductivity (mS/cm)	1.73	0.35	2.08	2.43	0.91	2.20	12
Total N (Kjeldahl)	34416.67	2874.92	37291.58	40166.50	27000.00	38000.00	12
Nitrate as N	1.00	0.00	1.00	1.00	1.00	1.00	12
Nitrite as N	1.00	0.00	1.00	1.00	1.00	1.00	12
Ammonia N	6666.67	817.24	7483.91	8301.14	5500.00	8100.00	12
Phosphorus (total)	7612.50	668.08	8280.58	8948.66	6330.00	8840.00	12
Calcium	15558.33	1860.33	17418.66	19279.00	12100.00	17600.00	12
Magnesium	2204.17	196.21	2400.38	2596.59	1880.00	2470.00	12
Potassium	901.67	102.41	1004.08	1106.49	690.00	1070.00	12
Sodium	1073.33	156.05	1229.38	1385.43	840.00	1330.00	12
Aluminium	5961.67	441.89	6403.56	6845.45	5230.00	6660.00	12
Arsenic	4.82	0.47	5.29	5.76	3.90	5.40	12
Cadmium	2.87	0.35	3.22	3.57	2.30	3.80	12
Chromium	39.00	5.80	44.80	50.60	30.00	51.00	12
Copper	1081.67	93.40	1175.07	1268.47	940.00	1250.00	12
Iron	12725.00	1190.21	13915.21	15105.41	10900.00	15200.00	12
Lead	297.50	28.96	326.46	355.42	250.00	350.00	12
Mercury	7.48	1.25	8.73	9.98	5.60	9.90	12
Nickel	25.83	2.82	28.66	31.48	22.00	31.00	12
Selenium	7.42	0.95	8.37	9.31	5.80	9.30	12
Zinc	1172.50	109.72	1282.22	1391.94	1020.00	1380.00	12
HCB	0.05	0.00	0.05	0.05	0.05	0.05	12
BHC (other than g-BHC)	0.05	0.00	0.05	0.05	0.05	0.05	12
Lindane	0.05	0.00	0.05	0.05	0.05	0.05	12
Dieldrin	0.23	0.07	0.30	0.36	0.12	0.35	12
Heptachlor	0.05	0.00	0.05	0.05	0.05	0.05	12
DDD	0.05	0.00	0.05	0.05	0.05	0.05	12
DDE	0.05	0.00	0.05	0.05	0.05	0.05	12
DDT	0.05	0.00	0.05	0.05	0.05	0.05	12
Total DDTs	0.05	0.00	0.05	0.05	0.05	0.05	12
PCB	0.17	0.11	0.28	0.39	0.10	0.39	13
Aldrin	0.05	0.00	0.05	0.05	0.05	0.05	12
Chlordane	0.12	0.04	0.15	0.19	0.05	0.17	12

9 Environmental Profiles of the Food Disposal Options

Sub-investigation 2

A Life Cycle Assessment Comparison of the Environmental Impacts of the Disposal System Options.

Sub-Investigation 2 - Contents

1 Introduction to Life Cycle Assessment

1.1 What is LCA?

LCA is a methodology for examining all environmental impacts associated with a product, process or service "from cradle to grave" - from production of the raw materials to ultimate disposal. LCA was developed in order take into account issues that are not addressed by other environmental management tools such as Environmental Impact Assessment. It has proved itself particularly useful as a technique for comparing two or more alternative options in terms of their combined environmental impact and ecological sustainability:

> "Published life-cycle studies are already being used to support a wide variety of public marketing claims, and to drive policy decisions. Some of the most widely publicised of these studies have compared plastic bags to paper bags, disposable diapers to cloth diapers, plastic drinking cups to paper cups, and beverage containers made from glass, aluminium, and plastic. Less publicised, but far more numerous, are the life-cycle studies being conducted ostensibly for internal use only, but which are driving industry and government agency decision making in terms of material selection and product design, and thus are having a direct affect on upstream material suppliers as well as downstream customers and stakeholders." Rhodes & Brown (1997)

1.2 LCA methodology in brief

LCA methodology is being standardised within the ISO framework (ISO 14040 series). This framework consists of four phases:

1. goal and scope definition,
2. inventory analysis,
3. impact assessment, and
4. interpretation,

These phases are all interlinked as shown in Figure 1. A diagrammatic explanation of the methodology appears in Appendix A. In common with other assessment methodologies, LCA is an iterative procedure in which the analyst must first ensure the scope and goal of the analysis are clearly stated, thus "goal definition" is usually referred to as the first step of an LCA.

In the second step, the analyst takes a process engineering mass-balance approach to an entire service supply system or product life-cycle, and gathers information on the individual unit-operations involved. This is known as "inventory analysis" (ISO14041) and the output is a list of resources consumed and wastes produced as a consequence of all the processes involved.

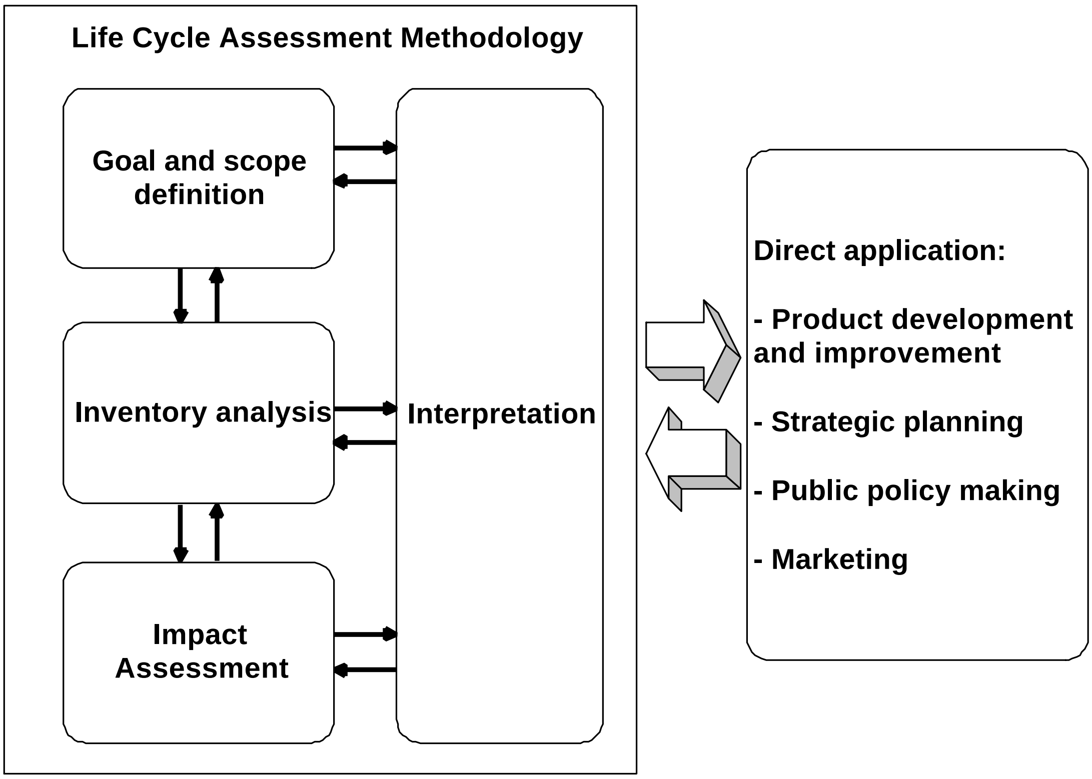


Figure 1: General LCA framework

In the third or "impact assessment" step of LCA, the items in the inventory are associated with aspects or objects of environmental concern. For example, emissions of refrigerants can lead both to global warming and damage to the ozone layer, and would be associated with both these impact categories in an LCA (as shown in Appendix A). Several waste products may have an effect within one impact category, and where appropriate they are normalised in the LCA. For example, methane is 21 times more potent as a greenhouse gas than carbon dioxide[1], so if the only greenhouse gases resulting from a product life-cycle are methane and carbon dioxide, the mass of methane emitted would be multiplied by 21 and added to the mass of carbon dioxide emissions to calculate the global warming potential of the life cycle in carbon dioxide mass-equivalents.

In the final "interpretation" step, the results of the impact assessment are examined to draw conclusions and/or decide whether further analysis is warranted. This may involve sensitivity analysis and statistical determination of whether significant differences exist (ISO 14042).

[1] On a 100-year timescale (IPCC 1996a & 1996b)

2 LCA Goal and Scope Definition

2.1 Goal definition

In-Sink-Erator is the leading supplier of residential, sewer-based food waste disposal systems. In-Sink-Erator approached the Cooperative Research Centre for Waste Management and Pollution Control (CRCWMPC) for assistance regarding an environmental, technical, economic and social assessment of their product. Within this overall project, staff of the Centre for Water and Waste Technology (CWWT) at the University of NSW were asked to perform an environmental life cycle assessment (LCA) of the In-Sink-Erator technology. The aim of this project was to independently assess the environmental profile of the In-Sink-Erator technology on the holistic basis of the ISO14040 standards. In order to reinforce the credentials of the study, and to obtain the necessary data, a steering committee for the project was constituted including representatives of the NSW EPA, Sydney Water, the NSW Waste Boards, Nature Conservation Council, Local Government and Shires Association and In-Sink-Erator. Thus, while the study is the property of In-Sink-Erator, the primary intended audience is the project's steering committee.

2.2 Scope definition

This LCA compares the In-Sink-Erator food waste processor (FWP) system with the alternative options of:

- Home composting;
- Co-disposal of food waste with municipal waste; and
- Centralised composting of green (food + garden) waste.

The functional unit ("fu") definition is the disposal of the food waste produced by a household in one year. This amounts to 182 kg (wet) per annum (BIEC 1998). This corresponds with the average generation of food waste per capita in households (CCWB 2000)[2].

The beneficial use of by-products, such as compost and biosolids (avoided products), is not part of the study.

[2] While food waste generation currently amounts to 210 kg/hh*a, a reduction is predicted to 170 kg/hh*a in the year 2006 (CCWB 2000).

The foreground systems[3] listed above are shown in Figure 2. The study was set in the context of medium to high density residential application of the different waste disposal options in the inner-urban environment of Waverley in Sydney. In setting the system boundaries, the standard LCA principle of following all materials resources from their source in the environment to the system, and following all recurrent emissions to their re-entry to the environment, has been followed. Although in other LCA studies, the non-recurrent (construction) impacts associated with long-lived equipment are generally less important than recurrent impacts, the extent of the capital equipment requirement of each food waste disposal option varies considerably, so it is necessary to include the impact of the manufacture of the equipment or facilities in some way. Assuming data on the assembly or construction processes is not available, it is consistent to take into account the production of materials prior to assembly/construction, where the majority of the impacts generally occur (Clift, 1998). Two approaches to the assessment of the extent of material requirements exist:

1. The incremental approach: account for the additional materials required as a consequence of expansion of existing infrastructure to deal with the processing of the functional unit of the LCA study.

2. The proportional approach: account for the impact of material acquisition for each entire process step and allocate the appropriate proportion of the total to the functional unit.

As the construction of a green waste processing facility for food and garden compostable waste would have to begin from scratch, rather than be an expansion of existing infrastructure, the proportional approach was adopted for this study. This allowed the inventory analysis to be made in a consistent manner across the four options.

Some commonality of unit processes was encountered: co-disposal and centralised composting result in the production of leachates which are disposed to sewer as is the In-Sink-Erator liquor, causing additional incremental impacts due to additional volumes of effluent delivered to the sewage treatment plant. The use of the In-Sink-Erator, home composting and centralised composting systems result in a reduction of impacts associated with co-disposal of food waste with municipal waste. Apart from these issues of avoided impacts, no allocation issues were encountered. The fertiliser products produced by the waste disposal systems are considered bonus by-products. The waste disposal service provided to urban householders represents an unavoidable need. Sale of the co-products of the systems as part of a business venture does not influence the need for a waste disposal system. Therefore, in LCA terms, the allocation of impacts to the provision of the waste disposal service was 100%.

[3] The term foreground system is defined in chapter 3.1.

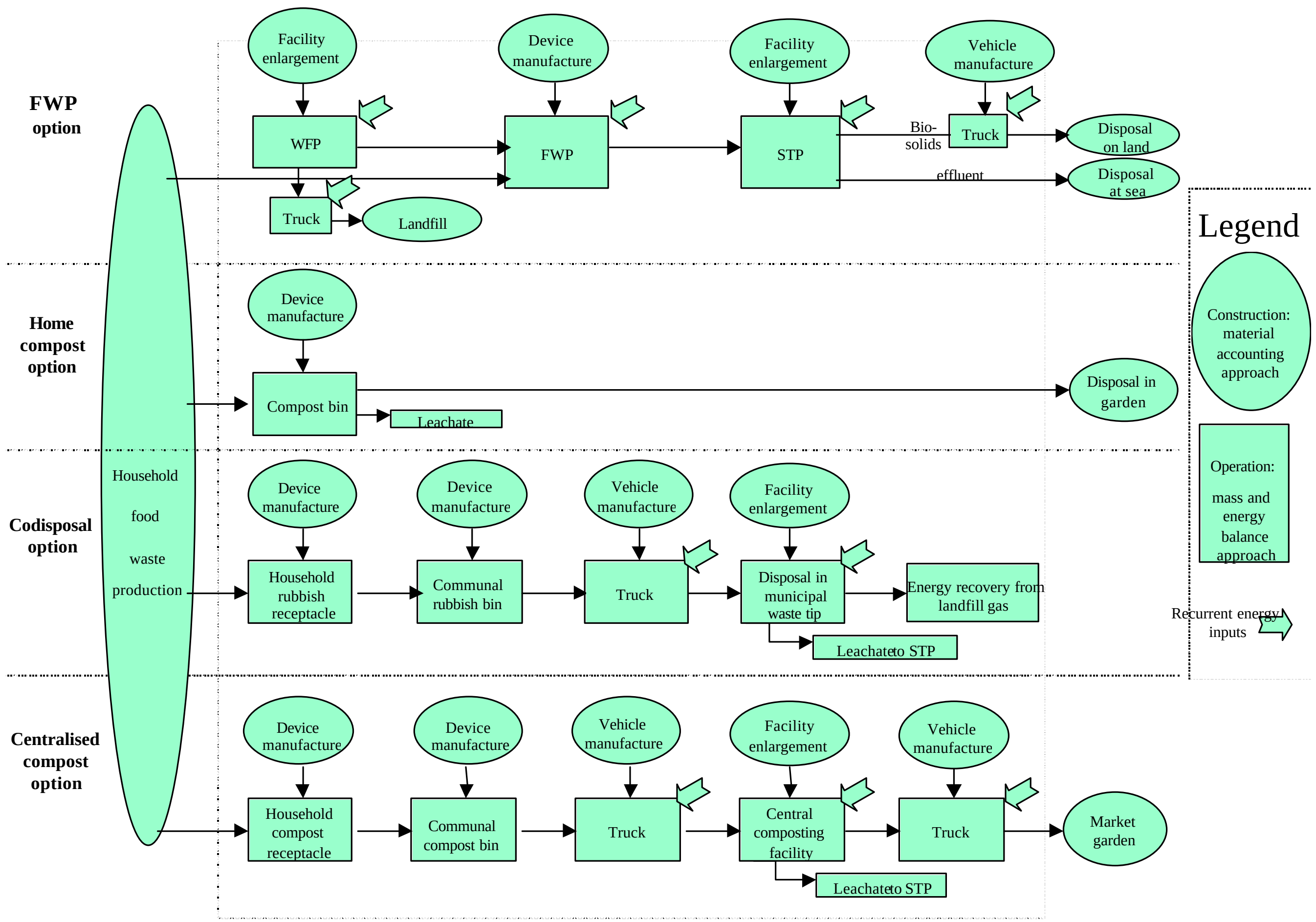


Figure 2: Alternative options for disposal of food waste - LCA system boundary

2.3 Assumptions in this LCA

For this LCA several assumptions had to be made based on the research and decisions made during Steering Committee Meetings. Most important assumptions are listed below:

Food waste processor: It is assumed that the FWP operates correctly and no maintenance occurs over the lifespan of 12 years.

Home composting: The home composting unit is made of polyethylene. It is assumed that home composting is correctly operated. Therefore food waste degrades under aerobic conditions.[4] The lifespan is assumed with 12 years.

Co-disposal: The disposal of food waste with municipal waste is common practice. No major assumptions had to be made concerning the collection of waste. It is assumed that degradation in landfill takes place under fully anaerobic conditions. Generated biogas is used for energy recovery. However, there are several uncertainties in quantifying the amount of recovered energy, and this is discussed in section 5.2.2 'Sensitivity Analysis'.

Centralised composting: Waverley Council currently collects garden waste at the kerb fortnightly (Fuller 2000a). It is assumed that:

a. a centralised composting system for food and garden waste runs parallel to the existing MSW system;

b. green waste is collected weekly;

c. the same number of trucks is required for collecting the green waste as for collecting municipal solid waste; and

d. the capacity of the centralised composting facility is 50,000 t/a.

[4] Household composting is generally a misnomer in a strict microbiological sense: as household composting operations are often poorly oxidised, "anaerobic silage" conditions arise in the compost pile, leading to methanogenesis and the emission of sulfides (Ashbolt 2000). Backyard composting can cause nuisance odours for neighbours, however this study assumes it is correctly maintained and odour-free. See 5.1.4

3 LCA Inventory Analysis

3.1 General introduction

Inventory analysis is the second phase in a life cycle assessment and is concerned with data collection and calculation procedures. The operational steps in preparing a life cycle inventory (LCI) are:

– data collection;
– relating data to unit processes and/or functional unit;
– data aggregation; and
– refining the system boundaries (ISO 14041).

Before beginning the inventory analysis in this LCA, data collection was facilitated by drawing specific flow diagrams (see Figure 2) that outlined relevant unit processes by describing unit processes and by developing a list of relevant information for each unit process.

In this LCA study a distinction is made between the foreground and the background systems. According to Clift *et al.* (1999) a clear distinction can be made between unit processes that are the focus of the study, and other operations that exchange materials or energy with them but which are not so central to the issues addressed by the study. The foreground system is defined as the "set of processes whose selection or mode of operation is affected directly by decisions based on the study", while the background system "comprises all other processes which interact directly with the foreground system, usually supplying material or energy to the foreground or receiving material or energy from it" (Clift *et al.*, 1999). Since the characteristics of background systems are not generally under the control of the manager of the foreground systems, they can be analysed as single processes without loss of useful output data. Taking this approach allows the analyst to assess the systems of direct relevance to the reader in greater detail.

3.2 Data collection

Data collection was based on:

– Site inspections (Eastern Creek Composting Facility, Malabar STP);
– Sydney Water Pollution Reduction Program Reports;
– LCA studies;
– Australian LCI data (electricity, gas, coal, transportation etc.)
– LCI research; and
– LCIA research.

After validation (mass and energy balances) the data were related to unit processes and the functional unit (see Section 2.2). Finally, the data were aggregated for the Life Cycle Impact Assessment (LCIA) phase (see Chapter 4). This procedure was performed several times as it became clearer which data were most significant and required further refinement.

Data is contained in planning documents produced for Sydney Water Corporation by consultants (Sydney Water, 1998) and public data (Sydney Water Corporation, 1999a, 1999b), supplemented by numerous communications with local government, waste managers and suppliers of waste management equipment. Data was also sourced from scientific literature (eg: Kogan and Torres, 1996; Tchobanoglous *et al.*, 1993). The output data from this LCA is considered prospective in nature, since it is based on estimates of future necessary plant and equipment using contemporary operational observations. As the supplier and literature data come from a wide range of sources, it is difficult to make generic statements about accuracy.

3.3 Process tree and definition of the system boundaries

In an LCA, all flows should be traced in such a manner that inputs and outputs at the product system boundary are flows of raw materials entering the system being studied. These flows either have been drawn from the environment without previous transformation, or leave the system and are discarded into the environment without subsequent human transformation (Guinee *et al.*, 1998). This rather theoretical approach can lead to an endless regression of data collection, and therefore, system boundaries must be defined. The definition of system boundaries is based on the initial process trees (see Figure 2).

The inventory for the foreground system included construction and operational impacts. Process impacts of the background systems were included, but the “cut-off” rule of not including the impacts resulting from the installation of the background systems was applied. This is generally justified on the basis that:

(a) for most background system supply chains, the proportion of the output of the chain which would be directed to the foreground system is minimal; and

(b) the impact of plant construction activities is generally much less than the impacts of their operations.

Equipment is assumed to have a lifespan in accordance with the manufacturers’ recommendations. For example, the annual impacts associated with construction of sewage treatment facilities are appropriately scaled down by a factor of 35 to take into account their lifespan (Sydney Water Corporation, 1999b). As the materials used in construction of the plant and equipment (primarily concrete and steel) are recyclable and considered to reduce environmental impact in other product systems, the disposal of equipment is not considered in this LCA. Additionally, as we shall see, the material and energy flows associated with construction are considerably smaller than those associated with operation of the systems, and it is therefore to be expected that operational issues will dominate the total environmental impact of the system relative to construction and disposal.

In all systems, food waste is treated with other wastes. The impacts of the construction and operation of the systems are allocated according to the proportion of the system load which the food waste represents.

The systems were described diagrammatically in Figure 2. More detailed Sankey diagrams of the systems as created in the GaBi 3 LCA software package (used to perform this study) are included in the following chapters.

3.3.1 Food waste processor (FWP) option

The system boundaries of the In-Sink-Erator option begin at the point of disposal of household food waste. The foreground system consists of a Model 75 In-Sink-Erator with the associated water supply and sewage treatment facilities.

Materials

The Model 75 FWP chosen for this study is In-Sink-Erator's largest, and is claimed by the manufacturer to be their best and most popular model. Detailed information on the material components was obtained from the US offices of the company (Hartmann, 2000b). The top seven materials, comprising over 98% of the unit, including the cardboard delivery packaging, were included in the analysis. The unit was allowed a lifespan of 12 years after discussion with the manufacturer (Hartmann, 2000a) and technicians (Dishmaster Appliances, 2000).

In assessing the environmental impact of the water supply and sewage treatment facilities, the inventory analysis takes into account the proportion of the throughput of these systems which is caused by the processing of food waste.

Water purification is performed in sand beds at Prospect Water Filtration Plant. On the basis of Sinclair Knight Merz (1997), construction of the 3 GL/day water filtration plant was associated with the use of 30 000 m^3 of reinforced concrete. 15 t of steel reinforcing were assumed to be required per 100 m^3 concrete. The plant was allowed a lifespan of 45 years, in accordance with Sydney Water (1999a). The impacts were allocated on the basis of the lifespan of the plant and the proportion of the flow required by the functional unit. Unsurprisingly, in the first iteration of this LCA, it was shown that the environmental impacts of the materials required for construction of the water filtration plant were insignificant relative to the recurrent impacts, so further details of the construction were not required.

The sewage treatment facilities at Bondi Sewage Treatment Plant are "high rate primary", removing suspended solids without biological nutrient removal. The impacts of material acquisition for construction of the Bondi sewage treatment plant were modelled on the same basis as the water filtration plant except that the plant was given a lifespan of 35 years (Sydney Water, 1999a).

The manufacture of the In-Sink-Erator and any enlargement of the water filtration or sewage treatment plants are considered as background processes. It was determined early in the inventory analysis that the impact of the construction of the water and sewage treatment facilities was a minor component of the overall system impact. This is in part due to the multiple uses and long lifespan of this equipment. For this reason, it was not necessary to include the reticulation systems in the inventory, which have even longer lifespans of up to 150 years (Sydney Water Corporation, 1999b).

Operation

Using data available in Sydney Water (1999b), the average electrical consumption of the water filtration, water pumping, sewage pumping, sewage treatment processes and transportation of sludge was obtained.

The amount of water required to shred a given quantity of vegetable waste was 12.4 L/kg of food waste (Hartmann 2000). This figure was qualitatively confirmed by the experiment using 11 L per kilogram of waste (11% less) and by Diggelman & Ham (1998) using 10.3 L/kg. For this study the more conservative value of 12.4 L/kg of food waste was used. In the trial the energy drawn by the motor was 0.0196 kWh/kg waste, higher than the 0.0154 kWh/kg calculated on the basis of company information. For further calculations company information is used. These differences did not affect the qualitative outcome of comparisons between clearly different options in the LCA.

The nutrient figures produced by the CRC for Waste Management and Pollution Control are very different from those originally used in literature. Literature figures are approximately an order of magnitude lower for N and P than the experimental data used in the FWP option analysis. For this reason, the experimental data are included in the FWP option.

The sewage treatment unit operation was based on operational data (Sydney Water, 1999b) and planning data (Sydney Water 1998; Evans 2000; Gough 1999). This was used to predict the split of food waste nutrients (nitrogen and phosphorous) between the biosolids, the biogas generation from anaerobic digestion and the treated liquid effluent. A distance of 250 km was assumed for the delivery of biosolids, based on the location of markets between Goulburn, the Central Coast and the Central Tablelands. A product moisture content of 28% was based on Sydney Water (1998). Additional food waste characteristics were obtained from Tchobanoglous *et al.* (1993). The system modelled is shown in Figure 3.

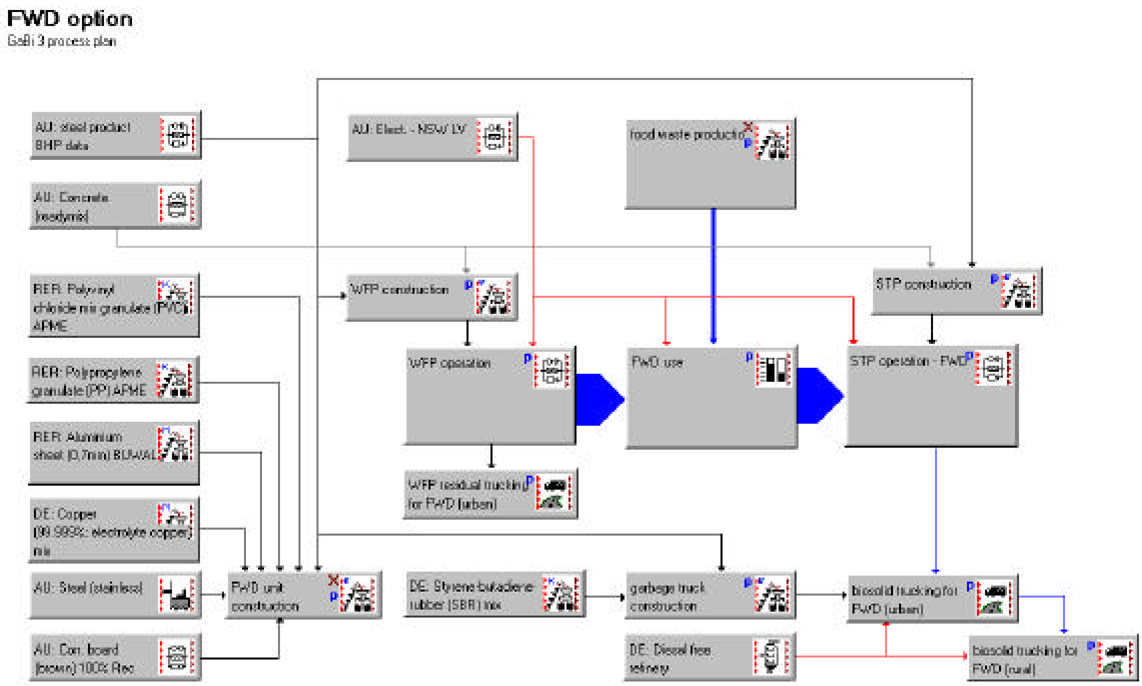


Figure 3: Sankey diagram of the FWP option[5]

[5] In these diagrams, blue arrows represent water or waste flows, red represents energy and black arrows indicate material flows. The width of the arrows is scaled proportionally to the maximum mass flow rate within each option.

3.3.2 Home compost option

This is the simplest system, connecting the kitchen with the garden via a standard polypropylene compost bin. Manufacture of the compost bin was considered as a background process.

Materials

Discussions with Rotoplastics (2000) and Hardwarehouse (2000) indicated the most common composting process used in urban environments involves a open-bottom polyethylene bin (virgin material) weighing 5 kg. Composting units made from 100% recycled polypropylene are also available (Rice 2000). For this study the virgin material was investigated. However, the use of locally recycled polyethylene would improve the environmental performance of the home composting option. Unfortunately reliable data on recycled polyethylene is not presently available. The compost bin was initially assumed to have a lifespan of 12 years. Sensitivity analysis showed that less conservative estimates of this value would not affect the ranking of alternative options.

Operation

It is assumed that the composting system is correctly operated (aerobic conditions)[6]. Detailed data from Jones *et al.* (1994) was used to estimate the leachate quality resulting from use of this type of composting bin under managed conditions. The quantity of leachate generated was reduced by the proportion of leachate resulting from the inclusion of garden waste, so that the figures represent a genuine comparison with the FWP. (It was assumed that households do not dispose of garden waste in the FWP.) The more speculative methane production estimates of Jones *et al.* (1994) were not used. Instead, calculations were based on Tchobanoglous *et al.* (1993).

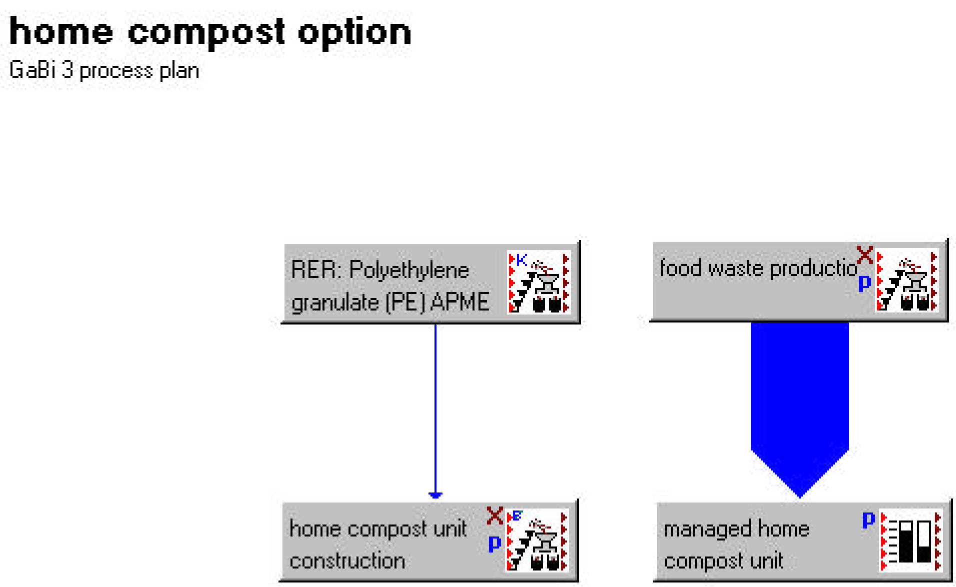


Figure 4: Sankey diagram of the home composting option

[6] In case of anaerobic conditions the pH value is low and therefore the decomposition is slow. In this case lime can be used in order to increase pH value and accelerate the decomposition process. According to Jackson (2000) approximately 0.5 l of lime could be used per functional unit. However, this is not common practice anymore (Jackson 2000) and therefore was not further investigated in this study.

3.3.3 Co-disposal option

This default route of food waste disposal was modelled with initial collection of household waste in an indoor kitchen tidy. The waste is transported to a landfill.

Materials

The household was equipped with a polyethylene bin weighing 400g (Nylex 2000).

Because the focus of the study is on medium-density housing, this bagged waste is transferred to a communal 240 L wheeled bin for council collection. Hardwarehouse (2000) indicated that the common 240 L communal waste bins weighs 15.5 kg. Based on the waste generation data in BIEC (1997), it was calculated that a block of 100 households would require 15 bins.

The total mass of a garbage truck is 14.2 tonnes Waverley Council (2000). The trucks consists mainly of iron and steel and synthetics (Schweimer & Schuckert (1996)).

Operation

The consolidated refuse is then trucked with council garbage trucks to a transfer station in Rockdale. At Rockdale, the waste is consolidated and then transported to Lucas Heights landfill for disposal. In accordance with Waverley Council operations, collection was assumed to occur weekly. The collection of waste from multi-residential dwellings in the Council area was allocated 220 hours/week of truck travel time based on Myers (2000). The impact of this trucking was calculated using the latest Australian data in Grant *et al.* (1999).

The resource consumption of landfilling operations was estimated on the basis of SAEFL (1998) and Grant *et al.* (1999).

In addition to leachate, the landfill generates gaseous emissions as a consequence of the addition of food waste and the use of earthmoving equipment. Gaseous emissions from food waste are actively captured and used for electricity generation (see chapter 5.2.2). Consistent with the home composting operation, methane emissions were calculated using Tchobanoglous *et al.* (1993). At Lucas Heights landfill 66% of the biogas was captured (Harvey 2000). Of the remaining, non-captured biogas (34%), 50% is oxidised at the cap layer and 50% is released to the atmosphere (Fuller 2000b).

Leachate is treated at Cronulla Sewage Treatment Plant. Leachate generation data were taken from Southern Sydney Waste Board (1999). Background system analysis included the manufacture of the household and communal waste bins and the proportion of the trucks used to transport the waste.

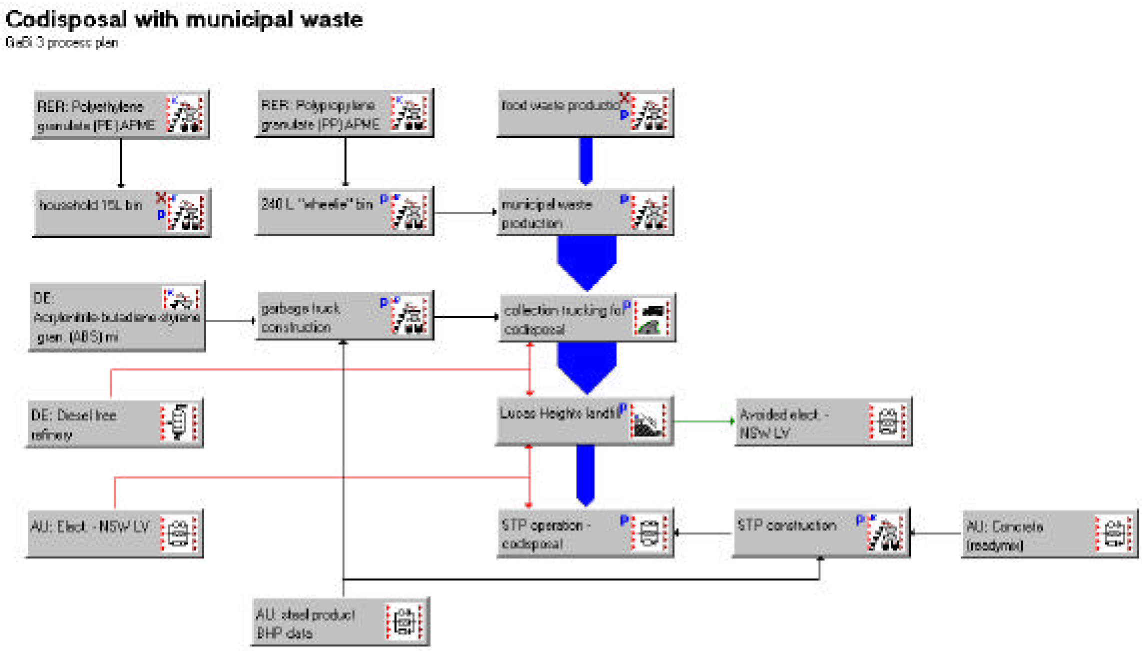


Figure 5: Sankey diagram of the co-disposal option

3.3.4 Centralised compost option

This is the most complex system: the food waste is collected with green (garden) waste in household and communal bins separate from the general (inorganic) waste stream.

Materials

The bins required for this option were the same type as those used in the co-disposal option, except that, based on the BIEC (1997) values for green waste generation in Waverley, only 5 bins per hundred households would be required for weekly collection. The weight of a collection truck is 10.1 tonnes (Waverley Council (2000)). The material composition is based on Schweimer & Schuckert (1996).

The size of the composting facility which would be required for handling additional green waste was chosen to reflect economic reality: the 50000 t/year capacity is the same as that chosen for the recently completed composting facility at Eastern Creek (Australian Native Landscapes, 1996). The area required for this facility was estimated, based on published data from nine other plants in the USA and Europe (Biocycle, 1998-99), as 2700 m^2. An architect and site engineer (Peters, 2000) was contacted for estimates of the concrete and steel required to enclose this space (to allow for odour control as discussed in Appendix B). Material requirements for other unit operations were assessed as previously described.

Operation

Trucks collect and deliver waste to a central facility in Sydney's geographic centre for stabilisation by aerobic composting.

The collection system for food and garden waste was assumed to operate in parallel with the co-disposal operation, using separate compactor trucks. The collection of residual waste and biowaste from multi-residential dwellings takes place on a weekly basis.[7] Since the trucks would be required to visit the same number of households and travel similar distances, the same truck use was used in this option as the co-disposal option. It might be argued that since fewer bins will be emptied, it is appropriate to apply a shorter usage time. However, the environmental impact of diesel trucks is lower while idling rather than accelerating from a standstill or travelling at speed. Thus, at this level of generality, it is appropriate to assume the number of households and the distance travelled control the environmental impact, and to apply sensitivity analysis to this assumption. Based on the sensitivity analysis, this assumption is robust.

Aerobic composting occurs in an enclosed facility to allow odour and vector control. The energy consumption of the composting facility was estimated on the basis of a site visit to the Eastern Creek Composting Facility and operating data supplied by Australian Native Landscapes staff (Hudson, 2000). The quantity and quality of emissions were calculated using Tchobanoglous *et al.* (1993) and Jones *et al.* (1994) on the basis of aerobic composting.

The composted material is then delivered to gardens and market gardens in the Sydney Basin. Liquid effluent is treated by high-rate primary methods. The same background systems are assessed as in the co-disposal option, with additional truck use and the construction of a central composting facility taken into account.

[7] There are other options for the collection of residual waste and green waste, such as 1) collection of residual waste and biowaste weekly from one split bin by the same truck and 2) collection of biowaste weekly and residual waste fortnightly (Fuller 2000). However, the Steering Committee agreed on the collection mode mentioned above. Hence, alternative options have not been quantified.

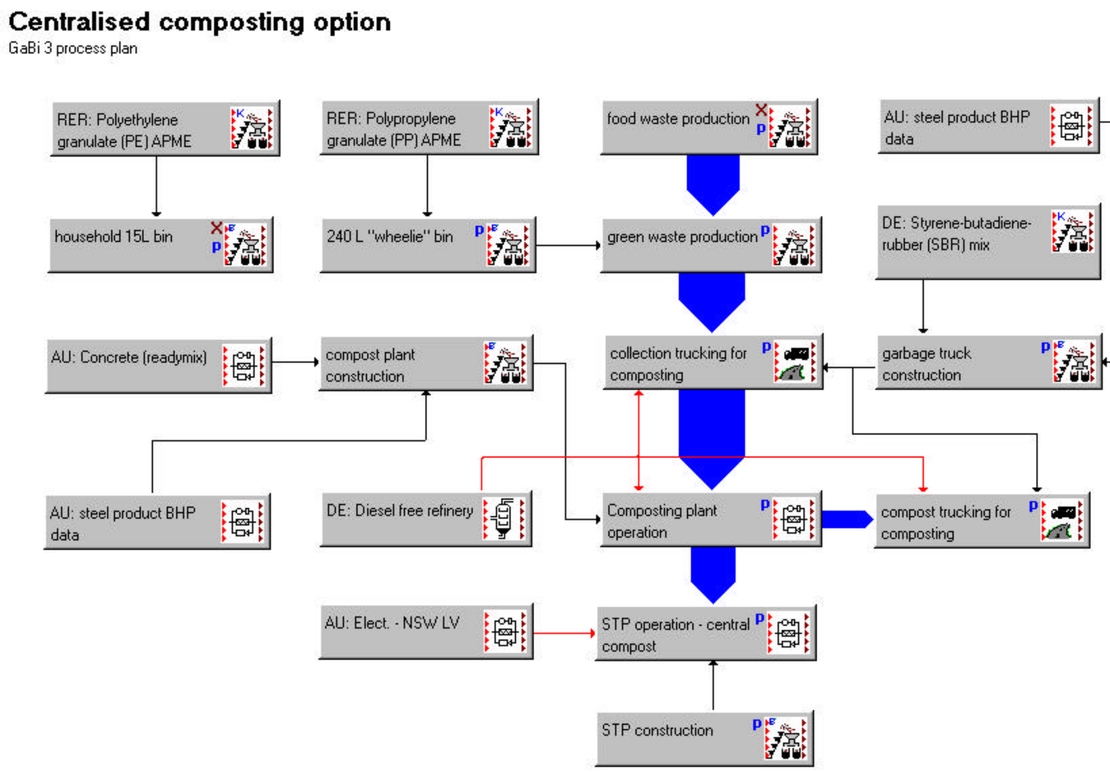


Figure 6: Sankey diagram of the centralised composting option

4 Life Cycle Impact Assessment

Life cycle impact assessment (LCIA) is the third phase of LCA. The purpose of LCIA is to better understand environmental impacts caused by the emissions and environmental interventions of a product or service.

In the LCIA phase environmental issues (impact categories) are modelled. Therefore, category indicators are used to condense and explain life cycle inventory (LCI) results. Category indicators reflect the aggregated emission or resources use for each impact category. These category indicators represent the potential environmental impacts (ISO 14040, 1998).

4.1 Description of Life Cycle Impact Assessment Framework according to ISO 14042

It is the aim of LCIA to examine the potential environmental impacts of a product system by using category indicators derived from LCI results. The LCIA phase provides information for the interpretation phase (ISO 14043, 1998).

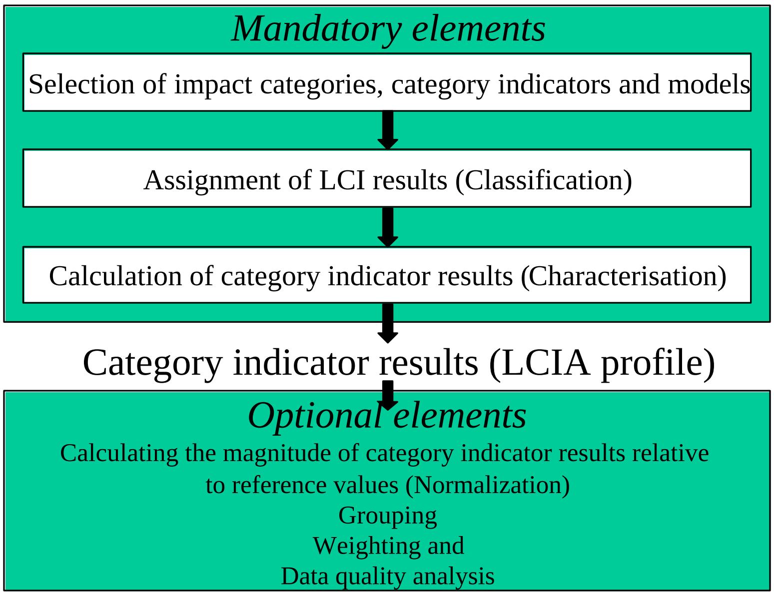


Figure 7: Elements of LCIA (ISO 14042, 1998, p 4)

LCIA consists of mandatory and optional elements. The *mandatory elements* are:

– Selection of impact categories, category indicators, and models;
– Assignment of LCI results (Classification) to the impact category; and
– Calculation of category indicator results (Characterisation).

Optional elements of LCIA are:

– Calculation of the magnitude of category indicator results relative to reference values (Normalisation);
– Grouping; and

– Weighting.

Optional elements can be applied depending of the goal and scope of the study. The sequence of mandatory and optional elements are shown in Figure 7.

This study is limited to the mandatory elements of LCIA and to the normalisation step. Further optional elements are not taken into account. The normalisation was performed within the limits of data availability. Data was available for the normalisation of energy consumption, global warming potential, eutrophication potential and acidification potential.

4.2 Selection of impact categories, category indicators and models

In the first step of LCIA impact categories, category indicators and models are selected that are associated with LCI results. Over the last decades a large number of impact category models have been developed, including:

- Abiotic Resource Depletion,
- Biotic Resource Depletion,
- Land Use,
- Climate Change (Global Warming),
- Stratospheric Ozone Depletion,
- Human Toxicity and Ecotoxicity,
- Photochemical Oxidant Creation,
- Acidification, and
- Nutrification.

Most of these impact assessment models are still being developed, and only a few model such as Climate Change have achieved international acceptance. Currently, there is no consensus as to which impact categories should always be used in LCA (Jensen *et al.,* 1997). Instead, analysts select the categories on the basis of the goals of the study and the kinds of impacts associated with the particular system.

In Figure 8 the conceptual framework for defining indicators is given according to ISO 14042 (1998).

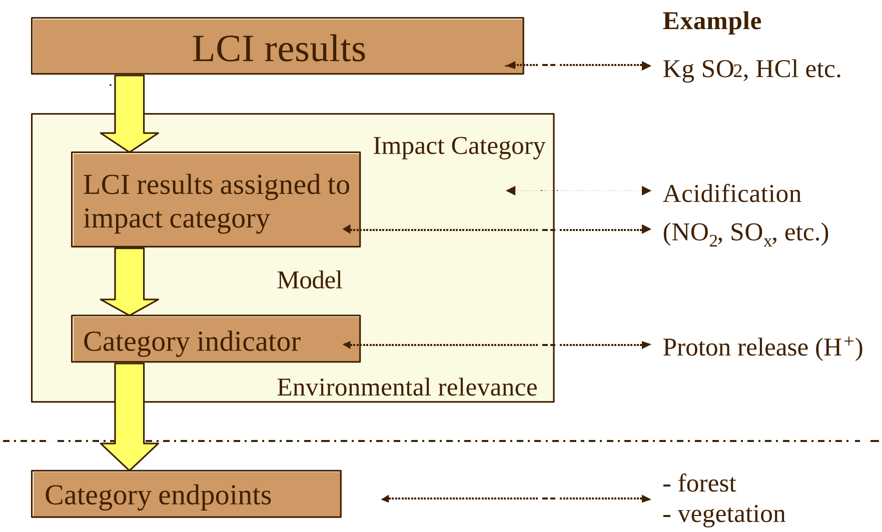


Figure 8: Concept of indicators (ISO 14042, 1998, p 5)

Guidance and requirements for the selection of impact categories, indicators and models are given in ISO 14042 which requires that the selection shall be consistent with the goal and scope of the study, and justification shall be provided for the selections. The impact categories shall reflect a comprehensive set of environmental issues related to the product system (ISO 14042, 1998, pp. 5-6).

The environmental indicator and impact categories chosen for this study are energy consumption, global warming potential, human toxicity potential, aquatic ecotoxicity potential, terrestrial ecotoxicity potential, acidification and eutrophication. These were chosen on the basis that they are most relevant to the systems undergoing comparison. Other categories have been developed, such as ozone depletion potential, but this is not considered relevant to this study, nor is it in the project brief.

Although not strictly an environmental impact category, energy consumption is useful as an indicator of the process intensity and the use of non-renewable resources. It also can provide useful explanatory data for examining global warming potential, and is in any case, energy consumption is a prerequisite for the evaluation of the global warming potential of process systems. Global warming potential is obviously of international and local interest, given Australia's status as a major per capita emitter of greenhouse gases. Global warming potential is usually evaluated on a 20, 100 or 500 year timescale. For this study, the most commonly used timescale has been selected - 100 years. Human toxicity potential of airborne contaminants is of considerable interest in urban environments such as the Sydney region where this study was carried out, and has been studied in depth by Heijungs et al., (1992), Cowan et al., (1995), Lynch et al., (1995), Guinée et al., (1996a and 1996b), Udo de Haes (1996), Hauschild and Wenzel (1998a and 1998b), RIVM *et al*., (1998), and Huijbregts (1999). Aquatic ecotoxicity and eutrophication potential are considered highly relevant to an environmental comparison of these food waste disposal options, given the high moisture content of food and its capacity to generate high quantities of nutrient-enriched leachate on degradation. Since most of the options under study involve large amounts of coal-based electricity and diesel-powered trucks, terrestrial ecotoxicity and acidification potential are also considered necessary impact categories in this LCA.

4.3 Classification

In this second mandatory step the environmental interventions (emissions) are assigned to defined and selected impact categories. The assignment of inventory data is the minimum requirement of LCIA. The classification should emphasise 1) assignment of LCI results that contribute exclusively to *one* impact category and 2) identification of LCI results that relate to more than one impact category (IOS 14042, 1998). Classification can be used to identify and flag environmental issues associated with inventory data. Classification is a qualitative step based on scientific analysis of relevant environmental processes.

4.3.1 Energy consumption

Although energy consumption is an environmental indicator rather than an impact category, it rather, takes into account the energy demand per functional unit. Energy consumption from different sources are considered: electricity from black coal, natural gas, biogas, and fuel. Since the only important renewable energy resource used in this system is the endogenous biogas, energy consumption represents an indicator of the consumption of important non-renewable and renewable resources. The consumption of non-renewable resources is a common focus of LCA studies.

4.3.2 Global warming potential

This category considers releases of greenhouse gases into the atmosphere as a result of human activities and natural sources. Main contributors to global warming are carbon dioxide (CO_2), methane (CH_4), halocarbons (halons, chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs)), nitrogen oxides (NO_x), including nitrogen dioxide (NO_2), nitric oxide (NO), and nitrous oxide (N_2O), non methane volatile organic compounds (NMVOC) and particulate matter of various compositions and sizes. The main quantitative contributors to global warming potential are carbon dioxide, methane and nitrous oxide.

4.3.3 Human Toxicity

The impact category human toxicity contains effects of toxic substances on humans. The potential effect on humans depends on the actual emissions, the fate of the specific substance emitted to the environment and the time of exposure. This category is difficult to model because of the fate of toxic substances and their intermedia transport (Jensen *et al* 1997). In Heijungs *et al* (1992) separate characterisation factors have been defined for emissions of toxic substances to the environmental media *air* (human toxicity to air (HTA)), *water* (human toxicity to water (HTW)) and *soil* (human toxicity to soil (HTS)). These effect scores for the media air, water and soil can be added to provide a single medium-independent effect score for human toxicity:

$$\textit{Human Toxicity} = \sum_i ((HCA_i \times m_{a,i}) + (HCW_i \times m_{w,i}) + (HCS_i \times m_{s,i})$$

with

m_i = emitted quantity of substance i to air (a), water (w) and soil (s)

Equivalence factors for relevant substances are listed in Heijungs *et al.* (1992).

4.3.4 Eco-toxicity

Eco-toxicity deals with effects of toxic substances on terrestrial and aquatic ecosystems. The potential effects on ecosystems depend on the actual emission, the exposure to these emissions and the fate of specific substances in terrestrial and aquatic ecosystems. This category is as complex as human toxicity. Reasons are the large number of mechanisms, affected species and intermedia transport of substances in the ecosystem (De Haes 1999). In Heijungs *et al.* (1992) emissions to water and soil are taken into account. Emissions to water are considered to be toxic only for aquatic ecosystems, emissions to soil are considered to be toxic only for terrestrial ecosystems. Separate characterisation factors have been defined for emissions of toxic substances to the environmental media water (ECA) and soil (ECT), and these are used to calculate the effect score for aquatic and terrestrial ecotoxicity:

$$\textit{Aquatic Ecotoxicity} = \sum_i (ECA_i \times m_{w,i}) \quad \text{and} \quad \textit{Terrestrial Ecotoxicity} = \sum_i (ECT_i \times m_{s,i})$$

with

m_i = emitted quantity of substance i to water (w) and soil (s)

Equivalence factors for relevant substances are listed in Heijungs *et al.* (1992).

4.3.5 Acidification

Acidifying substances cause a large diversity of impacts on soil, groundwater, surface water, organisms and ecosystems. The most important acidifying compounds are SO_2, NO_x and NH_x. In Heijungs *et al* (1992) acidification potentials are used as characterisation factors to calculate the total indicator for acidification:

$$\textit{Acidification} = \sum_i (AP_i \times m_i)$$

with

m_i = emitted quantity of substance i

The total contribution is expressed in kg SO_2-equivalents. Equivalence factors for relevant substances are listed in Heijungs *et al* (1992).

4.3.6 Eutrophication

Eutrophication covers all environmental impacts due to high level of macro nutrients. Nitrogen and phosphorus are the most important eutrophicating elements. This enrichment may cause a shift in the composition of species, an increase of biomass production in aquatic and terrestrial ecosystems, and high nutrient concentrations in surface water. In Heijungs *et al.* 1992 eutrophication of N, P, and C is aggregated by quantifying their contribution to biomass formation. Eutrophication potentials are used as characterisation factors to calculate the total indicator:

$$Eutrophication = \sum_i (EP_i \times m_i)$$

with

m_i = emitted quantity of substance i

The total contribution is expressed in kg PO_4^{3-}equivalents. Equivalence factors for relevant substances are listed in Heijungs *et al* (1992).

4.3.7 Odour

Two main approaches to quantitative odour assessment exist. One approach is to examine the malodorous air on the basis of the concentration of individual odorous compounds and apply "ground level concentration" (GLC) criteria in assessing the significance of the odours. The other main approach involves "odour performance criteria". Rather than focussing on the concentration of individual contaminants, this approach treats malodorous air as a mixture of contaminants (a more detailed description of both approaches is given in Appendix B).

In the absence of uniform quantitative data, it is appropriate to restrict the treatment of odour to a qualitative discussion of the odour sources in each of the four options assessed in this study (see chapter 5.1.4).

4.4 Characterisation

Characterisation involves the conversion of LCI results to common units using characterisation factors (ISO 14042, 1998), and the aggregation of the converted results within the impact category. The outcome of calculation is a numerical indicator. The result of characterisation represents the additional load to that category per functional unit.

In Heijungs *et al.* (1992) the calculation of characterisation per impact category is described as follows:

$$Impact\ Category = \sum_i m_i \ x\ equivalence\ factor_{impact\ category,i}$$

where

i	= type of emission (e.g. a substance such as CO_2)
m_i	= quantity of emission (e.g. kg of CO_2)
equivalence $factor_{impact\ category,i}$	= relative contribution of each substance to the impact category

The characterisation step is applied to LCI results by multiplying emitted quantities by equivalence factors applicable to each impact category. This calculation creates the environmental profile of each system under consideration. Detailed results are shown in Chapter 5.

As an example of the characterisation process used for each impact category, Table 1 shows the equivalence factors used for global warming potential. The full list of equivalence factors is given in Houghton *et al.* (1995). Each impact category refers to one reference substance. The reference substance for global warming potential is CO_2. The contribution of the reference substance is equal to 1. Other substances are expressed relative to this reference substance.

Table 1: Global warming equivalence factors for selected substances according to Houghton *et al.* (1995) [8]

Substance	Chemical formula	Lifetime, years	Equivalence factors
Carbon dioxide	CO_2	Variable	1
Methane	CH_4	12.2±3	21
Nitrous oxide	N_2O	120	310
CFC-11	$CFCl_3$	50 ± 5	4000
CFC-12	CF_2Cl_2	102	8500
CFC-13		640	11700
HCFC-22	CHF_2Cl	13.3	1700
HCFC-123	CF_3CHCl_2	1.4	93
Tetrachloromethane	CCl_4	42	1400
HFC-23	CHF_3	264	11700
HFC-32	CH_2F_2	5.6	650
HFC-41	CH_3F	3.7	150
Chloroform	$CHCl_3$	0.51	4
Methylene chloride	CH_2Cl_2	0.46	9
Sulphur hexafluoride	SF_6	3200	23900

Carbon dioxide, methane and nitrous oxide are the major contributors to global warming potential. They are emitted in large quantities by energy conversion processes.

4.5 Normalisation

Within normalisation all LCI and LCIA results for the functional unit are expressed as fractions of a well-defined reference contribution of a given community over a given period of time (Heijungs, 1997). In ISO 14042 (1998) the normalisation step is considered as an optional element of LCIA.

The aim of normalisation is to better understand the order of magnitude for each indicator of a system under study. It can provide information on the relative significance of the indicator results. In this case study it was found helpful to express the contribution of the functional unit to each impact category relative to a New South Wales or per capita level.

[8] These data are based on a time horizon of 100 years.

In Table 2 reference data are given for energy consumption, global warming potential, acidification potential and eutrophication potential. The information refers to Australian and New South Wales populations and is also given on a per capita basis. For the calculation, an Australian population of 18,751,000 and a New South Wales population of 6,342,000 is used (Australian Bureau of Statistics, 1998). The reference year is 1998 for global warming potential and energy consumption. The reference year for human toxicity potential is 1995.

Table 2: Annual normalisation data for energy consumption, global warming potential, acidification potential and eutrophication potential[a]

	Unit	Australia	NSW	Per Capita
Energy Consumption	MJ	2.85×10^{12}	1.01×10^{12}	158×10^{3}
Global Warming Potential	kg CO_2 equivalent	402.4×10^{9}	141.8×10^{9}	22.3×10^{3}
Acidification Potential	kg SO_2 equivalent	2.87×10^{9}	9.71×10^{8}	151×10^{0}
Eutrophication potential	kg P equivalent	1.31×10^{8}	4.42×10^{7}	6.90×10^{0}

[a] Grant *et al*. (1999)

4.6 Data quality and sensitivity analysis

In LCA studies, two types of sensitivity analysis are preferred. The first type tests the assumptions concerning the system by varying the configuration and/or boundaries. This type of analysis has the potential to produce large variations in results. In the current study, this type of sensitivity analysis is not performed. It is possible to imagine an infinite array of variations in the food waste processor (FWP), co-disposal and centralised composting systems. However, since they are (or would be) operated as businesses under various types of permitting legislation, they can be expected to run reliably and thus are less liable to accidental variations in system conditions[9].

The second type of sensitivity analysis involves variation of input values for a particular system. Ideally, each data element in a life cycle inventory should be collected with a standard deviation reflecting the level of certainty associated with each datum. Monte Carlo simulation of the results would then allow overall data tolerances to be assigned to the output. This level of sensitivity analysis is rarely performed in LCA due to the:

- computational intensity of the system model required;
- scarcity of meaningful data uncertainties; and
- dominance of a few variables.

[9] For example: if an enclosed centralised composting facility were to allow anaerobic conditions to occur in it, one would expect the intense odour generation to result in rapid remedial steps being taken maintain the amenity of the site as a place of work.

However, this last point offers a simpler alternative – variation of the most relevant input variables in the system – and this approach has been adopted for this work. After complete modelling of the alternative options, the model output was examined to determine which element of each option was the most significant in contributing to the different impacts. As is often the case with LCA, it was found that one item often generally dominated most of the impact categories. In this case it was:

- FWP option: FWP unit electricity consumption
- Home composting option: composting unit lifespan
- Co-disposal option: fuel consumption in mixed waste collection
- Centralised composting option: fuel consumption in compostable waste collection

Previous estimates of FWP electricity consumption and our own measurements were within 15% of each other. The lifespan of the home composting unit is difficult to estimate since it depends the level of care with which it is used. Nevertheless, it is considered unlikely to last less than a decade, 16% less than the lifespan (12 years) chosen for this study. As the impact of the home composting option is relatively low anyway, use of a very long lifespan (say 25 years) in the sensitivity analysis would not have a major impact on the ranking of alternatives, and was therefore not examined[10]. The trucking estimates are believed to be accurate to within a 20% margin or error. For this study, each of the parameters listed above was varied by 20% and the output of the LCA model obtained. The results are shown as error margins in the figures in the following chapter. In this LCA study, this approach leads to clear distinctions between significant and insignificant differences between impacts.

[10] The most significant variable in the home composting option is the type of composting rather than the lifespan of the composting device. Being a question of system definition, it was agreed at the Steering Committee Meeting (13th of June 2000) to consider a correctly managed home composting system only.

5 LCA Interpretation

In this Chapter the In-Sink-Erator food waste processor (FWP) is compared with the alternative options. The comparison is made on the system boundaries determined in Chapter 2.2. However, environmental impacts from co-disposal do *not* consider energy recovery because of its high data uncertainty. Energy recovery from landfill and Bondi Sewage Treatment Plant are discussed in more detail in Chapter 5.2.2.

The results are shown in terms of energy consumption, global warming potential, human and aquatic and terrestrial eco-toxicity, acidification and eutrophication.

Results shown in Appendix D (see Table 12 and Table 13) contain for each option absolute numbers and the relative contribution of relevant processes to each impact category.

5.1 Analysis of the results

5.1.1 Energy consumption and global warming potential

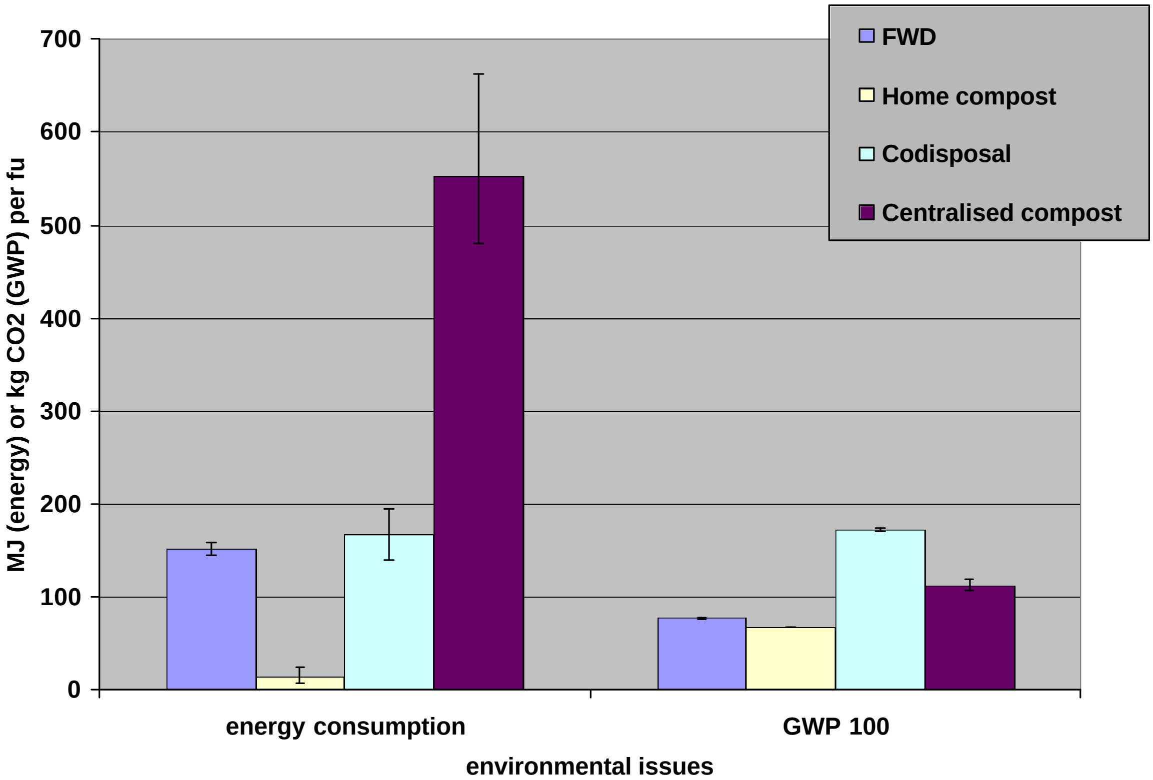


Figure 9: Energy consumption and global warming potential

At 151 MJ/fu, the FWP option is an important user of energy although the centralised composting option uses much more. Some of the energy used in the FWP option is consumed by the unit itself (14% of the total energy consumption), but the biosolids trucking operation consumes more energy (30.6%). Additionally, the pumping of water to the unit (4.4%) and from it to the sewage treatment plant (4.3%) are important energy consuming operations. The balance of the energy is attributed primarily to materials production.

Like the food processor option, the co-disposal option also requires recurrent energy input, in this case, 167 MJ/fu for truck-based transportation (57%) and site works (8.5%). The two options are not significantly different in terms of total energy consumption.

Running the centralised composting option involves intensive energy expenditure totalling 553 MJ/fu. 18% of the total is used for the shredding and diminution of particle size, the sorting of shredded materials and the turning of windrows. As with the co-disposal option, however, this is less than the energy involved in collecting and trucking materials to the central composting facility (57%). While it might initially be expected that the co-disposal and centralised composting options would have similar energy demands, the dictates of hygiene require weekly collection of the small amounts of compostable waste. Therefore, the energy consumption is made clearly higher on a per food waste mass basis by the fact that the diesel energy consumed covering the distances involved cannot be partially allocated to the collection of a larger quantity of municipal waste.

The energy required[11] for the home composting option is entirely that required for the manufacture of the large outdoor composting bin – 14 MJ/fu.

Perhaps surprisingly, the LCA results are markedly different for global warming potential. The key controlling variable here is the oxygen concentration during the breakdown processes. As the metabolic processes are assumed to operate aerobically in home composting and central composting options.

The home composting option generates 67.2 kg CO_2-equivalents[12] with a mere 0.458 kg CO_2-equivalent released during the manufacturing processes for the raw materials of the bin, while centralised composting option contributes 112.3 kg CO_2-equivalent to global warming potential (59% breakdown of organic matter, 25% trucking and diesel refinery, 11% on site operation and 4% others).

FWP is second best performer with 76.8 kg CO_2-equivalents (83.4% anaerobic digestion at Bondi STP, 4.7% trucking and diesel refinery, 4.9% electricity production, 6.4% material production). However, it must be stated that CO_2 generation from aerobic decomposition of biosolids originating from food waste on land is *not* part of the system boundaries. The contribution to global warming potential would increase if the application was part of the study.

[11] The figures discussed here include all the energy required to produce the materials for each option and the energy demands of operation. Embodied energy (eg: the heating value of the plastic garbage bins) is excluded. If included, this would add 2, 18, 13 and 5 MJ/fu to the total energy consumption of the FWP, home compost, codisposal and centralised composting options, respectively.

[12] Under anaerobic conditions, home composting would release 271.8 kg of CO_2-eq.

The (anaerobic) co-disposal option is an underperformer with 172.0 kg CO_2-equivalents per functional unit (94.4% from degradation and flaring of organic material and 4.3% trucking). 47.1 kg CO_2 and 19.7 kg methane are produced from the anaerobic degradation of food waste. This is a consequence of the anaerobic conditions which prevail during the microbial breakdown of organic matter in this system, which lead to the generation of methane. Methane is 21 times more potent as a greenhouse gas than carbon dioxide (on a 100 year timescale) and so these emissions determine the comparison of options for global warming potential. 66% of the methane is captured and flared at Lucas Heights (Harvey 2000). Flaring fully converts methane into CO_2 (35.7 kg CO_2). 34% of the methane is not captured. It has been assumed that 50% of non-captured methane is oxidised into CO_2 at the cap layer (9.2 kg CO_2), while the other 50% of methane is release to the atmosphere (70.3 kg CO_2-equivalents) (Fuller 2000b). However, it has to be stressed that this figure indicates *only* biogas generation and flaring. The number does not take into account combustion for energy recovery (see chapter 5.2.2).

5.1.2 Human toxicity and aquatic and terrestrial eco-toxicity

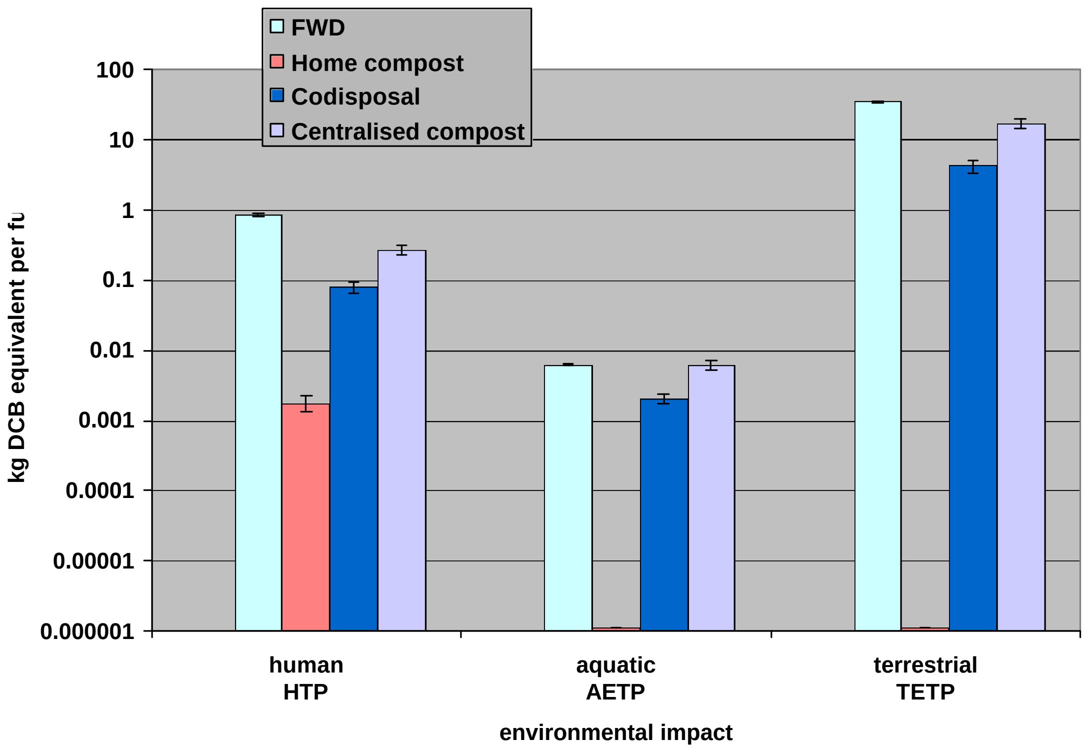


Figure 10: Human toxicity, aquatic and terrestrial eco-toxicity

A comparison of the options in regard human toxicity, aquatic and terrestrial eco-toxicity provides a clear ranking of alternatives: home composting is by far the most environmentally sound alternative (HTP: 0.002kg dichlorobenzene (DCB) - equivalents, AETP and TETP: 0.000001kg DCB-eq.). The next best alternative is co-disposal (HTP: 0.079kg DCB-eq., AETP: 0.002kg DCB-eq., TETP: 4.298kg DCB-eq.), followed by centralised composting (HTP: 0.271kg DCB-eq., AETP: 0.006kg DCB-eq., TETP: 16.92kg DCB-eq.) and FWP (HTP: 0.866 kg DCB-eq., AETP: 0.006kg DCB-eq., TETP: 35.04 kg DCB-eq.). Home composting has a significant smaller contribution than the other options to all types of toxicity potentials (Figure 10 has a logarithmic scale).

The contribution of home composting to toxic effects is the result of the production polymer for the compost bin. During the operation of the bin, no contribution to human and eco-toxicity occurs.

The human toxicity potential of the co-disposal option is mainly caused by trucking operations during the collection of waste (42%) and diesel refining (31%). 9% of the total potential has its source in diesel emissions on site and 12% is emitted by the generation of the electricity required on site. Aquatic and terrestrial eco-toxicity are dominated by the rubbish collection operations (AETP: 53%, TETP 71%) and diesel refining (AETP: 9%, TETP: 12%), while the on-site use of the diesel fuel causes 8% and 10% of the aquatic and terrestrial ecotoxicity potential, respectively. Electricity generation contributes only 2% of the aquatic and 4% of the terrestrial ecotoxicity potential.

Centralised composting provides a similar picture to co-disposal: 41% of human toxicity potential is caused by trucking, 35% by diesel refining and 20% by operation on site. Aquatic and terrestrial eco-toxicity is fully determined by diesel production.

The majority of the toxicity potential caused by the FWP option is the result of the extraction and production of materials rather than the operation of the FWP itself. Fully 72% of the human toxicity potential stems from the production of copper and 22% from electricity generation. 75% of aquatic toxicity originates in material production (45% aluminium and 30% copper). Diesel refining causes 13% of the potential impact and electricity generation 12%. Terrestrial ecotoxicity is similar to aquatic ecotoxicity: 83% has its origin in material production (7% aluminium and 76% copper). Electricity generation results in 12% of the potential impact compared with 5% from diesel refining.

5.1.3 Acidification and Eutrophication

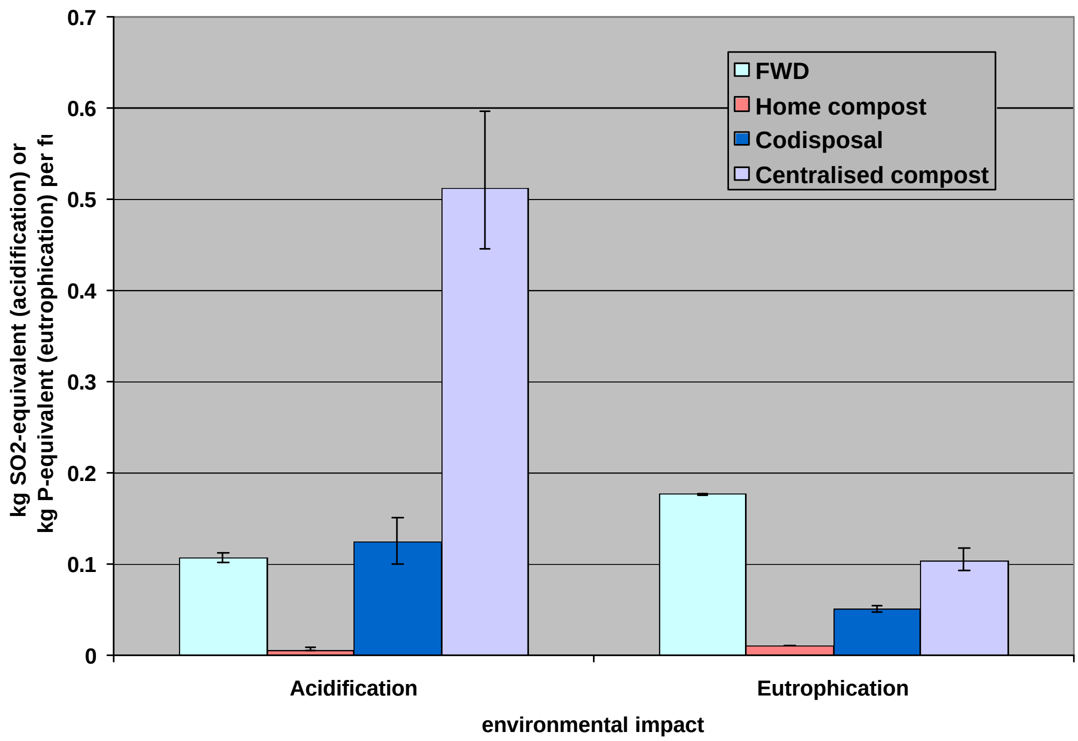


Figure 11: Acidification and eutrophication

A comparison of the options in terms of acidification potential reveals the centralised composting option has the highest environmental impact: 0.512 kg SO_2 equivalents emitted. This is a consequence of the release of nitrous oxides in the combustion of diesel fuel. The FWP system is clearly better, emitting 0.106 kg SO_2 equivalents, which is better than the co-disposal option (0.125 kg SO_2 equivalents). The home composting operation performs the best, with a contribution of 0.006 kg SO_2 equivalent to the acidification issue.

The FWP system is the least favoured option in terms of eutrophication potential, emitting 0.177 kg P equivalent to water (river and seas) based on experimental data carried out in this project. This figure is controlled by the ability of the sewage treatment plant to remove nutrients from suspension and from the aqueous phase of sewage. Bondi STP is a "high rate primary" plant, so approximately 50% of the influent nitrogen and phosphorous are released in the treated effluent. Central composting is better in terms of eutrophication (0.104 kg P equivalent). The co-disposal option releases 0.051 kg P equivalent respectively. These figures are lower than the FWP due to the sequestration of nutrients in the landfill. The home composting operation performs well against all the technology-intensive options, releasing only 0.010 kg P equivalent per functional unit under aerobic conditions due to the emission of a weaker leachate.

5.1.4 Odour

In the absence of uniform quantitative data, it is appropriate to restrict the treatment of odour to a qualitative discussion of the odour sources in each of the four options assessed in this study.

Food waste processor:

1. *Trucking*: Diesel trucks emit a variety of gaseous airborne contaminants and soot, however, the most unpleasant odours would be expected from trucking operations transporting biosolids, municipal waste and green waste. There are no models of the significance of these emissions (Jiang, 2000). As a result of FWP usage an increase in biosolid loads from the STP of between 31 and 311 t/a has been predicted, depending on the market penetration (see Table 9). This equates to an additional 1 – 11 truck movements per year, or 0.3% to 2.8%. Additional odours resulting from the small increase in truck movements or truck loads are considered to be very small. It can be concluded that trucking movements resulting from FWP usage would have a small marginal impact on odours.

2. *Water filtration and In-Sink-Erator operation*: These operations are essentially odourless.

3. *Sewage treatment*: The Bondi sewage treatment plant is entirely enclosed or underground. Three mechanical ventilation systems draw air from the plant and clean the air with sodium hypochlorite and or caustic soda solutions. As a consequence of these engineering controls, and the plant's windy position on the Sydney coastline, resident odour complaints are rare[13].

Home composting:

No impacts from home composting units occur under fully aerobic conditions.

[13] Sydney Water received a total of 83 odour complaints in FY97/98 regarding its coastal sewage treatment plants (this includes Warriewood, North Head, Bondi, Malabar, Cronulla, Bellambi, Bombo, Port Kembla, Shellharbour and Wollongong - Sydney Water, 1999).

Co-disposal with municipal waste:

1. *Collection*: In practice, the prevention of nuisance odour emissions from household and communal food waste collection systems, requires that the associated bins should be emptied each week (Bragg 2000). This was assumed for this LCA study. The emission of fugitive nuisance odours from trucks collecting waste can be expected.

2. *Landfill*: A wide variety of malodorous compounds can be expected at landfill sites. It is difficult to say which are the result of the decomposition of food waste and which are derived from the wide variety of other putrescible material delivered to such sites.

Centralised composting:

The discussion of collection is also relevant here (see section co-disposal with municipal waste).

In an assessment of the environmental impacts of the Eastern Creek Green Waste Processing Facility (Waste Service, 1995), "Dynamic Olfactometry" (DO) was performed using odours trapped at the windrow surfaces after the first turning of the windrows. The plume modelling concluded that the odours emitted by the facility would not adversely effect the nearest residential dwelling, approximately 400m to the south-west. Discussions with the Waste Boards (Bragg, 2000) suggest that composting facilities receiving food waste would be required by the EPA and/or Department of Health to enclose the windrows in order to prevent free travel by disease vectors including flies. Such facilities would then require mechanical ventilation (Australian Standards, 1991), presenting the opportunity to install odour scrubbers, should that be required.

5.1.5 Human health effects from separate food waste collection

Organic waste is collected separately in a number of countries. However, investigations with regards to potential impacts on human health are very rare. In the Netherlands a study has been published investigating green waste as a source of microbiological air pollution after investigation of microbiological loads in houses (Ministerie 1998, see Appendix C for a selective translation of the study). This research investigates the exposure to living micro-organism (mould and bacteria) and their toxins.

For several years the organic waste fraction from households has been collected separately in the Netherlands. Green waste can be used for the production of compost. The separation of waste takes place in the household. However, the digestion of organic waste by bacteria and mould already starts in the kitchen. There is often a significant increase of bacteria and mould growth in organic waste buckets and in wheelie bins for organic wastes outside the household. Therefore, the domestic waste, and particularly the organic fraction, can be an important source of microbiological exposure both in the household and working environment. Microbiological exposure includes viable mould and bacteria as well as dead micro-organisms (including their cell wall particles and exudate).

From previous studies[14] it is known that inhalation of microbiological agents can cause various respiratory disorders, e.g. specific allergies, immunity and infective reactions both in upper (nose, throat) and deeper respiratory tract and lungs. Moreover, acute toxic effects can appear due to exposure to high concentrations of microorganisms and their toxicity, resulting in fever and other flu symptoms (so-called organic dust toxic syndrome (ODTS)). Other symptoms might occur such as irritation of eyes, nose, throat and skin, discomfort of stomach and intestine, and diarrhoea.

Until now, there have been no results concerning the nature and scale of the exposure of microbiological agents as a result of waste separation and waste buckets in houses. Some studies have been published with regards to the exposure of microbiological agents during waste collection, in material recycling facilities (MRF) and in compost industries. This studies reports high to very high exposure to living micro-organisms (mould and bacteria) and their toxins.

Measured concentrations of these microbiological agents are significantly higher in households with separated organic waste collection than in households without it: the concentration is 1.6 – 3.0 times higher per m^2 than in households without separate waste collection. However, a very important factor is the type of floor covering. The concentration of microbiological components is 10 – 100 times higher for a textile floor covering (carpet etc.) compared with a plain covering, such as wood. The effects are *independent* from each other. For example the concentration of microbiological agents is equal to 1 in a household with a plain floor covering and without separate food waste collection. In a household with the same flooring material and with separate waste collection, the concentration is 1.6 – 3.0 times higher. In a household with a textile flooring material and no separate food waste collection, the concentration is 10 – 100 times higher, while in a household with textile flooring material and separate food waste collection it is 50 – 300 times higher.

However, little has been found concerning potential effects on human health. Reported human health effects include respiratory disorders and discomfort of the stomach and intestine.

5.1.6 Normalisation of results

Normalisation clarifies the importance of environmental impacts of one alternative against another. Hence, the results from Chapter 5.1.1 and 5.1.3 are normalised with respect to per capita contributions to the total environmental impacts (see Chapter 4.5). The normalisation covers energy consumption, global warming potential, acidification and eutrophication potential. Human and ecotoxicity are not considered due to the lack of normalisation data for these impact categories.

Normalisation calculations are performed as follows: the contribution of each alternative option to each impact category is divided by the annual normalisation data per capita and by a factor of 2.1. This factor represents the average number of persons in an Australian household. The maximum value on a per capita basis for all impact categories was 1.22% (see Table 3).

[14] Investigation of working environments with high micro-biological exposure.

Energy consumption

Centralised composting consumes 0.17% of the total annual energy consumption per person, while the FWP and co-disposal options require 0.05%, respectively. No energy is consumed by home composting.

Global warming potential

Co-disposal causes the highest impact with 0.37% of the total per capita annual contribution. The remaining options have relatively little potential impact on global warming (centralised composting 0.24%, FWP 0.16% and home composting 0.14%).

Acidification

The centralised composting option contributes 0.16% of the average annual personal contribution to acidification potential, while the other options have lower impacts – the FWP and co-disposal options cause 0.03% and 0.04%, respectively. No impact results from home composting.

Eutrophication

The FWP options makes a greater contributions to eutrophication potential compared with centralised composting, co-disposal and home composting (FWP 1.22%, centralised composting 0.72%, co-disposal 0.35% and home composting 0.07%).

Table 3 Normalised data on a per capita basis

Option	Energy consumption	GWP	Acidification potential	Eutrophication potential
FWP	0.05%	0.16%	0.03%	1.22%
Home composting	0.00%	0.14%	0.00%	0.07%
Co-disposal	0.05%	0.37%	0.04%	0.35%
Centralised composting	0.17%	0.24%	0.16%	0.72%

5.2 Sensitivity and uncertainty analysis

5.2.1 Generic considerations

As is apparent from Figure 9, Figure 10 and Figure 11, there are significant differences in the potential impacts of the four options, while in some cases, different options have a similar potential impact on impact categories. For example, in Figure 9, comparison of the energy demand of the FWP and the home composting options shows a difference of an order of magnitude, while the FWP and co-disposal options have similar energy demands. Generally, the options are so differentiated, that a clear preference hierarchy exists for each impact category. Where there is an exception to this generalisation, the potential impacts of similar options are well within the tolerances specified by the sensitivity analysis, as shown in the figures using error bars (Figures 9 – 11). This allows the reader some confidence in the ranking of options within each impact category.

5.2.2 Energy recovery from landfills

Biogas from landfills is increasingly used for energy recovery. However, a wide range of gas capture rates is given in literature ranging from 30% up to 85% (Grant *et al* 1999; ICF 1999, EC 1998). At Lucas Heights 2 landfill it is claimed to capture and utilise 66% of the biogas for energy recovery (Harvey 2000). Biogas generation is calculated based on Tchobanoglous *et al* (1993). The plant efficiency is assumed to be 36.5% (Menzies 2000).

However, estimates of avoided environmental impacts from energy recovery from landfills are highly uncertain. Hence, avoided environmental impacts have been calculated for biogas capture rates ranging from 10 to 100%. The avoided environmental impacts lead to an actual reduction of the environmental impacts from co-disposal compared with a landfill without flaring and energy recovery.

Energy recovery from landfill reduces the use of fossil fuels (coal) for electricity production and the reduced release of greenhouse gases into the atmosphere. This double benefit is recognised in the variable capture rates proposed leading to benefits separately quantified and combined into specific impact categories (see Table 4).

Table 4 Avoided environmental impacts from energy recovery depending on biogas capture rate

Capture rate	Energy input [MJ/a*fu]	Global warming [kg CO_2 eq/a*fu]	Human toxicity [kg DCB eq/a*fu]	Aquatic eco-toxicity [kg DCB eq/a*fu]	Terrestrial eco-toxicity [kg DCB eq/a*fu]	Acidifi-cation [kg SO_2 eq/a*fu]	Eutrophi-cation [kg P eq/a*fu]
10%	-103.4	-18.0	-0.5	-0.002	-9.9	-0.061	-0.003
20%	-206.9	-35.9	-1.0	-0.004	-19.8	-0.122	-0.007
30%	-310.3	-53.9	-1.5	-0.006	-29.6	-0.183	-0.010
40%	-413.7	-71.9	-2.0	-0.008	-39.5	-0.244	-0.013
50%	-517.2	-89.8	-2.5	-0.010	-49.4	-0.305	-0.017
60%	-620.6	-107.8	-3.0	-0.012	-59.3	-0.366	-0.020
70%	-724.0	-125.8	-3.5	-0.014	-69.2	-0.427	-0.023
80%	-827.5	-143.8	-3.9	-0.016	-79.0	-0.488	-0.027
90%	-930.9	-161.7	-4.4	-0.018	-88.9	-0.549	-0.030
100%	-1034.3	-179.7	-4.9	-0.020	-98.8	-0.610	-0.033

5.2.3 Energy recovery from anaerobic digestion at Bondi Sewage Treatment Plant

At Bondi, STP biosolids are anaerobically digested, and currently the biogas is combusted. A small proportion of the energy recovered supplies the heat for the digesters via a boiler. However, if the biogas were to be fully used for electricity generation, environmental impacts could be avoided.

For calculating the potential avoided environmental impacts several parameters were assumed – capture rate of dry material 51% (Evans 2000); fraction of volatiles 72% (SWC 1998); volatiles destroyed 50% (SWC 1998); and gas capture rate 100%. The plant efficiency for energy recovery is assumed to be same as at the landfill (conversion factor 36.5%).

Table 5 shows that there is high potential for environmental improvements. Avoided environmental impacts are comparable with a gas capture rate of 60 – 70% at landfills for all impact categories except global warming potential (see Table 4). Global warming potential does not change significantly because all biogas is combusted at Bondi STP anyway. Avoided electricity production resulted in 66.5 kg avoided CO_2-equivalence.

Table 5 Avoided environmental impacts from energy recovery at Bondi Sewage Treatment Plant

	Energy input [MJ/a*fu]	**Global warming** [kg CO_2 eq/a*fu]	**Human toxicity** [kg DCB eq/a*fu]	**Aquatic eco-toxicity** [kg DCB eq/a*fu]	**Terrestrial eco-toxicity** [kg DCB eq/a*fu]	**Acidification** [kg SO_2 eq/a*fu]	**Eutrophication** [kg P eq/a*fu]
Avoided environmental impacts	-698.5	-66.5	-3.3	-0.014	-66.7	-0.412	-0.023

6 Macro environmental considerations

Based on the findings in this LCA study (see chapters 2.3, 4 and 5) total environmental impacts can be estimated for following scenarios looking at different market penetrations of food waste processors (FWP). The scenarios encompass increased market penetration by FWP of 5%, 15%, 25% and 50%.

In chapter 6.1 - 6.4 it is assumed that all results calculated on the basis of the functional unit can be transferred to Waverley Council area. Waverley Council has a population of 24,900 persons in 11,954 households.

6.1 Water use

12.4 litres of tap water are required to shred 1 kg of food waste (see chapter 3.3.1). Consequently, 2.26 m^3 water are needed for treating the functional unit (182 kg of food waste per household per year). The total additional water usage per year can be calculated by extrapolating the water usage per functional unit on the population of the Waverley municipality.

A realistic market penetration of 5% leads to an additional water usage of 1.3 ML/a. Other scenarios cause a linear increase of water consumption (see Table 6).

Table 6 Additional water usage per year depending on different market penetration scenarios

Market penetration of FWP	Water use for FWP [ML/a]
5%	1.3
15%	4.0
25%	6.7
50%	13.5

6.2 Variation of total environmental impacts depending on different market penetrations of FWPs

Total environmental impacts from food waste in landfill can be calculated on the basis of Figure 9, Figure 10 and Figure 11 assuming that the entire food waste from all households in the Waverley area is disposed of to landfills (the so-called *reference scenario*). The figures in Table 7 (row 2 “0% FWP/100% landfill”) show the environmental impacts on landfills of the entire food waste generated in Waverley which is obtained by multiplying environmental impacts per functional unit by the number of households.

Environmental impacts per functional unit differ for the co-disposal and the FWP option as shown in chapter 5.1. Additionally, it is obvious that total environmental impacts will change if the market penetration of the FWP increases. In Table 7 the variation of total environmental impacts is indicated relative to the reference scenario. Values in Table 7 are calculated on the basis of environmental impacts per functional unit, number of households in Waverley area and different market penetrations of FWPs ranging from 5 to 50%.

An increased market penetration would lead to a reduction of greenhouse gas emissions from 1999 t CO_2/a (5% market penetration) to 1487 t CO_2/a (50% market penetration). The contribution to acidification and energy consumption would improve slightly. Impacts on other impact categories would worsen if market penetration by FWP increased (see Table 7).

Table 7 Total environmental impacts from food waste from landfill and FWP depending on different market penetrations

Waste Treatment		Energy	Global warming	Human toxicity	Aquatic eco-toxicity	Terrestrial eco-toxicity	Acidifi-cation	Eutrophi-cation
FWP	**Landfill**	[GJ/a]	[t CO_2 eq/a]	[t DCB eq/a]	[t DCB eq/a]	[t DCB eq/a]	[t SO_2 eq/a]	[t P eq/a]
0%	**100%**	1995	2056	0.9	0.02	51.4	1.49	0.61
5%	**95%**	1985	1999	1.4	0.03	69.8	1.48	0.68
15%	**85%**	1966	1885	2.4	0.03	106.5	1.46	0.83
25%	**75%**	1947	1771	3.3	0.04	143.2	1.43	0.98
50%	**50%**	1900	1487	5.7	0.05	235.1	1.38	1.36

Analysis of *relative changes* in the overall environmental performance of the system provide a better insight into the consequences of different market penetrations by FWP. A market penetration of 50% relative to the reference scenario would result in:

- a reduction of global warming potential (-28%), energy consumption (-5%) and acidification potential (-7%), and
- increases on human toxicity (factor 6), aquatic eco-toxicity (factor 2), terrestrial eco-toxicity (almost factor 5), and eutrophication (factor 2).

6.3 Changes in energy consumption for Water Filtration Plant, operation of FWP and Sewage Treatment Plant

FWP consume energy for:

- treatment and pumping of fresh water from the Water Filtration Plant (WFP) to the household,
- operation of the FWP, and
- pumping of waste water to the Sewage Treatment Plant (STP) and treatment at STP.

At the WFP, 1.40 MJ electricity/kL is required for pumping and treating fresh water (SWC 1999b), while 1.27 MJ electricity / kL is required for pumping and treating waste water (SWC 1999a). The FWP consumes 0.055 MJ per kg of waste. This results in an electricity consumption of 16.31 MJ / fu (WFP 3.15 MJ / fu for pumping and treating 2.26 m^3, FWP 10.07 MJ / fu for treating 182 kg and STP 3.10 MJ / fu for pumping and treating 2.44 m^3).

Table 8 Additional energy demand for Water Filtration Plant, operation of FWP and Sewage Treatment Plant depending on different market penetrations

Market penetration	Energy [GJ/a]
5%	10
15%	29
25%	49
50%	97

6.4 Loads diverted from MSW collection

In Waverley food waste is diverted from MSW collection by using FWP. This leads to a reduction of waste that goes to landfill, while the captured amount of food waste at Bondi STP (52 wet kg /fu) is recycled and trucked to a location where it can be used.

Table 9 Loads diverted from MSW collection and captured biosolids at STP

Market penetration	Loads diverted from MSW collection [t/a]	Loads of biosolids from STP [t/a]
5%	109	31
15%	326	93
25%	544	155
50%	1088	311

However, the overall transportation by truck does *not* decrease by diverting food waste from MSW. Transport can be measured in tonne-kilometres (tkm) which expresses the net load being transported by the total distance travelled with that load. While the transportation of food waste together with MSW requires 8.2 tkm/fu (distance from Waverley Council to Lucas Heights via Rockdale Waste Transfer Station 45 km), the transportation of biosolids requires 13 tkm/fu (distance Bondi STP to biosolids application is 250 km (Peters & Lundie 2000).

Table 10 Tonne-kilometers per annum depending on different market penetrations

Market penetration	Tonne-kilometers per annum [tkm/a]	Relative change [%]
0%	97903	---
5%	100778	2.9%
15%	106528	8.8%
25%	112278	14.7%
50%	126653	29.4%

7 Conclusions

This LCA study allows conclusions to be drawn with regards to

- the comparison of four different food waste disposal options (food waste processor (FWP), home composting, co-disposal and centralised composting), and
- additional general conclusions based on these results.

7.1 Comparison of four different food waste disposal options

Energy consumption: Home composting performs best due to its small energy consumption during the manufacturing process (14 MJ/fu). Food waste processor and co-disposal options do not differ much in terms of energy, 151 MJ/fu and 167 MJ/fu, respectively. The centralised composting option has the highest energy demand (553 MJ/fu) due to its intense collection and trucking activities.

Global Warming Potential: These results are significantly different to energy consumption. The most important variable is the breakdown process of food waste. Home composting generates least CO_2-eqivalents (67.2 kg), followed by FWP (76.8 kg CO_2-eq.), centralised composting (112.3 kg CO_2-eq.) and co-disposal (172.0 kg CO_2-eq.). In this comparison flaring of biogas from landfill is included while energy recovery is *not* taken into account. This has been separately discussed (see below as well as in chapter 5.2.2 and 5.2.3).

It should be noted that for each option all greenhouse gas emissions originating from the degradation process of food waste within the system boundaries are taken into account. If the CO_2 from the degradation process from food waste were to be excluded from the comparison, the contribution to global warming potential would be reduced to 0.5 kg CO_2-eq. for home composting, 14.0 kg CO_2-eq. for FWP, 45.6 kg CO_2-eq. for centralised composting and 124.9 kg CO_2-eq. for co-disposal option.

Modelling of the interrelated soil chemical processes which result from the application of biosolids and compost was explicitly excluded because of its complexity.

Human toxicity, aquatic and terrestrial eco-toxicity: A clear ranking of alternatives is possible with regards to human and eco-toxicity: home composting is by far the best option, followed by co-disposal, centralised composting and the FWP. The only contribution from home composting to human and eco-toxicity is caused by the manufacturing process. Impacts to human and eco-toxicity from co-disposal and centralised composting are mainly caused by trucking operations and energy supply, while the FWP impacts are due to the extraction and production of materials used in its manufacture.

Acidification: Again the home composting options scores best (0.006 kg SO_2 eq.). The FWP and co-disposal option cause higher acidification impacts (0.106 kg and 0.125 kg SO_2 equivalent, respectively). Centralised composting is rated last as a consequence of trucking activities (0.512 kg SO_2 equivalent).

Eutrophication: The FWP makes the largest contribution to eutrophication, adding 0.177 kg P equivalent to water, based on experimental data. This results in high environmental impacts because of the Bondi Sewage Treatment Plant's limited capacity for nutrients removal ("high rate primary treatment"). All other options perform better – home composting (0.010 kg P eq.), co-disposal (0.051 kg P eq.) and centralised composting (0.104 kg P eq.).

Based on quantitative LCA results an overall assessment can be made with regards to the four options under consideration (see Table 11):

– Home composting has the smallest environmental impact on all impact categories. The environmental performance would be even better if recycled material were to be used instead of virgin material in the production of compost bins.
– The FWP unit is second best regarding energy consumption, global warming potential and acidification.
– Co-disposal is the second best performer in human toxicity, aquatic and terrestrial eco-toxicity and eutrophication potential.
– Centralised composting has a relatively poor environmental performance due to its energy intense collection activities (two collection systems for residual waste and green waste operating parallel on weekly basis). Other collection modes (weekly clearance of split bins or collection of green waste weekly and residual waste fortnightly) would reduce environmental impacts to all impact categories due to smaller energy consumption. These were not quantified in this study, and more research is needed.

Table 11 Ranking of FWP options based on quantitative LCA results

Rank	Energy	Global warming	Human toxicity	Aquatic eco-toxicity	Terrestrial eco-toxicity	Acidifi-cation	Eutrophi-cation
1	HC	HC	HC	HC	HC	HC	HC
2	FWP	FWP	CD	CD	CD	FWP	CD
3	CD	CC	CC	CC	CC	CD	CC
4	CC	CD	FWP	FWP	FWP	CC	FWP

FWP food waste processor
HC home composting
CD co-disposal
CC centralised composting

Normalisation: This report does not attempt to apply societal values to determine which of the four options is overall the most preferable in environmental terms. However, it should be stated that when normalised to per capita emissions, the data indicates the FWP's contribution to eutrophication produces the greatest relative potential impact during food waste disposal (1.2%), followed by the centralised composting unit (0.7%). The co-disposal option makes significant contributions to global warming potential (0.4%) and eutrophication potential (0.4%). The energy consumption and acidification potential of these four options is relatively small. This suggests the impacts of centralised composting in these categories should be of lesser concern to policy makers than other impacts made by all options in other categories. It would be worthwhile to revisit these data sets when more information becomes available concerning the normalisation of ecotoxic impact category values.

Energy recovery: Electricity generation from coal is associated with relatively high impacts in several environmental impact categories. Therefore, electricity generation from biogas can lead to high environmental improvements by the FWP and co-disposal options. However, quantifying environmental benefits from biogas generation and energy recovery at landfills are highly uncertain (see chapter 5.2.2). At Bondi Sewage Treatment Plant biogas is currently not used for electricity production. Therefore, the electrical energy production at landfill and Bondi Sewage Treatment Plant can *only* be considered as a theoretical estimate. Most important parameters are the amount of generated biogas, plant efficiency and gas capture rate.

Odour: Impacts on odour could not be quantified due to the absence of uniform data. Sources of odour could be trucking of recycled waste and sewage treatment for the FWP option, operation of the home composting *only* in case of anaerobic digestion, trucking and landfill for co-disposal, and operation of centralised composting.

Human health effects from separate food waste collection: Separate food collection leads to higher concentrations of microbiological agents in households and during the collection of food waste. Effects on human health include respiratory disorders and discomfort of the stomach and intestine. However, reliable statistical information is not available regarding direct effects on human health due to higher concentrations of microbiological agents.

7.2 General conclusions from macro environmental considerations

Water use: The usage of FWP leads to an additional water usage of 2.26 m^3 per household per year. A market penetration of FWPs of 5% consumes approximately 1.3 ML/a of additional water in the Waverley municipality (see chapter 6.1).

Variation of total environmental impacts depending on different market penetrations of FWPs (chapter 6.2): An increase in market penetration to 50% would cause a reduction of greenhouse gases (-28%), energy consumption (-5%) and acidification (-7%). However, environmental impacts to other impact categories would rise dramatically due to the contribution made by the extraction and production of materials for the manufacture of FWP, and the additional loads of nutrients to water. At a market penetration of 50%, human toxicity would increase by factor of 6, aquatic eco-toxicity by a factor of 2, terrestrial eco-toxicity by a factor of 5 and eutrophication by a factor of 2. Overall energy consumption and acidification would remain the same.

Change of energy consumption depending on different market penetrations of FWPs: A FWP consumes 16.3 MJ/fu, thus the energy consumption amounts to 10 GJ/a assuming a current market penetration of 5% in the Waverley area (see chapter 6.3).

Loads diverted from MSW collection: Food waste processors divert food waste from MSW collection in Waverley at the rate of 109 t/a based on 5% market penetration. At the same time 31 t/a of biosolids are captured at Bondi STP and are applied on land. However the use of FWPs increases the total transportation impacts by 2.9% due to the long transport distance from Bondi STP to the application on land (see chapter 6.4).

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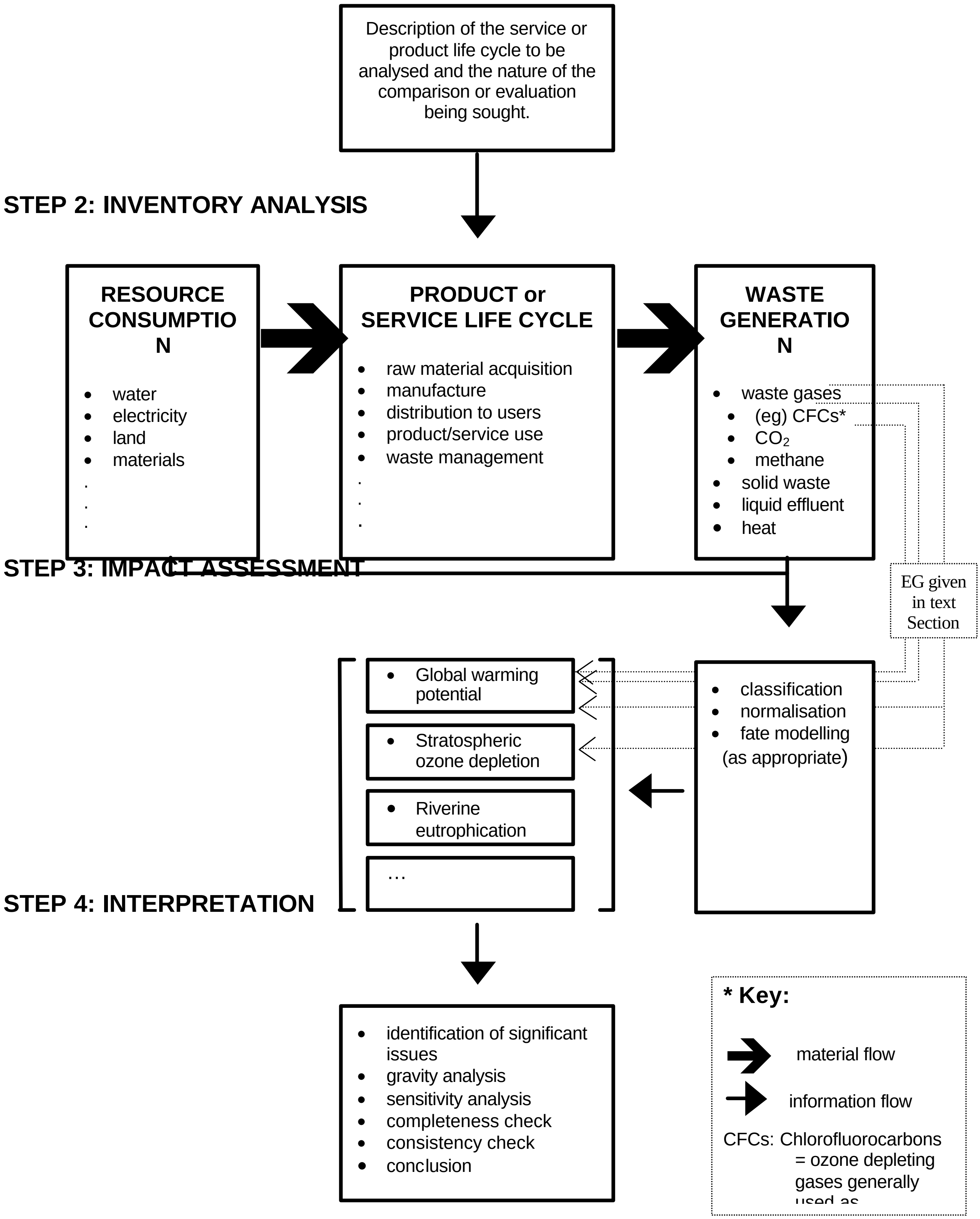
APPENDIX A: DIAGRAM OF LCA METHODOLOGY

STEP 1: SCOPE AND GOAL DEFINITION



APPENDIX B: ODOUR ASSESSMENT

Two main approaches to quantitative odour assessment exist. One is to examine the malodorous air on the basis of the concentration of individual odorous compounds and apply "ground level concentration" (GLC) criteria in assessing the significance of the odours. This approach has been developed by the Environment Protection Authority of Victoria. It involves the examination of the emission strength of an odour source, computer modelling of the gaseous plume, and comparison of the predicted concentration with the appropriate GLC criterion at the odour receptor. This allows for the dilution of the plume over distance. The GLC criteria are set according to health or nuisance criteria – whichever is more stringent. One difficulty with this approach is that different complex combinations of odours, as may be expected from composting operations, may be more or less offensive as a consequence of their composition. This is discussed further below. The GLC approach is recommended as generally applicable to all potential sources of odours except composting facilities and intensive livestock operations (Ministry for the Environment, 1995), and is not discussed further in this report.

The other main approach involves "odour performance criteria". Rather than focussing on the concentration of individual contaminants, this approach treats malodorous air as a mixture of contaminants. This is more applicable to sites with the potential of nuisance odours, such as composting operations, than sites where health risks exist on account of toxic gaseous emissions (Ministry for the Environment, 1995). As with the GLC approach, this involves modelling and comparison of computer model output with air quality criteria, but the initial characterisation of the odour source is performed on the basis of its detectability by a trained panel of "expert noses" in a process called "Dynamic Olfactometry" (DO) (Jiang and Sands, 1999). This treats the sampled air as a mixture, and does not attempt to separate its constituents.

The application of DO depends on the modelling of the actual plume dispersion environment, which will vary from multi-unit dwelling to multi-unit dwelling. While DO has been applied to development applications for large point-sources such as sewage treatment plants, we are not aware of it having been applied to moving sources such as trucks, let alone indoor odours resulting from the presence of food waste receptacles or bins as part of a centralised food waste system (Jiang, 2000). Poutschi *et al.* (1991) discuss the "hedonic tone" (effectively: "unpleasantness") of odours. They found wide variations in responses to odour within population groups. For example, while adults found the smell of cut grass to have "pleasant" or "neutral" hedonic tones, teenagers found it "unpleasant". The hedonic tone of "pure" food waste odour may be very different from that of a centralised system in which food waste is blended with municipal wastes (co-disposal option) or greenwaste (centralised composting option). Therefore it is inappropriate to apply simple scaling factors to a model of foodwaste degradation. Performing the necessary olfactometric investigations would involve considerable cost, and is outside the terms of this environmental assessment.

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APPENDIX C: Green Waste as a Source of Microbiological Air Pollution: Investigation of Microbiological Loads in Houses

Translation of the Dutch Study:

GFT (groente, fruit en tuinafval) – afval als bron van microbiele luchtverontreiniging. Onderzoek naar microbiele belasting in woningen

By Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Miliuebeheer: Nr. 1998/44

Content of the Study

1 Microbiological burdens in household by separate collection of GFT

1.1 Concentration of microbiological organisms in floor coverings

1.2 Concentration of microbiological organisms in the air (through measurement of endotoxins, glucans, extracellular polysaccharides (EPS))

2 Effects of microbiological burdens on human health

2.1 Intake concentration from microbiological loads

2.2 Technical description of intake and possibilities to prevent intake

2.3 Inventory of health problems

2.4 Characterisation of health risks (toxicological effects, allergies)

2.5 Relationship between measured exposure and health effects (asthma, allergies, stomach trouble)

Aims and Objectives

This report has two main objectives:

1. To determine to what extent separate waste collection leads to an increase in microbiological load in and around households.
   – Determine different concentrations of microbiological agents in flooring material with and without separate waste collection in households;
   – Understand the extent of exposure to biological agents in air caused by emptying organic waste bucket into an organic waste container near/next to the household.

2. Characterisation of microbiological exposure during waste collection (household waste and particularly organic waste) and compilation of related effects on human health:
   – concentration of microbiological agents measured during collection;
   – connection to the manner of waste collection (frequency of waste collection, technology etc.) and the exposure to microbiological agents;
   – inventory and specification of effects on human health (nature, frequency and duration) for organic waste collectors;
   – understand the physiological mechanisms that cause impacts on human health such as toxic effects, allergies etc. in order to understand health risks better; and
   – connection between measured exposure and effects on human health.

1a) Investigation of the housing conditions: Results

A total of 100 households were investigated (49 households with and 51 households without separate organic waste collection). In each household two samples of the floor material were taken. This is a commonly used method to determine quantitatively the exposure to house-mite allergies (Dutch: *huisstofmijtallergenen*). Samples were taken in the living room and in the kitchen. The households were located in cities with approximately 30,000 inhabitants. Most of the households are one-family houses, while some households were in multi-dwelling units. An experiment was carried out in order to quantify the exposure of viable mould and total bacteria and biological agents in materials by measuring their concentration during emptying the bucket and some time later after emptying the bucket in the container.

Different microbiological components were measured:

– Endotoxins as a measure for gram-negative bacteria; and

– Glucans and extracellular polysaccharides as a measure for mould concentrations.

Endotoxins can cause respiratory disorders, such as chronic bronchitis and reduced lung function. Glucans are considered to have similar effects on human health.

Measured concentrations of these microbiological agents are significantly higher in households with separated organic waste collection than in households without it: the concentration is 1.6 – 3.0 times higher per m^2 than in households without separate waste collection. However, a very important factor is the type of floor covering. The concentration of microbiological components are 10 – 100 times higher for a textile floor covering (carpet etc.) compared with a plain covering, such as wood. The effects are *independent* from each other. In other words:

> The concentration of microbiological agents is equal to 1 in a household with a plain floor covering and without separate food waste collection. In a household with the same flooring material and with separate waste collection the concentration is 1.6 – 3.0 times higher. In a household with a textile flooring material and no separate food waste collection is 10 – 100 times higher, while in a household with textile flooring material and separate food waste collection the concentration is 50 – 300 times higher.

The concentration of microbiological agents is similar for houses without separate food waste collection and for houses with separate food waste collection but instant emptying in a 'biopack' outside the house. Houses with a separate food waste bucket have a significantly higher concentration of microbiological agents in flooring material (1.4 – 2.5 times) than houses with waste without any organic fraction. The varying concentration is probably caused by different water contents (evaporation and absorption) for storing non-separated, mixed waste and storing food waste in a separated bucket. In waste buckets with mixed waste, liquid can easily be absorbed by packaging materials and other materials with are not present in the case of separate food waste collection. It is most likely that there are "different climates" for mould and bacteria in buckets with and without separate food waste collection.

The concentration of microbiological agents also depends on the frequency of emptying the food waste bucket. In houses where the bucket is emptied once a week or less, the concentration is 1.3 – 3.5 times higher than in houses where the bucket is emptied more than once a week. Indeed, there are significant differences in houses with separated food waste bucket and houses with waste without organic fraction: houses with separated food waste bucket have 2.0 – 7.6 higher concentrations than houses without separate organic buckets. If the GFT bucket (bucket with organic waste) is emptied more than once a week, concentrations are smaller than in houses without GFT bucket (1.4 – 2.5 times).

An increased concentration of mould and bacteria occurs during the opening and emptying of the separate food waste bucket. Exposure to mould spores is 10 times higher upon opening. This higher concentration vanishes 15 minutes after emptying the bucket. The concentration of living bacteria and other microbiological components does not increase.

1b) Investigation of living environment: Conclusions and Interpretation

There is a significant increase in microbiological agents due to separate collection and storage of GFT-waste in houses, particularly if emptying takes places once a week or less. Notably, high concentrations microbiological agents can occur if a textile flooring material is used in the house. In any case, it is recommended that the GFT bucket should be emptied regularly and more than once a week.

Based on this study, it is not possible to make a statement to what extent a higher concentration of microbiological agents in house dust (Dutch: *huistof*) is responsible for an unacceptable increase of load of lungs and therefore additional health risk. The concentration of microbiological agents in house dust has not been investigated. Until now there are no human health threshold values for measured substances in house dust to which it can related. Previous studies have shown that higher concentrations of microorganisms and microbiological agents in house dust can lead to serious problems with asthmatic and reduced functioning lungs. Similar health risks occur in wet houses. The flooring material seems to be the most influential factor compared with separate food waste collection and the frequency of emptying. Based on this study it is impossible to quantify the health risk. The only way to quantify this risk is by undertaking a more detailed investigation amongst the entire population.

IIa) Investigation of refuse collector

The investigation of garbage collectors consists of different sub-studies.

– *Inventory of general health condition*: A questionnaire was sent to 18 local and regional cleaning services. 155 waste collectors participated in the survey. They were asked when they were sick because of “general” respiratory disorders (Dutch: *luchtwegklachten*), such as cough, breathlessness, “whistling in the chest” etc. The same questionnaire was sent to supervisors (office workers, cleaning services, and postman). The aim was to identify respiratory disorders in the upper and lower part of the lungs that are probably related to working conditions. A higher percentage of waste collectors complained about health problems than supervisors, however, the difference is not significant.

– *General investigation of lung function*: 87 garbage collectors from eight companies participated in investigating their own exhalation (Dutch: *piekstroom* (PEF)). It was monitored three times a day over a two weeks period. PEF is the maximal exhalation speed. The speed is lowered by narrowed respiratory tracts (asthmatic reactions). Only in a few cases *no* indication was found of a clearly work-related narrowing of the respiratory tracts. There is also an indication of different stability of lung function (Dutch: *longfunctie*) during working days and days off. A correlation due to the exposure to microbiological agents can not be excluded, although other factors might possibly be involved.

– *Serological blood examination*: The blood of 93 garbage collectors was investigated with respect to antibodies against mould. The presence of such antibodies, especially of so-called IgE class, indicates an allergic reaction against mould as a results of exposure during work. Only a few workers showed weak IgE reactions against mould – no more than in other occupation groups. This means that the appearance of so-called “type I” allergies against mould[15] is not likely amongst garbage collectors. Antibodies of IgG class against mould were found in high concentrations. The results are comparable with other IgG anti-mould antibodies. Similar concentrations are found amongst workers exposed to laboratory animals, and bakers. The explanation is most likely that this mould occurs everywhere. The (much) higher exposure of garbage collectors to mould does not obviously lead to a higher production of IgG anti-mould antibodies.

[15] Quick reactions as known from allergies against grass pollen and pets.

– *Investigation of exposure*: An investigation was carried out wherein the garbage collectors used a mask that filtered all substances inhaled by a person per working day. The exposure is characterised by the quantity and composition of components, ie. endotoxins, glucans and extracellular polymeric substances (EPS). 78 garbage collectors were involved in this investigation in four large cites. 180 samples were taken.

  The average substance exposure was 0.58 mg/m^3. This value is significantly lower than in other working environments and occupations, e.g. bakeries and agricultural industries. The exposure to endotoxins is on average 40.2 endotoxins units (EU) per m^3. This factor is 10 – 20 times lower than in other working environments typical for exposure to organic substances (e.g. pig and poultry livestock breeding, compost industry), but of the same order of magnitude as in the potato manufacturing where a correlation was detected between a relative low exposure to endotoxins and a reduced function of lungs. The average value for garbage collectors is barely below an advised Dutch value of 50 EU/m^3 per 8-hour shift. 35% of the samples exceeded 50 EU/m^3 and 18% exceeded 100 EU/m^3.

  The concentration of glucans is 1 – 1.5 $\mu g/m^3$. This value is lower than in the compost industry (4 – 6 times) or on cattle farms. EPS could be measured only in some samples. For glucans and EPS there are no threshold values in the Netherlands.

On the basis of this study it is not possible to prove an unequivocal correlation between the collection of garbage (frequency, packaging of garbage etc.) and the exposure to microbiological agents.

– *Concentration of mould and bacteria at garbage trucks*: 150 samples were taken in order to measure the concentration of viable mould and bacteria behind the truck. Mould, total bacteria and gram-negative bacteria concentrations are higher (factor 10 – 100 for mould, 2 – 6 for total and gram-negative bacteria. The average concentration behind the garbage truck for mould is 1 x 10^5 KVE/m^3 and for total and gram-negative bacteria 1 x 10^3 KVE/m^3. There is no indication that the higher concentration leads to a significant increase of asthmatic and allergic, bronchial reactions.

– *'Neuslavage' investigation*: 59 garbage collectors participated in an investigation of neuslavage. The nasal cavity is flushed with a solution of physiologic salt. The fluid is analysed particularly with regards to specific types of cells and proteins (cytokines IL-8 and IL-6). These cells and proteins indicate infections in the nasal cavity. The average concentration of both cells and cytokines IL-8 were always higher for garbage collectors than for supervisors (e.g. office workers). However, the concentration for cytokines IL-6 were similar for garbage collectors and supervisors. The concentrations were highest at the end of the day and the end of the week. It can be concluded that garbage collectors have more and/or more intense infections of the upper respiratory tract, particularly in the nares, than supervisors. This can be attributed to the higher exposure of "neutrofiele granuloctyten". Most likely, this is a so-called "non-specific defence reaction" of the body due to the inhaled micro-organisms.

IIb) Investigation of garbage collectors: Conclusions and Interpretation

It can be concluded that there is a measurable exposure to microbiological agents during the collection of garbage. This exposure is considerably smaller than in other industrial sectors because most of the activities take place outdoors. However, the measured concentration of endotoxins is just below the advised Dutch threshold for human health, and this threshold is regularly exceeded. Considering experiences in other industries, it can not be excluded that long-standing exposure of employees to these endotoxins will affect human health, e.g., by causing chronic bronchitis and reduced lung functions.

A *remarkable finding* of this study is that the exposure to microbiological agents does *not* significantly differ between the collection of GFT waste, waste without organic material and mixed waste. This finding conflicts with the results from the housing conditions. Currently there is no good explanation for this. However, on the basis of these results, it can *not* be concluded that separate collection of GFT waste will lead to an increase in microbiological exposure of the waste collectors compared with mixed waste collection.

The different methods used to characterise the effects on human health provide a homogenous picture: there is a relatively limited, but not negligible, exposure to microbiological agents. There is a small increase in number of health complaints but without a clear pattern of symptoms. Also, there is an increase in number of complaints with regards to reduced lung function and bronchial hyperactivity, but again without a clear pattern of symptoms. The 'neuslavage' study shows significant differences between garbage collectors and supervisors in infections of the upper respiratory tract. It is most likely that these reactions are related to the exposure to microbiological agents during work. The same pattern is shown in an older study analysing human health effects on employees in a compost plant. The exposure of garbage collectors and employees of the compost plant are qualitatively comparable, but the exposure of garbage collectors is quantitatively smaller. Therefore, the degree of infection is smaller.

Similar infections in deeper lungs can be expected if dust particles, viable and dead mould and bacteria, that cause infections in the nares, accumulate in the lungs. It seems to be likely that complaints of reduced lung function and bronchial hyperactivity can be attributed to the same infections. At present, it can not be verified if the chronic exposure leads to a reduced lung function and to chronic bronchitis. Further research is needed to investigate the state of health of garbage collectors over a period of several years, particularly the function of the lungs and the appearance of diseases in upper and deeper respiratory tract and lungs.

APPENDIX D: Summary of quantitative results for each food waste disposal option

Table 12 Impacts of each food waste disposal option

	EC [MJ/fu]	**GWP 100** [kg CO2 eq/fu]	**HTP** [kg DCB eq/fu]	**AETP** [kg DCB eq/fu]	**TETP** [kg DCB eq/fu]	**AP** [kg SO2 eq/fu]	**EP** [kg P eq/fu]
FWP	151.0	76.8	0.866	0.006	35.0	0.106	0.177
Home compost	14.4	67.2	0.002	0.000	0.0	0.006	0.010
Co-disposal	166.9	172.0	0.079	0.002	4.3	0.125	0.051
Centralised compost	552.6	112.3	0.271	0.006	16.9	0.512	0.104

EC Energy consumption
GWP 100 Global Warming Potential 100
HTP Human Toxicity Potential
AETP Aquatic Eco-toxicity Potential
TETP Terrestrial Eco-toxicity Potential
AP Acidification Potential
EP Eutrophication Potential

Table 13 Relative contribution of food waste disposal options distinguished per process and impact category

		EC	GWP 100	HTP	AETP	TETP	AP	EP
FWP								
Operation		[MJ/fu]	[kg CO2 eq/fu]	[kg DCB eq/fu]	[kg DCB eq/fu]	[kg DCB eq/fu]	[kg SO2 eq/fu]	[kg P eq/fu]
	FWP electricity	14.0%	3.0%	13.3%	7.5%	7.5%	15.3%	1.0%
	wfp electricity	4.4%	0.9%	4.2%	2.4%	2.4%	4.9%	0.3%
	stp electricity	4.3%	0.9%	4.1%	2.3%	2.3%	4.7%	0.3%
	biogas combustion at stp	0.0%	83.4%	0.0%	0.0%	0.0%	0.0%	0.0%
	stp effluent	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	87.4%
	trucking	30.6%	3.9%	1.6%	0.0%	0.0%	36.5%	8.5%
	diesel refining	4.5%	0.8%	0.0%	12.7%	4.8%	2.9%	0.4%
Capital equipment								
	Copper	2.9%	0.0%	72.0%	29.9%	76.1%	19.8%	0.0%
	Aluminium	5.6%	0.9%	0.0%	45.3%	7.0%	4.0%	0.0%
	Steel	11.9%	3.5%	0.0%	0.0%	0.0%	6.0%	0.0%
	Concrete	6.8%	2.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Others		15.0%	0.7%	4.9%	0.0%	0.0%	5.9%	2.0%
Total		100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Home Composting		EC	GWP 100	HTP	AETP	TETP	AP	EP
Operation		[MJ/fu]	[kg CO2 eq/fu]	[kg DCB eq/fu]	[kg DCB eq/fu]	[kg DCB eq/fu]	[kg SO2 eq/fu]	[kg P eq/fu]
	Degradation of organic material	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	96.0%
Capital equipment								
	Plastic	100.0%	0.0%	100.0%	100.0%	100.0%	100.0%	4.0%
Total		100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Co-disposal		EC	GWP 100	HTP	AETP	TETP	AP	EP
Operation		[MJ/fu]	[kg CO2 eq/fu]	[kg DCB eq/fu]	[kg DCB eq/fu]	[kg DCB eq/fu]	[kg SO2 eq/fu]	[kg P eq/fu]
	Electricity generation	1.1%	0.0%	11.7%	1.9%	4.4%	0.9%	0.0%
	site electricity	0.2%	0.0%	0.0%	0.0%	1.0%	0.0%	0.0%
	STP electricity	0.2%	0.0%	0.0%	0.0%	0.7%	0.0%	0.0%
	diesel refining	9.6%	0.0%	31.3%	9.0%	12.0%	0.0%	3.4%
	site operations incl degradation of organic material	8.5%	94.4%	8.8%	7.7%	10.4%	9.4%	9.3%
	stp operations	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	5.4%
	Collection	57.5%	4.3%	41.9%	52.5%	70.7%	76.5%	77.0%
Capital equipment								
	pe	17.7%	0.0%	2.0%	0.0%	0.0%	4.7%	2.9%
	Pp	3.2%	0.0%	1.3%	0.0%	0.0%	3.2%	1.4%
	steel	0.0%	0.0%	0.2%	0.0%	0.0%	0.0%	0.0%
others		2.1%	1.3%	2.8%	28.9%	0.9%	5.2%	0.6%
Total		100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Centralised Composting		EC	GWP 100	HTP	AETP	TETP	AP	EP
Operation		[MJ/fu]	[kg CO2 eq/fu]	[kg DCB eq/fu]	[kg DCB eq/fu]	[kg DCB eq/fu]	[kg SO2 eq/fu]	[kg P eq/fu]
	collection trucking	57.4%	21.5%	40.5%	0.0%	0.0%	61.3%	50.8%
	compost trucking	0.7%	0.3%	0.5%	0.0%	0.0%	0.8%	0.0%
	diesel production for facility	11.8%	3.7%	35.0%	88.4%	90.1%	4.3%	0.0%
	site operation incl degradation	18.0%	70.5%	19.9%	0.0%	0.0%	30.3%	25.0%
	electricity for STP	0.1%	0.0%	1.0%	0.0%	0.3%	0.0%	0.0%
	STP operation	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	19.7%
Capital equipment								
	styrene	0.0%	0.0%	1.5%	11.4%	9.5%	0.0%	0.0%
Others		12.0%	4.0%	1.5%	0.2%	0.2%	3.3%	4.5%
Total		100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

10 Capital and Operating Costs of the Food Disposal Options.

Sub-investigation 3

Cost Comparison of the Disposal System Options.

Sub-Investigation 3 – Contents

1 Introduction

This part of the study presents capital and operating costs at Bondi STP that would result from the operation of FWP units in Waverley Catchment. A cost analysis of the alternative food waste disposal options is then undertaken.

2 Capital and Operating Costs that would Result from Operation of FWP Units

2.1 Capital Costs

Bondi STP is a primary sedimentation plant. The main sewage treatment unit operations, ie screens, grit tanks and the primary sedimentation tanks, are mainly designed using hydraulic criteria to ensure suitable flow velocities and detention times through grit tanks and primary sedimentation tanks.

The results from this investigation show that flows contributed by FWP units in the Waverley Catchment study area for any of the adopted market penetration levels would be very small compared to the Mean Average Daily Flow treated at the scaled-down Bondi STP (Bondi STP was scaled-down by assuming that it only treated a flow of 7.314 ML/d, ie the Mean Average Daily Flow from the Waverley-Bondi Eastern Slopes Intercepting Sewer). At 50% market penetration, FWP units would only contribute an extra 0.5% to the Mean Average Daily Flow. It is considered that these small flow increases would not require capital upgrades of the screens, grit tanks and the primary sedimentation tanks at Bondi STP.

The annual mean Oil & Grease concentration in influent to Bondi STP was reduced by 40% to 23 mg/L during 1999 (refer Appendix 2 in Sub-investigation 1). This decrease was mainly achieved by the chemically assisted sedimentation facilities. The 50 percentile EPA Licence limit for effluent Oil & Grease is 30 mg/L.

This investigation indicated that a 15% FWP market penetration in Waverley Catchment could result in an increased Oil & Grease load to the scaled down Bondi STP of 2 to 7%, translating to an influent concentration of up to 25 mg/L. (A 50% FWP market penetration could increase Oil & Grease loads by 12 to 35%.) At 15% market penetration, it is possible that the EPA discharge limit for Oil & Grease could continue to be met with no additional chemical dosing requirements or by increasing the chemical dosing rate using the existing equipment. The same holds at 50% market penetration if the increase in Oil & Grease load was near the bottom of the range. Additional chemical dosing would be required to meet EPA licence requirements if the additional Oil & Grease contributed by the operation of FWPs was nearer the top of the range. However, without chemical dosing tests it is not possible to comment whether the existing chemical dosing equipment could provide the additional dosing requirements or whether the dosing equipment would require upgrading.

The volumes of dewatered biosolids that would be produced by the operation of FWPs in Waverley Catchment are very small. A 50% FWP market penetration would result in about 12% additional biosolids being produced. The same increase in sludge produced from the primary sedimentation tanks would be expected. These increases are considered to be marginally undesirable. Of the market penetrations studied, it is considered that a FWP market penetration of beyond 25% may necessitate the sludge digesters, dewatering centrifuges and biosolids handling and transport facilities requiring capital upgrades.

2.2 Operating Costs

Operating cost increases at Bondi STP as a result of FWP units in Waverley Catchment are considered below in terms of total plant and individual unit process costs. Operating costs for the twelve month period to December 1999 were provided by Sydney Water (refer Appendix 1). Relevant costs for the scaled-down Bondi STP are summarised in Table 1 and were used to calculate costs for treating flows from FWPs in Waverley Catchment.

Table 1 OPERATING COSTS AT BONDI STP (FOR 1999)

Type of Operating Cost	**Annual Operating Cost ($)**	**Unit Cost ($)**
Total plant (Note 1)	785,000	294/ML treated
Primary sedimentation	67,000	713/dry tonne sludge
Chemically assisted sedimentation (CAS)	1,760	19/dry tonne sludge
Digestion tanks	48,000	512/dry tonne sludge
Sludge dewatering	12,000	125/dry tonne sludge
Biosolids disposal	37,000	388/dry tonne sludge
Total of Process costs	165,760	

Note 1. Includes all process costs including pumping and ocean outfall, plant services, management costs, capital projects, administration costs, financial adjustments and licence fees.

Total plant and individual unit process operating costs for treating flows from FWPs in Waverley Catchment are shown in Tables 2 and 3.

Table 2 OPERATING COSTS TO TREAT FWP FLOWS BASED ON TOTAL PLANT COST

Market Penetration	**Flow (ML/y) (Note 1)**	**Annual Cost ($)**	**Incremental Increase (%)**
Current-5%	1.5	450	0.06
Future-15%	4.0	1,200	0.2
Future-25%	6.9	2,000	0.3
Future-50%	13.5	4,000	0.5

Note 1. From data in Table 4.3 of Sub-investigation 1.

Table 3 OPERATING COSTS TO TREAT FWP FLOWS BASED ON INDIVIDUAL UNIT PROCESS COSTS

Market Penetration	**Dry Solids (tonnes/y) (Note 1)**	**Annual Cost ($)**						**Increm. Increase (%)**
		Primary Sed.	**CAS**	**Digestion Tanks**	**Sludge Dewater.**	**Biosolids Disposal**	**Total**	
Current-5%	2.6	1,865	50	1,340	325	1,015	4,595	3
Future-15%	7.9	5,600	150	4,020	980	3,045	13,795	8
Future-25%	13.1	9,315	250	6,690	1,635	5,070	22,960	14
Future-50%	26.1	18,635	500	13,380	3,265	10,140	45,920	28

Note 1. From Table 4.11 Sub-investigation 1.

Comparison of the costs in Tables 2 and 3 with those in Table 1 demonstrates that FWPs in Waverley Catchment would result in very small increases in operating costs at Bondi STP based on total operating costs.

However, specific costs for individual process units could increase by up to about 30% at FWP market penetrations of 50%. It should be noted that individual process costs are only for the unit processes at Bondi STP that would be impacted by the operation of FWPs. Furthermore, these costs do not include costs for plant services, management, capital projects, administration, financial adjustments and licence fees.

3 Cost analysis of alternative food waste disposal options

Two approaches to cost analysis have been examined in accordance with the project brief. Costs which would be incurred by a household producer of food waste have been estimated and a separate estimation is made of the overall initial capital costs, which might be borne by a number of stakeholders. The estimates are based on discussions with staff of Waverley Council (Galante, 2000), suppliers of waste and composting bins (Rotoplastics (2000), Nylex (2000), Hardwarehouse (2000)), a licensed, Sydney-based installer of In-Sink-Erators (Dishmaster Appliances, 2000) and information provided by the relevant utilities (SWC (1999), Energy Australia (2000)).

3.1 Methodology for the cost assessment

The assessment is based on the Net Present Value Method:

$$NPV = \sum_{t=0}^{10} C_t \cdot (1+i)^{-t}$$

with t = years ranging from 1 to 10,
C_t = costs in year t, and
I = annual discount rate.

The NPV is calculated for a range of discount rates (5 – 10 %).

3.2 Costs to the resident

For the purpose of including both initial and annual costs to the resident, the Net Present Value method was applied using a time period of 10 years and annual discount rates of 7.5 %.

3.2.1 Food Waste Processor

The initial cost for a FWP was taken as $ 815.00. This is based on the most commonly used FWP unit Model 75, costing $ 750.00 (Bonsak 2000)[1], plus installation amounting to $ 65.00.

The annual electricity costs are $ 0.15 based on 5.46 c/kWh (Energy Australia 2000). Annual water costs amount to $ 2.04 (SWC 1999).

3.2.2 Home Composting

A home composting unit costs approximately $ 45 (Rotoplastics (2000), Nylex (2000), Hardwarehouse (2000). The home composting unit is used for food and garden waste. The ratio of food waste to compostable green waste is 0.78. Thus, the proportion of food waste on the compost bin is $ 35.03.

There are no operating costs assuming a correctly operated composting system.

3.2.3 Co-disposal

No capital costs are assumed since the co-disposal system is already in place.

The annual waste collection charge is $ 235.00 (Waverly Council 2000). The proportion of this for food waste is $ 55.38 based on a ratio of 4.25:1 (total waste:food waste) calculated using BIEC (1997).

[1] It should be noted that FWPs can be purchased from $159 to $750 (Bonsak 2000).

3.2.4 Centralised Composting

The centralised composting system requires an additional household bin ($ 14.00) and a communal bin ($ 89.00) (Rotoplastics (2000), Nylex (2000), Hardwarehouse (2000)). The household food waste portion of the communal bin is $ 3.46[2].

For the council waste collection charge two approaches were taken:

1. The annual waste collection charge is $ 235.00 (Waverly Council 2000). The proportion of this for food waste is $ 55.38 (see section co-disposal); and
2. Council estimate of the expected food waste charges $ 17.52[3] (Galante 2000).

All operating and capital costs are summarised in Table 4:

Table 4 Net Present Values of the four food waste disposal options considering operating and capital costs

	FWP	**[$]**	**Home Composting**	**[$]**	**Co-disposal**	**[$]**	**Centralised composting**	**[$]**
Capital costs	FWP unit (model 75)	750.00	Portion of home compos-ting unit	35.03			Househould bin	14.00
	Installation	65.00					Portion of communal bin	3.46
Operating costs	Electricity costs	0.15			Portion of annual waste collection charge	55.38	Portion of annual waste collection charge *or*	55.38
	Water costs	2.04					Council esti-mate of the expected food waste charge	17.52
NPV[a]		830.04		35.03		435.52		155.26 – 452.98

[a] 7.5% discount rate

These results, as summarised in the figure below, indicate the food waste disposer option is approximately twice as expensive to the householder as the next least expensive options.

Co-disposal ranges from $ 396 per year (discount rate 10%) to $ 483 per year (discount rate 5%).

[2] Based on the assumption that 5 bins are required for 100 households. The ratio of food waste to green waste in Waverley is 1:1.28 (BIEC, 1997), the density of food waste is 425 kg/m^3 (Grant et al., 1999) and the volume of the bin is the standard 240 L.

[3] The costs for food waste charges are based on estimated total annual costs for biowaste (green and food) collections on a weekly basis (approximately $680,000 per annum) divided by the number of households multiplied with the proportion of food waste in the biowaste (Galante 2000).

The upper estimate of the cost of centralised composting is very close to the estimated cost of co-disposal. Note that both of these figures are obtained by assigning a proportion of the current Council waste disposal charges to the collection of food waste. This approach takes a point of view for the householder that a cost saving through the avoidance of current food waste disposal procedures is not obtained. The money the householder pays is merely redirected. There is a significant difference between the upper and lower estimates of the cost of the centralised composting option ranging from $ 143 (discount rate 10%, food waste charges $17.52 per household and year) to $ 500 discount rate 5%, food waste charges $55.38 per household and year).

The home composting option is by far the least expensive option.

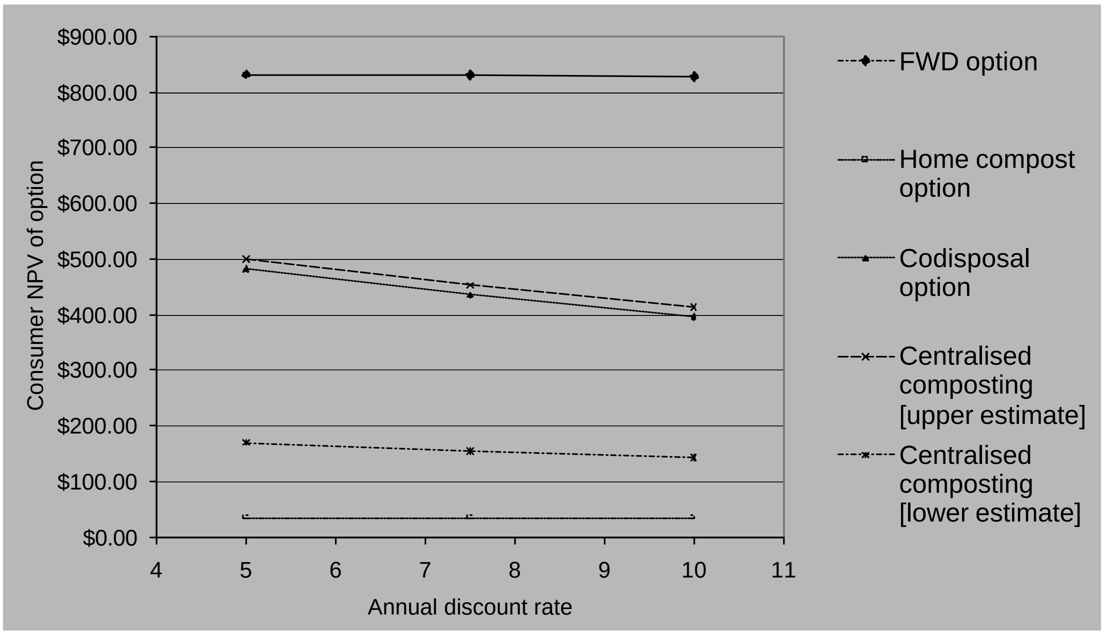

Figure 1 Net Present Value for four different food waste disposal options depending on discount rate

3.3 Overall capital costs

The overall capital costs are calculated as the cost to residents together with the additional capital cost required to establish or upgrade the waste treatment facility. For the purposes of this comparison, this facility cost was determined by assigning that fraction of the total which corresponded to the food waste disposal option's utilisation of the available capacity. An incremental approach was taken in estimating capital costs – where facilities already exist (i.e. in the co-disposal option) capital costs were set to zero.

3.3.1 Food Waste Processor

Most of the capital cost is related to the FWP unit itself (99.99%).

The incremental capital cost for the treatment of effluent was taken to be the cost of constructing additional grit tanks at Bondi STP. The grit tanks are the part of the plant least able to accept additional flows according to Sydney Water (1998).

The overall capital costs range from $ 487,151 (5% market penetration) to $ 4,871,504 (50% market penetration) in Waverley Council.

3.3.2 Home Composting
Home composting units result in a capital cost ranging between $ 20,940 and $ 209,396 depending on the market penetration.

3.3.3 Co-disposal
No additional capital costs are required.

3.3.4 Centralised Composting
In Waverley, garden waste is collected every fortnight (Fuller 2000). However, a centralised garden *and* food waste collection system and a composting facility do not exist for Waverley Council. Thus, the setup of this system requires substantial investment in capital equipment. Household and communal bins have to be purchased. The cost of recycling trucks was estimated as $75,000 on the basis of Browne (1996).

There is much published data in the literature on the cost of centralised composting facilities (Biocycle, 1998-99) and this was used to generate the cost curve:

$y = 8802x^{1.144}$

where

y = plant capacity in tpa
x = capital cost of the plant and equipment in millions of US dollars.

(The correlation coefficient (R^2) for this relation is 0.826.) An exchange rate of A$1.64/US$ was assumed (a typical rate for early March 2000). A facility capacity of 50,000 tpa was assumed.

The overall capital cost ranges from $ 144,266 for a 5% market penetration to $ 1,354,036 for a 50% market penetration. A large proportion of the capital cost arises through the purchase of trucks (68% - 73%), while the composting facility (19% - 24%), household bins (6%) and communal bins (2%) contribute less.

Table 5 Capital cost for FWP, home and centralised composting as a function of market penetration

Waverley market penetration				
	5 %	**15 %**	**25 %**	**50 %**
Food Waste Processor				
STP upgrade	$25	$75	$125	$249
FWP unit (model 75)	$487,126	$1,461,377	$2,435,628	$4,871,255
Total	**$487,151**	**$1,461,452**	**$2,435,753**	**$4,871,504**
Home Composting				
Home composting units	$20,940	$62,819	$104,698	$209,396
Total	**$20,940**	**$62,819**	**$104,698**	**$209,396**
Centralised Composting				
Household bin	$8,368	$25,103	$41,839	$83,678
Communal bin	$2,071	$6,212	$10,353	$20,707
Collection trucks	$98,605	$295,816	$493,027	$986,054
Composting facility	$35,222	$92,019	$143,814	$263,597
Total	**$144,266**	**$419,150**	**$689,033**	**$1,354,036**

The FWP option is the most expensive of the four options examined. The high initial cost of the unit itself, and its installation, dominates the figures. Centralised composting is the next most expensive alternative, due to its reliance on the use of a dedicated fleet of collection trucks for both the collection of the green waste and for the delivery of compost to the consumer. Home composting was more expensive than co-disposal in terms of initial costs, as the co-disposal system is the status quo and therefore has only operating costs.

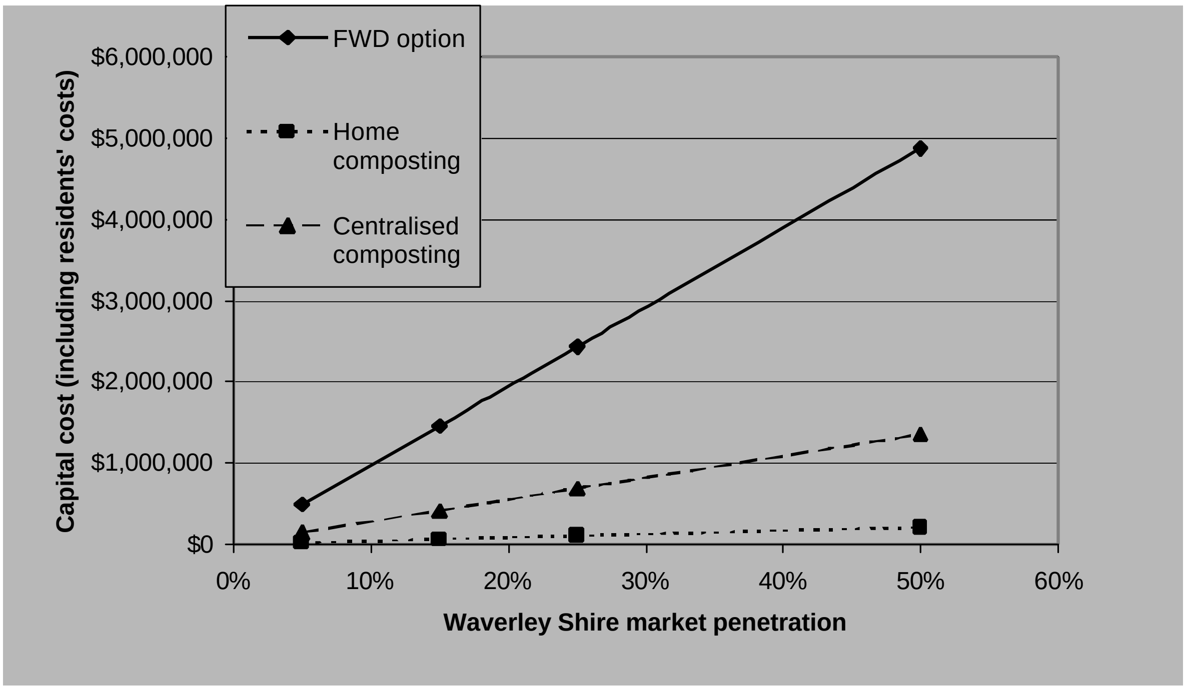

Figure 2 Capital costs for food waste disposer, home and centralised composting

Note that the cost of the centralised composting system has been estimated on the basis of the proportion of a 50 000 tons per year facility. This size of facility is considered realistic for these calculations. For low market penetration rates, it is assumed that the facility would find alternative sources of compostable material in order to carry out its operations, and the capital cost of the facility is reduced in proportion to how much of the plant's capacity is used by the food waste.

4 Conclusions

The results from this investigation show that flows contributed by FWP units in the Waverley Catchment study area for any of the adopted market penetration levels would be very small compared to the Mean Average Daily Flow treated at the scaled-down Bondi STP. It is considered that these small flow increases would not require capital upgrades of the screens, grit tanks and the primary sedimentation tanks at Bondi STP.

A 15% FWP market penetration in Waverley Catchment could increase Oil & Grease loads to the scaled-down Bondi STP by 2 to 7%. It is possible that the EPA discharge limit for Oil & Grease could continue to be met at this market penetration level with no additional chemical dosing requirements or by increasing the chemical dosing rate using the existing equipment.

The volumes of dewatered biosolids that would be produced by the operation of FWPs in Waverley Catchment are small. Of the market penetrations studied, it is considered that a FWP market penetration of beyond 25% may necessitate the sludge digesters, dewatering centrifuges and biosolids handling and transport facilities requiring capital upgrades.

FWPs in Waverley Catchment would result in very small increases in operating costs at Bondi STP based on total operating costs. However, specific costs for individual process units could increase by up to about 30% at FWP market penetrations of 50%. It should be noted that individual process costs are only for the unit processes at Bondi STP that would be impacted by the operation of FWPs. Furthermore, these costs do not include costs for plant services, management, capital projects, administration, financial adjustments and licence fees.

On the basis of either the total capital cost or the cost to the residents, the FWP option is the most expensive, and the cost of the unit dominates both values. However, the cost of the food waste processor option can be considered as an 'upper estimate' because the largest and most expensive model was investigated.

The co-disposal of waste does not involve additional capital expenditure as this is the current operating system, however, the cost to the householder of this system is at the high end of estimates of the cost to the householder of the centralised composting option. However, the lower cost estimate to the residents for the centralised composting options seems to reflect better economic reality than the upper estimate.

Home composting is the least expensive option for the householder.

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APPENDIX 1

OPERATING COSTS FOR BONDI STP FOR 1999

Bondi Process Costing Report - YTD as at period 12-99/00

Process Cost	Unit	Actual Cost $	Unit Cost $ / Unit	98/99 Total Unit Cost $ / Unit
Screenings	*Dry Tonnes Screens*	725,930	2,375	2,648
Grit	*Dry Tonnes Grit*	401,395	579	555
Primary Sedimentation	*Dry Tonnes Sludge*	1,186,198	713	628
Chemically Assisted Sedimentation	*Dry Tonnes Sludge*	31,071	19	92
Pumping	*ML Treated*	449,845	9	8
Ocean Outfall	*ML Treated*	129,856	2	2
Secondary Processes	*ML Treated*	0	0	0
Tertiary Processes	*ML Treated*	0	0	0
IDAL	*ML Treated*	0	0	0
Odour Control-Scrubbers	*Kilograms sulphide*	412,405		0
Thickeners/DAF	*Dry Tonnes Sludge*	0	0	0
Digestion Tanks	*Dry Tonnes Sludge*	851,586	512	597
Sludge Dewatering	*Dry Tonnes Sludge*	208,303	125	166
Screening: By-Product Disposal	*Dry Tonnes Screens*	240,513	787	1,184
Grit: By-Product Disposal	*Dry Tonnes Grit*	183,272	264	330
Scum: By-Product Disposal	*Dry Tonnes Grit*	0	0	0
Sludge: By-Product Disposal	*Dry Tonnes Sludge*	645,489	388	413
Plant Services	*ML Treated*	452,652	9	5
Miscellaneous Processes	*ML Treated*	2,163,691	41	37
Risk Management	*ML Treated*	1,850	0.04	0
Integrated Management Systems	*ML Treated*	2,280	0.04	0
OHS&R Management	*ML Treated*	165,000	3.15	0
Capital Projects	*ML Treated*	9,198	0.18	0
Environmental Improvements	*ML Treated*	0	0.00	0
TOTAL PROCESS		8,260,531		
Unit Cost / Mgl	*Total Process Cost $$ / Mgl*		158	146
Unit Cost / Dry Tonne	*Total Process Cost $$ / Dry Ton*		3,103	3,032
Administration		4,149,745		
Dep., Fin. & P.Yr adjs		2,998,874		
TOTAL PLANT		15,409,149		
Unit Cost / ML	*Total Cost $$ / ML*		294	271
Unit Cost / Dry Tonne	*Total Cost $$ / Dry Tonnes*		5,789	5,634

Outputs		**YTD**	**98/99 YTD**
Screens	*Dry Tonnes*	306	259
Grit	*Dry Tonnes*	694	829
Sludge	*Dry Tonnes*	1,663	1,527
Megalitres Treated	*ML Treated*	52,379	54,417
Sulphide Extracted	*Kilograms removed*	0	0

Cost of Operating the Waverley-Bondi Eastern Slopes Submain

Two estimates are:

(1) Cost of Operating BOOS $\times$ Area of Submain catchment $\div$ (Area of BOOS catchment)

= \$6,799,720 $\times$ 222.5 $\div$ 3,900

= \$400,000 per year

(2) Cost of operating BOOS $\times$ Volume of sewage transported by Submain $\div$ (Volume of BOOS)

= \$6,799,720 $\times$ 6 $\div$ 145

= \$300,000 per year

BOOScost
24 July 2000

11 Additional Health Risks of the Food Disposal Options.

Sub-investigation 4

Microbial Risk Assessment of the Disposal System Options.

Sub-Investigation 4 - Contents

1 Summary

The three objectives given for the microbial risk assessment component of this study were:

- Microbial risks associated with sewer overflows caused by FWP units;
- Relative microbial risks between the four processing options; and
- Risks associated with disease vectors.

A formal quantitative microbial risk assessment (QMRA) approach was undertaken at a screening level to compare risk between the various options under consideration. To compare pathogen risks, each of the four possible pathogen groups was represented by an index organism; *viz*: a virus (rotavirus), a bacterium (*Salmonella typhimurium*), a parasitic protozoan (*Giardia lamblia*) and a helminth (*Ascaris lumbricoides*). The selection of four representative organisms was an improvement upon most published microbial risk assessments.

Rotavirus was chosen as it is the most infectious sub-group of viruses excreted by humans (enteric viruses), which have been extensively studied due to their high infectivity and prevalence amongst children and the elderly. Non-typhoid salmonellae were chosen, as they are commonly associated with foods in the kitchen, are relatively hardy in the water environment and may regrow in food wastes. Of the parasitic protozoa, *Giardia lamblia* is the most numerous and highest risk protozoan from untreated sewage, and it is more infectious than *Cryptosporidium parvum*. Although helminths (worms and flukes) are not prevalent in Australia, *Ascaris lumbricoides* was chosen as its eggs (ova) are the hardiest amongst the helminths; hence it serves as a conservative index organism for the helminths.

Risk were characterised in a way to answer the first two project objectives, such that (referring to the risk pathways identified in Figure 1):

- Probability of infection if 1mL of sewer overflow was accidentally ingested (exposure point A);
- Probability of infection from raw food wastes (exposure point B) and home compost (exposure C) based on accidental ingestion of 1g of material; and
- Probability of infection from compost produced from a centralised facility (exposure point D) based on accidental ingestion of 1g of compost.

Risks from two other possible pathways, 1) the additional pathogen load from food wastes to sewer for ocean outfall or to land with biosolids, and 2) the co-disposal of wastes to a central municipal landfill and leachate to STP, were considered negligible (Haas *et al*., 1996) and were not assessed.

Overall the study identified that:

- Risks from overflows from raw sewage would be unacceptable, however, FWP units may only marginally increase the rate of sewer overflows during periods when the sewer is already flowing at 100% (such as during storm events).
- Domestic composting, without the addition of pet faecal wastes or meat products, was predicted to result in acceptably low infections rates for all the pathogen groups.
- Commercial composting (including human faecal wastes) appears satisfactory from the point of view of no significant pathogen risks.

- Overall vector-based diseases were not considered significantly different due to the operation of FWP units and on-site domestic composting in approved containers.

2 Introduction

Disease potential from sewerage-systems has traditionally been evaluated via enumeration of faecal indicator species such as *E. coli* and faecal streptococci, with their comparison to acceptable guidelines. A major failing of this guideline approach is that faecal indicator organisms do not directly indicate pathogen presence, particularly after some form of treatment, and are therefore often not or only poorly correlated with disease outcome (Payment *et al*., 1997; Levy *et al*., 1998; Smith & Rose, 1998). Consequently, the relationship is particularly uncertain in novel systems producing multiple effluent streams with differing characteristics, such as in a comparison of kitchen wastes, compost and sewage overflows.

In contrast to the guideline approach, formal quantitative microbial risk assessment (QMRA) now offers an alternative to estimate health outcomes (Haas *et al*., 1999). QMRA is based upon estimating the exposure to specific pathogens, then using defined dose-response relationships the probability of infection/illness is characterised (Table 1). Recent advances in microbial exposure assessment now utilise probability distributions (probability density functions, PDFs) rather than point estimates (means), to better account for the variation in numbers of pathogens encountered (Teunis & Havelaar, 1999). Hence, the likelihood of infection is derived from this probability distribution of pathogen numbers via Mote Carlo simulation of pathogen numbers for each pathogen dose-response model, giving a statistical representation of the risk due to each exposure pathway identified.

The study of diseases in populations (epidemiology) could in theory also be applied to assess risks from the use of food waste processor (FWP) units. There are, however, four important factors that would make such an approach pointless. Firstly traditional epidemiological methods have a low sensitivity for detecting outbreaks (Frost *et al*., 1996). Second, there is a relatively high endemic rate of viral and bacterial infection in the community, which is seasonal, however resulting illness rates (i.e. what is typically detected) are extremely variable (Payment, 1991; Beaudeau *et al*., 1999; Mead *et al*., 1999). Third, the very low infective dose of viral and protozoan pathogens, hinders the identification of an outbreak source (Gale, 1996). Lastly, not only would it be a very costly exercise to have sufficient numbers of households (some thousands) to compare those with and without FWP units (intervention study design considered the most sensitive), but it would also be important to assess disease from sewer overflows and vectors which would occur outside of the intervention groups.

Given the vast array of possible pathogens present, it is not possible to assess all, hence a selection of key members (referred to here as index organisms) is made based on the circumstances and data available. For this study, each of the four possible pathogen groups was represented by an index organism; *viz*: a virus (rotavirus), a bacterium (*Salmonella typhimurium*), a parasitic protozoan (*Giardia lamblia*) and a helminth (*Ascaris lumbricoides*) (Table 2). The selection of four representative organisms was an improvement upon most published microbial risk assessments (Ashbolt *et al*., 1997; Olivieri *et al*., 1998; Teunis & Havelaar, 1999; Havelaar *et al*., 2000).

Table 1 Risk assessment paradigm for human health effects (adapted from Haas *et al.*, 1999)

Step	Aim
1. Problem Formalization and Hazard Identification	To describe acute and chronic human health effects associated with any particular hazard, including gastroenteritis, arthritis, diabetes etc. that may be caused by pathogens.
2. Exposure Assessment	To determine the size and nature of the population exposed and the route, amount, and duration of the exposure.
3. Dose-response Assessment	To characterize the relationship between various doses administered and the incidence of the health effect.
4. Risk Characterization	To integrate the information from exposure, dose-response, and health steps in order to estimate the magnitude of the public health problem and to evaluate variability and uncertainty.

Table 2 Major groups of disease-causing agents and examples used in the study

Group	Example	Environmental stage, shape and size (µm)
Viruses	rotavirus	Virion, spherical (0.02)
Bacteria	Salmonella typhimurium	Dormant rod-shaped cell (0.5 x 1.5)
Parasitic protozoa	*Giardia lamblia*	Cyst containing trophozoites, oval (14-16)
Helminths	Ascaris lumbricoides	Ova (egg) with thick cell wall (40)

Rotavirus was chosen as it is the most infectious sub-group of viruses excreted by humans (enteric viruses), which have been extensively studied due to their high infectivity and prevalence amongst children and the elderly (Gerba *et al*., 1996). Non-typhoid salmonellae were chosen, as they are commonly associated with foods in the kitchen, are relatively hardy in the water environment and may regrow in raw materials (Lahti & Hiisvirta, 1995; Yanko *et al*., 1995; Mead *et al*., 1999). Of the parasitic protozoa, *Giardia lamblia* is the most numerous and highest risk protozoan from untreated sewage, and it is more infectious than *Cryptosporidium parvum* (Bukhari *et al*., 1997; Payment *et al*., 2000). Though helminths (worms and flukes) are not prevalent in Australia, *Ascaris lumbricoides* was chosen as its eggs (ova) are the hardiest amongst the helminths (Blumenthal *et al*., 1996); hence it serves as a conservative index organism for the helminths.

Of the pathogens that may grow in the environment, bacteria responsible for legionnaire's and related diseases are the most important, given they have been isolated from some types of "composts". For example, *Legionella longbeachae* serogroup 1 infections are prevalent in South Australia and have outnumbered those due to *Legionella pneumophila* (primary pathogen from cooling tower outbreaks) (Cameron *et al*., 1991). *Legionella longbeachae* is common in poorly composted waste wood products used in potting mixes in Australia (Steele *et al*., 1990). Though the most commonly identified species in potting mixes were *L. longbeachae* serogroup 1 and *Legionella bozemanii*, other species may also be present in some samples (Steele *et al*., 1990).

Legionellae are not consistently found in source materials used to make potting mixes, but they multiplied quickly in the early stages of composting and reached high numbers within 4 weeks. Composting of waste wood products requires adequate moisture and nitrogen to be effective, and the process generates considerable heat. Even in winter, temperatures in the outer 300 to 400 mm of composting heaps are maintained for days between 25° and 35°C and are in the optimal range for the multiplication of soil legionellae and their associated free-living amoebae. Composting may be an important step in amplifying the numbers of *L. longbeachae* serogroup 1 and other legionellae common to pine bark and sawdust (although most are not considered pathogens). However, this is not data to indicate that legionellae are a problem from the composting of food or biosolids wastes (Hughes and Steele, 1994), and were therefore not further addressed in this microbial risk assessment.

3 Objectives

There were three objectives given for the microbial risk assessment component of this study, being to assess:

- Microbial risks associated with sewer overflows caused by FWP units;
- Relative microbial risks between the four processing options; and
- Risks associated with disease vectors.

Each of these objectives were addressed in the study design and are reported separately below.

4 Methodology

4.1 Estimation of pathogen numbers

The microbial hazards chosen for the study have already been described in the introduction and are given in Table 2. Further supporting evidence for the selection comes from a recent study of enteric pathogens from a random sampling of 1091 faecal samples from asymptomatic adults (no illness evident) from Melbourne, Victoria. Twenty-eight known pathogens were identified, giving a total carriage rate of 2.6% (Hellard *et al*., 2000). *Giardia* species were present in 18 specimens (1.6%), *Salmonella* in four (0.4%), *Campylobacter* in one (0.1%), *Cryptosporidium* in four (0.4%) and adenovirus in one (0.1%). The median age of those without a pathogen was 12.5 years compared with 6.6 years for those with a pathogen (P = 0.02). Hence, except for *Giardia*, pathogens were rarely found in asymptomatic individuals in the community, but the prevalence of pathogens was higher in children than adults. Looking at symptomatic people, rotavirus is the most prevalent cause of (childhood) diarrhoea (Barnes *et al*., 1998) and used in this study as a useful pathogen in its own right, but also to index the likely waterborne human caliciviruses (e.g. Norwalk) and hepatitis A virus (LeChevallier *et al*., 1999), as no dose-response data was available for the latter viruses.

The four index pathogens were treated as log-normally distributed particles coming from the faecal waste contribution of households (i.e. in raw sewage), with the additional source of Salmonellae also coming from kitchen wastes (to sewer or compost). Various studies have confirmed the log-normal distribution of pathogens in waters and solids (Petterson *et al*., 1999).

For log-normal distributions, the probability density function (PDF) for each pathogen is simply described by its mean and standard deviation (Table 3). The exposure pathways used in the study are given in Figure 1. It was assumed that no pathogen die-off occurred in the sewer, being consistent with the conservative risk assessment approach used throughout the study and consistent with published data (Table 4). For composting, die-off rates for domestic and commercial composters were used (Table 5). In general, pathogens are inactivated if the composting material is held at 53°C for 5 days, 55°C for 2.6 days, or 70°C for 30 minutes (Haug, 1993). The minimum temperature is 50°C (when only a few log reductions of faecal coliforms occurs in five days). Thus, as small-scale domestic composts are unlikely to reach the 50°C required for more than 5 days, an arbitrary value of 90% pathogen reduction was assumed, compared to 99.99% removal assumed for the commercial composting process. There is no standard for domestic composting and consequently no available data to support any pathogen die-off assumption or regrowth of salmonellae (Standards Australia, 1999). It was assumed that animal, but not human faecal matter may occasionally contaminate the domestic compost (via rodents' faeces [0.001% by weight of raw compost components]), but 0.1% human wastes may reach the commercial one (via disposable nappies).

4.2 Relative Microbial Risks from Sewer Overflows and Between the Four Processing Options

Risk were characterised in a way to answer the first two project objectives, such that (referring to the risk pathways identified in Figure 1):

- Probability of infection if 1mL of sewer overflow was accidentally ingested (exposure point A);
- Probability of infection from raw food wastes (exposure point B) and home compost (exposure C) based on accidental ingestion of 1g of material, assuming that meat wastes are not present, in accordance with guidelines for domestic composting; and
- Probability of infection from compost produced from a centralised facility (exposure point D) based on accidental ingestion of 1g of compost. Faecal cross contamination from nappies was assumed to occur.

Risks from two other possible pathways, 1) the additional pathogen load from food wastes to sewer for ocean outfall or to land with biosolids, and 2) the co-disposal of wastes to a central municipal landfill and leachate to STP, were considered negligible and were not assessed. For example, Haas *et al*. (1996) concluded that, even with conservative assumptions, the health risk to humans from exposure to microbial pathogens of faecal origin deposited in well-designed and operated sanitary landfills is below levels currently considered to be acceptable under U.S. drinking water regulations applicable to treated potable water supplies.

Overall, PDFs for each pathogen reaching exposure points A-D (Figure 1) were estimated using 5000 iterations of a Monte Carlo simulation package (@Risk V4.0, Palisade Corp., USA) attached to Excel 2000 (Microsoft) and the appropriate dose-response relationships for each pathogen (Table 6).

Table 3 Mean and standard deviations for index pathogens

Pathogen	Source	Mean (# L^{-1})	Standard deviation
Total viruses (=Rotavirus)	sewage	13,350	20,680
Salmonella typhimurium	sewage kitchen wastes	50,000 100,000	30,000 80,000
Giardia lamblia	sewage	35,000	30,000
Ascaris lumbricoides	sewage	50	100

Adapted from Ashbolt *et al*. (1997); Yates and Gerba (1998) and Grohmann (*pers. comm.*)

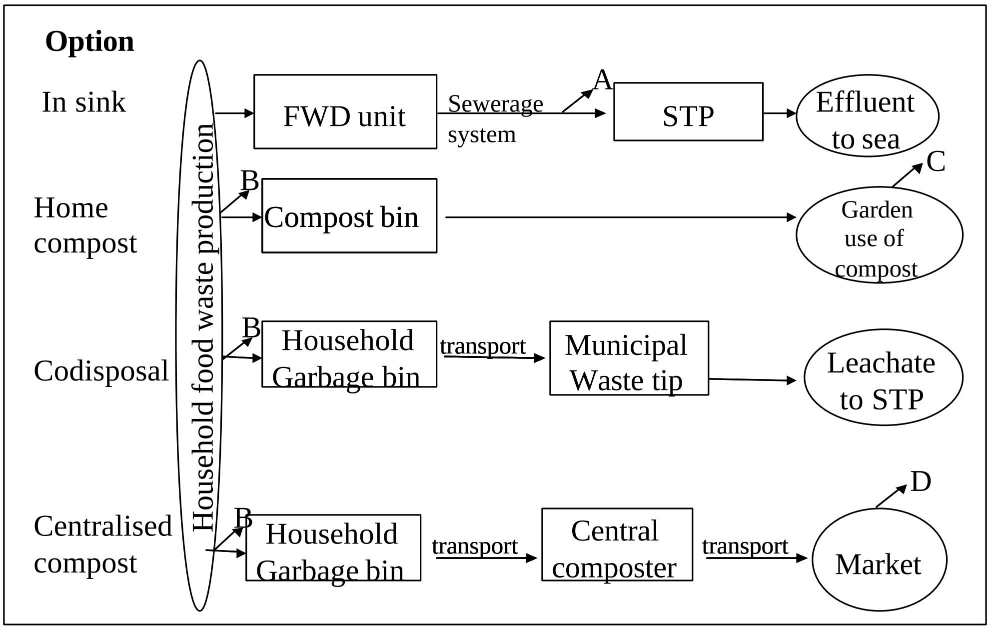

Figure 1 Exposure pathways and points (A-D) for the four disposal options

Table 4 Typical Pathogen Survival times at 20-30°C in various Environments

Pathogen/Indicator	**Survival time (days)**[1]		
	Wastewater	**Crops**	**Soil**
Bacteria			
Faecal coliforms (indicators)	<60, usually <30	< 30, usually <15	<120, usually <50
Salmonella spp.	<30, usually <10	< 30, usually <15	<120, usually <50
Parasitic Protozoa			
Entamoeba histolytica cysts	<30, usually <15	<10, usually <2	<20, usually <10
Human Viruses			
Enteroviruses (polio, echo & coxsackie viruses)	<120, usually <50	<60, usually <15	<100, usually <20

[1] Survival time for below detection, which often means for more than 99.9% removal. Note, however that there may be more than 10^5 pathogens.L^{-1} in a household with one infected person, so 99.9% removal means that there may still be more than100 pathogens.L^{-1} present after the time given in this table. Data adapted from Crook (1998).

Table 5 Time and temperature for enteric pathogen destruction in biosolids

Microbe	Exposure time (minutes) for destruction 50°C	55°C	60°C	65°C	70°C
Cysts of *Entamoeba histolytica*	5				
Eggs of *Ascaris lumbricoides*	60	7			
Brucella abortus		60		3	
Salmonella typhi		60	30		4
Escherichia coli			60		5
Mycobacterium tuberculosis					15-20
Enteric viruses					25

Data from Haug (1993)

Table 6 Best-fit dose-response parameters

Pathogen	Model[1] (P_{INF} =probability of infection; D=dose)	Illness rate	Illness Ref.
Giardia lamblia	exponential: $P_{INF} = 1 - e^{-\left(\frac{D}{50.23}\right)}$	50%	Regli *et al.* (1991)
Rotavirus	β-Poisson $P_{INF} = 1 - \left[1 + \frac{D}{5.60}\left(2^{1/0.27} - 1\right)\right]^{-0.27}$ ie $N_{50} = 5.60$, $\alpha = 0.27$	75%	Gerba & Rose (1993)
Salmonella typhimurium	β-Poisson: $N_{50} = 23600$, $\alpha = 0.313$	No available data assumed as for *Giardia lamblia*	
Ascaris lumbricoides	exponential: k=50.23	No available data assumed as for *Giardia lamblia*	

[1]From Ashbolt *et al.* (1997)

4.3 Risks Associated with Disease Vectors

Australia has a diversity of vectors and vector-borne human diseases. Mosquito-borne arboviruses are of greatest concern, but there are issues with other vector and pathogen systems. Mosquitoes were responsible for more than 35,000 cases of Ross River virus during 1991-1997 (Russell, 1998), and Mackenzie *et al*. (1994) have reviewed various vectorborne viruses, noting the importance of the a flavivirus that causes Murray Valley encephalitis.

In Russell's review (Russell, 1998) he noted that Barmah Forest virus is increasing nationwide, and unidentified bunyaviruses suspected of causing illness have been isolated. Cases of Murray Valley encephalitis have occurred in 14 of the past 20 years in northern Australia. Dengue is a continuing problem for northern Queensland, with various serotypes being active. Japanese encephalitis has appeared in the Torres Strait Islands and threatens mainland Australia. Though malaria is eradicated, almost 1,000 cases are imported annually and occasional cases of local transmission occur. With ticks, paralysis in children occurs annually in eastern Australia. Tick typhus (Queensland Tick Typhus - *Rickettsia australis*) occurs down the east coast, and (Flinders Island Spotted Fever - *Rickettsia honei*) in Bass Strait and probably Tasmania. Lyme disease is reported but its presence is controversial. Fleas were responsible for a recent outbreak of murine typhus (*Rickettsia typhi*) in Western Australia. Mites cause scrub typhus (*Orientia tsutsugamushi*), and there was a recent fatality in the Northern Territory.

Russell (1998) further commented that disease surveillance programs vary between states, and mosquito control programs are organized and effective in only a few regions. There are concerns for import of vectors such as *Aedes albopictus* (reported in the environs of Botany Bay in 1999 [NSW Health, 1999]) and export of pathogens such as Ross River virus; the former has occurred but the species has not become established, and the latter has occurred and has resulted in a major outbreak in the South Pacific. The predicted scenarios of increased temperature and rainfall with global warming are also causing concern for increases in vectorborne diseases, particularly the endemic arboviruses.

Hence, risks associated with vectors were based on increased mosquito likelihood. Given the lack of quantitative data on mosquitos and compost, however, only qualitative issues were addressed for the last objective of this report.

5 Results

5.1 Impact of Sewer Overflows Due to FWP Units

The results on the impact of food waste processor (FWP) units indicated negligible changes in pollutant loads in the adopted Waverley Catchment study area at all of the adopted market penetration levels compared to total loads received at Bondi STP (Nielson, 2000). Even at 50% market penetration, FWP units would contribute less than 1% additional loads of non-filterable residues (NFR) and nutrients and less than 2% additional loads of BOD_5 and COD. Therefore, the marginal increase in flow or solids from FWP units is minimal, but could still present a problem in parts of the system operating at 100% capacity, such as during storm events.

Furthermore, looking to 50% use of FWP units across the entire BOOS catchment would result in unacceptably high loads (about 15% increase) (Nielson, 2000) and potentially more sewer overflows at times of high rainwater entrainment. As reported by Nielson (2000), investigations in New York City have shown that no observable deposits of solids were observed in sewers in areas where FWP units were used (NYC, late 1990s). Thus sewer overflows are much more a reflection of leaky sewers than any hydraulic contribution from FWP units. This conclusion is supported by Dutch studies of their flat sewer systems (de Konig & van der Graaf, 1996), and data from Sweden (Nilsson *et al*., 1990). There does not appear to be any sound evidence in the literature to suggest that FWP units cause clogging or deposits of solids in pipes.

Therefore risks were simply calculated based on what is the risk if a person accidentally ingests 1 mL of sewage resulting from an overflow, to highlight the risks that overflows pose. The results presented in Table 7 support the emerging understanding of high viral risk from overflow impacts, such as the reported Norwalk-like virus outbreak at Parsley Bay, Sydney due to a leaking sewer (Ferson *et al*., 1993). An example of the distribution of risks is given for viruses in Figure 2; illustrating that 5 and 95 percentiles for viral infection risks were 29% and 71% respectively. Note that once *Giardia* cysts are released into warm water most will not be infectious after a week, whereas enteric viruses may remain infectious for many weeks (Fayer *et al*., 1998; Reynolds *et al*., 1998).

Table 7 Probability of infection due to accidental ingestion of 1 mL of sewage

Pathogen	Mean % Probability of infection
Rotavirus	52
Salmonella typhimurium	1.4
Giardia lamblia	18
Ascaris lumbricoides	0.37

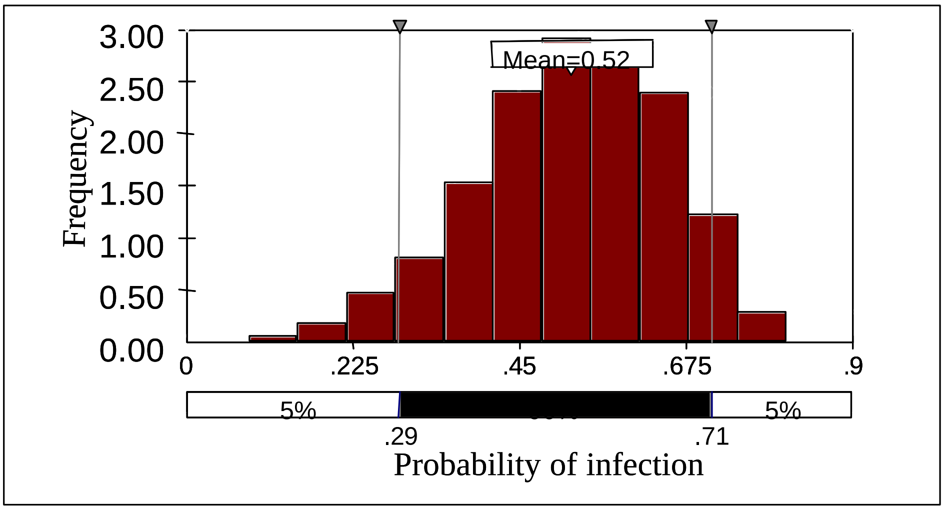

Figure 2 Probability of rotavirus infection if 1 mL of sewage ingested

5.2 Relative Microbial Risks between the Four Processing Options

The four processing options are illustrated in Figure 1 and the identified four exposure points were:

- In sink option, with accidental ingested from a sewer overflow (exposure point A) described in section 3.1;
- Probability of infection from raw food wastes (exposure point B) and home compost (exposure C) based on accidental ingestion of 1g of material; and
- Probability of infection from compost produced from a centralised facility (exposure point D) based on accidental ingestion of 1g of compost.

The estimated infection risks for the four exposure pathways are presented in Table 8. It is interesting to note that the risk of *Salmonella* infection from the ingestion of 1 g of raw uncomposted domestic kitchen wastes is equivalent to that of 1 mL of raw sewage, whereas a tenth and one hundred-fold less for *Giardia* and *Ascaris*. As no human wastes were assumed to be introduced into the kitchen wastes for composting, no human enteric viruses would be present. On the other hand, human faecal wastes from nappies resulted in an estimated rotavirus infection risk of 0.075% from commercially-produced compost, the highest risk estimated from the four microbial groups in this latter material.

In discussing what is an acceptable level of risk, it is interesting to compare the levels of protection between microbiological and carcinogen risk. If it is assumed that there is a 50-67% frequency of clinical illness following infection with rotavirus or *Giardia* (Gerba *et al*., 1996) then, using the lower bound of 50%, this translates to an annual risk of illness of 1 in 20,000. Gerba and colleagues do not cite a case-fatality rate for *Giardia*, but 0.1% in the general population seems to be a reasonable level based on other pathogens causing gastrointestinal symptoms (Gerba *et al*. 1996; Macler and Regli, 1993). This results in an annual risk of death of 1 in 20,000,000. Converting the annual risk to a 70-year lifetime risk to be comparable with rates cited for chemical contaminants results in a risk of 1 in $2x10^{-5}$; a figure which is similar to that considered acceptable by the WHO for carcinogenic risks. Hence, referring to Table 8, neither rotavirus nor *Giardia* would seem to offer an unacceptable risk except in pathway A.

Table 8 Likely infections per 1000 exposures for the four pathways by pathogen

	Mean	**SD**	**5th Percentile**	**95th Percentile**
Exposure A	**1 mL of raw sewage**			
Rotavirus	520	128	290	710
Salmonella	14	7.4	5.6	27.8
Giardia	180	16.1	156	208
Ascaris	3.5	6.1	0.21	12.3
Exposure B	**1 g raw collected food waste**			
Rotavirus	~0	~0	~0	~0
Salmonella	5.4	3.1	1.9	12
Giardia	0.019	0.0020	0.017	0.023
Ascaris	0.00037	0.0072	0.0000019	0.0013
Exposure C	**1 g mature domestic compost**			
Rotavirus	~0	~0	~0	~0
Salmonella	0.054	0.032	0.019	0.12
Giardia	0.019	0.0019	0.016	0.023
Ascaris	0.000036	0.000072	0.0000020	0.0013
Exposure D	**1 g mature commercial compost**			
Rotavirus	0.75	1.1	0.068	2.56
Salmonella	0.0113	0.008685	0.00315	0.0274
Giardia	0.199	0.01992	0.168	0.234
Ascaris	0.0038	0.0067	0.00037	0.0133

The outcome of infection, however, will vary according to a number of factors and many groups within society, such as the young, elderly, malnourished and so on are more susceptible to developing illness following infection than the general population. The causes of these health inequalities are various and include various genetic, geographical, behavioural and socio-economic factors (Table 9).

Looking at risks associated with salmonellae, however, are somewhat more difficult to assess. Most compost standards, including Australian (Standards Australia, 1999) recommend that species of salmonellae should be absent in about 50g of moist compost material. This checks two issues, one of satisfactory thermal kill during composting, and also that the material is stabilised so that if cross contaminated with raw material containing *Salmonella* spp., none would regrow. The latter is specifically tested to evaluate a new composting process to ensure sufficient stabilisation has occurred that regrowth is not an issue.

Table 9 Examples of factors that lead to inequality of health risk in relation to waterborne disease

Factor	Affects
Age	The very young and very old are more likely to acquire infections due to naïve or waning immunity and once infected are more likely to develop more severe outcomes.
Pre-existing disease	A person with AIDS or severe combined immunodeficiency syndrome is likely to suffer far more severe symptoms with cryptosporidiosis and other infectious illnesses.
Genetic	People with certain genotypes are more likely to experience complications such as joint problems following gastrointestinal infections.
Gender/Pregnancy	Certain infections are more severe in pregnancy, either increasing the risk of fatality for the woman (hepatitis E), or damage to the foetus (toxoplasmosis).
Behaviour	The amount of unboiled tap water an individual drinks will affect their risk of a waterborne infection. Foreign travel will expose an individual to risk of waterborne diseases that an individual will not have encountered at home. Other behaviours such as swimming will increase an individuals risk of acquiring infections by routes other than drinking water.
Socio-economic	The poorest members of society may suffer more severe disease due to malnourishment. The poorest members of society may suffer more serious economic consequences of illness because they are in jobs that do not pay sick leave or are not covered by health insurance for required health care. The poorest members of society may not have ready access to health care. Many waterborne diseases are more likely to spread to family members in overcrowded conditions.
Geography	Various waterborne diseases have marked geographical distributions; hepatitis E is largely restricted to tropical countries and tularaemia is more common in northern latitudes. The quality of water treatment and distribution systems differ markedly from one country to another and between locations in the same country.

While the ability to ensure thermal death is readily achieved by composting (see Table 5), the regrowth issue is far more controversial. Indeed, ranges of composts appear to have the same component that supports the growth of *Salmonella typhimurium* (Mamais *et al*., 1993). Nonetheless, regrowth not only relies on growth substrate, but also competitive advantage. While compost bacteria on agar plates appear not to suppress the growth of salmonellae, a few fungi do (Nielsen, 1989). On the other hand, Millner *et al*. (1987) showed that in compost inoculation assays, various bacterial rods and actinomycetes were suppressive, but the fungi were not. They also demonstrated that compost, which had reached 70°C for some time, was not suppressive to salmonellae, despite containing a range of microbes. Hence, regrowth of salmonellae is likely in poorly composted domestic wastes that are mixed with freshly contaminated material, but no regrowth figure is available from the literature.

Therefore, at this stage, domestic composting with uncontrolled temperatures and checks on compost maturity would have to be considered to contain salmonellae which may regrow and present an unacceptable risk. Without any salmonellae regrowth, however, no composting risks were considered unacceptable, although rotavirus risk from commercial composts was ranked the highest (Table 8).

5.3 Mosquito-Based Diseases

Dengue fever is probably the highest risk vectorborne pathogen associated with stagnant water in or nearby apartments in the area of this study. Dengue fever is caused by one of the four serotypes of the dengue virus and is transmitted by the urban mosquito *Aedes aegypti* and potentially *Aedes albopictus* in Sydney.

Risks can only be expected to increase if households have poorly organised pot plants with free water in sources and/or associated with on-site composting devices. Nonetheless, there is no reason to believe that owners of FWP units would be any different from other owners with only pot plants. Hence, increase risk would only be associated with compost leachate, which if acidic, would not allow the specified vectors to breed.

Russell (1999) has recently discussed the problems of constructed wetlands, which provide habitat for mosquitoes that can be nuisance pests and transmit pathogens such as arboviruses and malaria. In Australia, Ross River virus is responsible for thousands of cases annually in northern Australia of a disease that is severely debilitating, has regional incidence rates often exceeding 1:1000, and costs millions of dollars in health and other impacts. Though Ross River virus in not common in NSW, dengue fever is spreading south from northern NSW. Disease transmission depends on the urban mosquito *Aedes aegypti* which breeds in still water associated with pot plants and potentially in diluted compost leachate. Thus travellers may well introduce this virus to local mosquito populations in the Sydney environs, and global warming may allow the persistence of previously exotic vector-diseases (Russell, 1998) as indicated in New Zealand with two local mosquitoes, *Aedes notoscriptus* from the Auckland area, and *Aedes australis* from the Otago area (Maguire, 1994). Furthermore, introduction of new vector mosquitoes, particularly *Aedes albopictus*, could pose a threat in view of the high percentage of Australians expected to have no protective antibody.

Therefore, overall vector-based diseases were not considered significantly different due to the operation of FWP units and on-site domestic composting in approved containers. Furthermore, it should be standard local council information, that control of dengue epidemics involves the use of house screening and the removal of mosquito breeding sites such as stagnant water (McBride *et al*., 1998).

6 Conclusions

- Risks from overflows from raw sewage would be unacceptable, however, there was no evidence that FWP units would increase the rate of sewer overflows, except in sewers already operating at 100% capacity. .
- Potential salmonellae infections were the highest risks from accidental ingestion of raw food wastes, but still at an acceptable level. Risk from the other microbial groups were very low from exposure to raw food wastes.
- Commercial composting appears satisfactory from the point of view of no significant pathogen risks.
- Overall vector-based diseases were not considered significantly different due to the operation of FWP units and on-site domestic composting in approved containers.

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12 The Social Implications of the Food Disposal Options.

Sub-investigation 5

Social Impacts of the Disposal System Options.

Sub-Investigation 5 - Contents

1. Summary

Two focus group discussions were conducted to compare the relative merits (social factors) of four food waste disposal options in multi-unit dwellings in eastern Sydney. The options were assessed across four criteria: consumer choice, accessibility of the option, space requirements, and consumer uptake.

Disposal of food with municipal waste (the dominant current practice) was judged as being the least satisfactory of all the options. Individual garden composting, while environmentally ideal, was judged to be impractical for multi-unit dwellings.

The Food Waste Disposer system and the separate food waste collection with centralised composting were evaluated as being much more appropriate (across the four criteria) than the mixing of food and other waste. The key variable on which the value of the two favoured options was judged was the level of treatment and the potential for re-use that they offered. While the Food Waste Disposer system was most favoured, however, this assessment was provisional on the availability of a level of treatment that would enable re-use of the waste material.

2. Background

Focus group interviews were born in the late 1930's by social scientists who had doubts about the accuracy of traditional information gathering methods. Today focus group interviewing is used in market research to gather consumer perceptions and opinions on product characteristics and where the emphasis is placed on the understanding and thinking of consumers.

A detailed review of the application of focus groups for this type of research has been prepared by Krueger (1994). This research is not intended to be a survey of attitudes. The data derived from focus group research provide plausible interpretations and cannot be equated with statistically valid data.

The strength of the method is that it offers a carefully planned discussion designed to obtain perceptions in a defined area of interest (food disposal options in multi-unit dwellings) in a permissive, non-threatening environment.

3. Method

A pilot study was designed and conducted on 29 May 2000. This less formal group interview offered the opportunity to test the various aspects of the focus group technique (presentation of the research project; the wording of the questions; the flow of the questions; the respective roles of the two moderators; determination of follow-up questions). The final arrangement of questions is in Appendix 1.

Participants were formally invited to join either of two focus groups, which were conducted on 29 June 2000. An advertisement was placed in the *Wentworth Courier*, the primary suburban newspaper for Eastern Sydney (see Appendix 2). When an individual phoned one of the researchers inquiring about participating in the research, they were told that only residents in multi-unit dwellings in the Eastern suburbs would be eligible for inclusion in the study. The purpose of having two groups was to both double the number of participants and as a check on the quality of the data. A total of 15 interviewee (5 males and 10 females) allowed for the rejection of any views that were judged to be so extreme that they would bias the general findings. In the case of this study such rejection was not deemed necessary.

Participants were seated in a circle and offered light refreshments (tea and biscuits). The group discussions were audio recorded and were thus available for subsequent analysis.

The procedure followed in the design of the questions and flow of the discussion was drawn from Krueger.

4. Analysis of data

The information collected from the focus group discussions was judged to be raw data. The aim of the analysis was to look for trends and patterns that appeared across the two groups. Both the content and the emphasis or intensity of the respondents' comments were taken into account. Other considerations related to the consistency of comments and the specificity of responses in follow-up probes.

Background patterns

1. Participants responded to the invitation to speak their thoughts and feelings regarding the disposal of food waste from the kitchen. They all expressed their appreciation to the researchers for having arranged for this opportunity.

2. The term 'disposal' created an influential image for the majority of the interviewees. It was seen to be a negative image and one that conveyed predetermined judgements regarding outcomes.

Foreground patterns

1. The uniform attitude of the participants in the study, all unit dwellers, was of a "trade of" between the easy management of kitchen waste and a sense of being a 'good environmental citizen'. Participants spoke at length of the need for something 'that works' for them given a busy lifestyle and a restriction of space in multi-story units. It did not matter if the building was medium or high rise, this theme of the felt necessity for a trade-off was the same.

2. There was a strongly expressed feeling of dissatisfaction with the current waste disposal system by which the kitchen waste is mixed with the general waste and taken to landfill. When this issue was further explored it was found that the interviewees felt this current practice to be a waste of a potential and valuable resource. While they accepted that this is what happened and that they were 'part of the system', given that this is what they were paying for as a local government service, they were nevertheless conscious of feeling considerable discomfort.

3. The wish to be more adequately informed of what eventually happened to their waste gained momentum as each group discussion progressed. Clearly the interaction in the group, especially as regards possible disposal options, led to the development of the perception that to be able to make a more informed choice was desirable. The connection was then raised that a more informed choice would result in a feeling of increased responsibility.

Direct comparisons of options

1. *The Food Waste Disposer system* was judged to be highly useful for the very pragmatic reasons of (1) ease of use (2) no waste storage needed (3) no risk of vermin. The qualifications that were laid alongside the usefulness were (1) noise control (2) excessive use of water. Each time the

Food Waste Disposer was raised so was the question What *happens to the waste once it enters the sewerage system?* In summary, the FWP system was judged positively (accepting that the noise qualification above was sorted out) across all criteria as long as the end-of-pipe consequences were environmentally sustainable. The preference, as for all disposal systems, was for re-use of the converted waste as a resource.

2. *Individual garden composting* was assessed to be impractical for multi-unit dwellings. Composting was seen to be a positive thing to do with organic household waste, especially if combined with a garden, but without a backyard it was judged to be out of the question. The same general consensus related to householder-sized worm farms.

3. *Disposal of food with municipal waste*, as mentioned above under 'foreground patterns', was judged 'begrudgingly acceptable'. The issue of the kitchen waste being mixed with non-organic matter, and disposed of by burying, was seen to be the least attractive of all the options. The general consensus was that this was a waste of a resource.

4. *Separate food waste collection with centralised composting* was assessed to be vastly superior to mixing with municipal waste. Again, it was the question *What happens to the organic waste once it is collected?* that dominated the discussion. Participants were consistently concerned about the waste-to-resource issue and how this could be better managed. Each option was evaluated with this variable in mind. Secondary discussions occurred around the need for special storage requirements to guard against odours and vermin.

5. Conclusions

Having set a specific context for this study, namely, multi-unit dwellings, the key theme of the felt necessity for a trade-off between a practice that is easily managed and one that is ideally beneficial for the environment tended to dominate discussions. Perhaps the participants, because they responded to an invitation to discuss kitchen waste-management options, represented a population that articulated a high degree of environmental awareness (no evidence of an our-of-sight-out of-mind mentality). If this was so, the actual discussion of options did not show any unquestioned bias towards a particular option. Each option was considered in relation to the over-arching theme of the trade-off. Once the groups constructed this theme, and each group did so independent of the moderators and of the other group, each option was duly judged in relation to it.

The two most attractive options were the Food Waste Disposer system and the separate food waste collection with centralised composting. It was clear that only these two offered both adequate utility and potentially adequate environmental management. In both cases the obstacle to be addressed was the level of waste processing that was planned and the ultimate re-use of the processed product. If there was an adequate level of waste treatment available for the in-sink system then this was judged to be 'ideal' for multi-unit dwellings, as it would preclude potential problems associated with localised waste storage awaiting collection.

6. References

Krueger, Richard A. (1994) Focus groups: a Practical Guide for Applied Research. 2nd ed., London, Sage

7. Appendix 1 – Focus Group Questions

Getting Started:

Welcome etc.
Brief Overview of Topic
Ground Rules
Participants introduce themselves and tell a little about themselves.

Tape Recording

Identify self before talking

Role of First Moderator

Guides the entire process
Asks all the questions

Role of the Second Moderator

Take notes
Write & deliver 'Summary Statement'
Recording of answers

Topic

Evaluating the social implications (Social pros & cons) in multi-unit dwellings of 4 food disposal options:

- Food Waste Processor system (in-sink food disposal system)
- Individual garden composting
- Disposal of food with municipal waste
- Separate food waste collection with centralised composting.

Each option will be looked at from the following four points of view:

- Consumer choice
- Accessibility of the option
- Spare requirements
- Consumer uptake, including waste management behaviour and degree of participation in the option.

Opening Question:

The round robin question requiring brief factual answer (10-20 seconds):

How long have you been living in the Eastern Suburbs?

Introductory questions:

How many people live in your dwelling?
What do you currently do with your food wastes from the kitchen?

Transitions Questions:

These questions help participants envision topic in a broader scope.

Is the managing and disposing of kitchen waste a matter of much concern … do you think about it much?

Key Questions:

How do you feel *about the way that you presently dispose of your food scraps?*

What do you think *of individual garden composting?*

What do you think *of putting all your food scraps out with the weekly garbage?*

What are your thoughts *about an in-sink disposal system?*

What do you think about the local Council separately collecting food waste and then offering centralised composting?

How important is it for you to know what happens to your food waste?
- *Do you feel a sense of responsibility?*
- *Would you like to have choices?*

How big a factor for you is 'space'?
- *Space to store and dispose of waste?*

Ending Questions:

1. Summary Question

Asked after second moderator, that has given a short oral summary (2-3 minutes) of the main ideas that emerged:

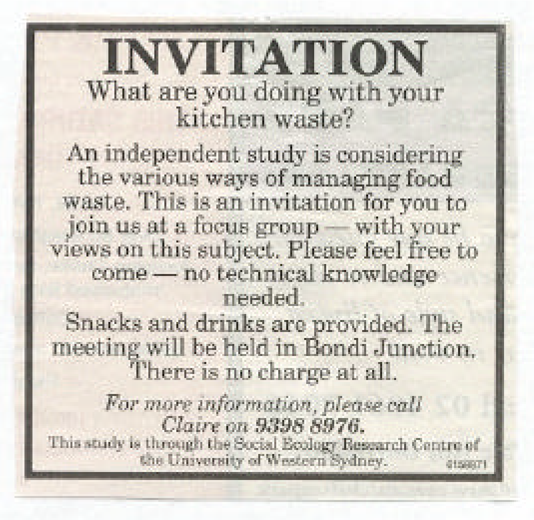
Is this an adequate summary?

2. Final Question

The moderator gives a short overview of the purpose of the study and then asks the question:

Have we missed anything?

8. Appendix 2 – *Wentworth Courier* Advertisement



INVITATION

What are you doing with your kitchen waste?

An independent study is considering the various ways of managing food waste. This is an invitation for you to join us at a focus group — with your views on this subject. Please feel free to come — no technical knowledge needed.

Snacks and drinks are provided. The meeting will be held in Bondi Junction. There is no charge at all.

For more information, please call Claire on ***9398 8976.***

This study is through the Social Ecology Research Centre of the University of Western Sydney.

13 Conclusions

The five investigations carried out in the course of this study have sought to evaluate the technical, environmental, economic, health and social aspects of the in-sink food waste disposal unit. The aim has been to quantify the positive and negative environmental impacts as well as the marginal infrastructure costs which would result from different levels of market penetration (5%, 15%, 25% & 50%).

The study has intentionally focused on multi-unit dwellings in the Waverley – Bondi area of Sydney, NSW, Australia.

The study has further sought to compare the FWP system with three other food waste management options (Home Composting, Co-disposal with MSW, and separate organic waste collection with Centralised Composting).

The salient outcomes from the five investigations are summarised below:

Technical Aspects of the FWP.

Sewerage systems differ from place to place, depending on factors such as age and the level of technology implemented. Undertaking a technical evaluation of the impact FWPs have on the sewerage system will necessitate defining the characteristics of the sewerage system in question, because the FWPs impact will be relative to the quantity of sewage and quality of treatment. The outcomes described in this study are relevant for the *Waverley/Bondi Eastern Slopes Intercepting Sewer*. While the methodology can be applied to other systems, care should be taken in transporting the results of the present study.

The additional hydraulic load resulting from the use of FWPs is very small. For the catchment area studied this load was calculated to be 0.007% of the *Instantaneous Maximum Flow* within the sewerage system, at 5% market penetration, rising to 0.07% at the 50% penetration level. This low additional load is not likely to increase the risk of sewer overflows, although if the sewer is running at full capacity during wet weather overflows may be experienced as a result of the total load.

The same applies to the hydraulic load on the STP: the additional flow contributed by FWPs in the study area at all market penetration levels examined is calculated to be very small compared to the flow treated at the Bondi STP attributable to the study area (the "scaled-down Bondi STP"): at 50% market penetration, FWP units would only contribute an extra 0.5% to the Mean Average Daily Flow. From a hydraulic load perspective, the STP would be able to cope with the additional load except when the plant is running at full capacity during wet weather when any additional load, including FWPs, will lead to an overflow situation.

The situation is different when considering the additional pollutant load on the STP. A 25% market penetration would lead to the production of 7% additional biosolids. Beyond this level, the performance of sludge digesters, dewatering centrifuges and biosolids trucking movements may be adversely affected.

The results for BOD_5 and Oil & Grease are more restrictive and indicate for a FWP market penetration of up to only 15% would operational problems not be expected at Bondi STP, while the NFR results would indicate a level of 20% (interpolated value) would be acceptable.

It follows from the biosolid, BOD_5, Oil & Grease and NFR results that for the area studied, an FWP market penetration of up to 15% will have no significant effects on the hydraulic load, capacity and performance of the sewerage system and the sewage treatment plant.

This must be tempered by the observation that increased levels of hydrogen sulphide generation would accompany any increased BOD_5 levels and this could lead to increased (but unquantified) corrosion and odour problems.

From the technical point of view, FWPs are not expected to have an impact on biosolids reuse, the marine environment or energy consumption associated with sewage treatment at the market penetrations studied.

Environmental Aspects of the Four Options.

The environmental profiles of the four disposal options are summarised in the following table:

Rank	Energy	Global warming	Human toxicity	Aquatic eco-toxicity	Terrestrial eco-toxicity	Acidifi-cation	Eutrophication
1	HC	HC	HC	HC	HC	HC	HC
2	FWP	FWP	CD	CD	CD	FWP	CD
3	CD	CC	CC	CC	CC	CD	CC
4	CC	CD	FWP	FWP	FWP	CC	FWP

FWP FWP
HC Home composting
CD Co-disposal
CC Centralised composting

The options have been ranked within each impact category but not across the categories as an overall impact assessment.

From an environmental point of view, well managed and controlled Home Composting is the most favoured option across all impact categories.

Of the other three options, the FWP was ranked approximately equal second with Co-disposal from the point of view of energy and acidification and equal second with Centralised Composting when considering global warming potential. It ranked fourth for the remaining categories of toxicity and eutrophication.

From these results the FWP is considered to represent a viable food waste disposal option with equivalent or smaller adverse impacts on energy consumption, global warming and acidification compared to co-disposal and centralised composting. When considering toxicity and eutrophication however, co-disposal is to be preferred over centralised composting and the FWP.

These impacts can be put into a wider perspective and compared with annual per capita emissions, where data is available:

Option	Energy consumption	GWP	Acidification potential	Eutrophication potential
Home composting	0.00%	0.14%	0.00%	0.07%
FWP	0.05%	0.16%	0.03%	1.22%
Co-disposal	0.05%	0.37%	0.04%	0.35%
Centralised composting	0.17%	0.24%	0.16%	0.72%

The results indicate that the FWP option has the greatest potential relative impact on eutrophication at 1.2%. This is followed by centralised composting at 0.7% and co-disposal at 0.4%. Relative impacts of all options on acidification and energy consumption are relatively minor, while for global warming potential of co-disposal and centralised composting are the highest.

These impacts relate to the “functional unit” defined for this study: the quantity of the food waste produced by a household in one year, that is 182 kg of wet food waste per annum. Accordingly, the impact ranking is independent of market penetration.

The environmental impact of the FWP compared to co-disposal of food waste was estimated as a function of market penetration. A market penetration of 50% would cause a reduction of greenhouse gases (-28%), energy consumption (-5%) and acidification (-7%). However, environmental impacts of the other categories assessed would rise dramatically due to the intense extraction and production of materials for the FWP unit and the additional loads of nutrients to water: increase of human toxicity by a factor of 6, aquatic eco-toxicity by a factor of 2, terrestrial eco-toxicity by a factor of 5 and eutrophication by a factor of 2. The overall energy consumption and acidification would remain the same.

Economic Aspects of the Four Options.

The study indicates that Home Composting is the least expensive option for the residents of multi-unit dwellings, while the FWP is the most expensive. The cost to the resident of Co-disposal and Centralised Composting are in between these two extremes, with that of Centralised Composting being marginally the cheaper.

From a system point of view, FWP appears again to be the most expensive option, and this cost increases beyond the 25% market penetration level in the study area as additional capital expenditure may be required at the sewage treatment plant. Pollutant load considerations are however likely to necessitate capital expenditure at a lower market penetration level (see above).

The Co-disposal system option would not necessitate additional capital investment (within limitations imposed by the existing landfill capacity) as this is the waste management option presently in place, whereas implementation of the Centralised Composting system option would necessitate capital expenditure since such a system suitable for food wastes does not exist within the Sydney area.

Health Aspects of the Four Options.

Assessment of the likelihood of ingestion of food waste from any of the four waste management options is beyond the scope of this study. It was possible however to evaluate the risk of infection in the event of ingestion occurring.

In the event of ingestion of raw sewage, the risk of infection was judged to be unacceptably high, however this risk was not attributable to level of FWP market penetration. As discussed above, the low additional load on the sewerage system attributable to FWPs is not likely to increase the risk of sewer overflows, although if the sewer is running at full capacity during wet weather overflows may be experienced as a result of the total load.

Of the remaining options, only home composting exhibit an increased risk in the event of ingestion occurring. This was of potential salmonellae infections from accidental ingestion of raw food wastes, but was judged to be at an acceptable level. Risk from the other microbial groups were very low from exposure to raw food wastes.

None of the options when operated correctly were judge to pose an additional risk of disease vectors.

Social Aspects of the Four Options.

From a social point of view, the Focus Group studies have shown that environmentally conscious occupiers of multi-unit dwellings, while conscious of the impact of waste management practices, are aware of the need for a trade off between easily managed and environmentally beneficial practices. In this context, the FWP and centralised composting system options are the most preferred and practical of the four options, but this is predicated on the requirement that the end product produced from the food waste (the biosolids or the compost) must be reused in an environmentally acceptable manner.

The selection of any waste management option for a particular waste stream will generally involve a trade-off because of the inherent difficulties in satisfying all selection criteria which are established. Informed decision-making therefore requires a transparent presentation of the relevant data so that the overall costs and benefits of the final decision can be understood. This study does not attempt to “sum” the various factors evaluated for the four food waste disposal options studied, or to score them relative to each other. Rather, the aim has been to assess the four options in terms of the given criteria so that impact of subsequent waste management decisions are quantified. as far as possible.

The following tables summarise the main points from the five investigations in terms of the six primary aims of this project:

AIM	Option 1 FWP
Current & future additional sewer load for the study area.	0.004 ML (5% penetration) to 0.037 ML (50% penetration) per day
Positive and negative macro environmental impacts from the use of FWPs:	
1. Occurrence of sewage overflows	Unlikely to impact.
2. Sewage treatment process	Little impact up to 15% market penetration. Some additional H_2S generation.
3. Biosolids reuse	Unlikely to impact.
4. Marine environment	Negligible impact.
5. Energy consumption	Negligible impact.
Food Waste loads diverted through FWP.	At 5% penetration, 109 tpa diverted, offset by 31 tpa additional biosolids.

AIM	Option 1 FWP	Option 2 Home Composting	Option 3 Co-disposal	Option 4 Centralised Composting
Environmental profiles	Ranked 2nd for Energy, Global Warming and Acidification, 4th for Toxicity & Eutrophication.	Preferred option across all impact categories.	Ranked 2nd for Toxicity and Eutrophication impact, 3rd for Energy and Acidification and 4th for Global Warming.	Ranked 3rd for Global Warming, Toxicity and Eutrophication, 4th for Energy and Acidification impacts.
Costs	**Private costs:** Most expensive option. **Public costs:** Low additional operating and capital cost.	**Private costs:** Cheapest option. **Public costs:** Not applicable.	**Private costs:** Mid-range. **Public costs:** No additional cost as the infrastructure exists.	**Private costs:** Mid-range. **Public costs:** High initial system cost.
Social implications	Preferred option in multi-unit dwellings.	Least practical option in multi-unit dwellings.	Least preferred option in multi-unit dwellings.	Equally preferred option in multi-unit dwellings.

The table demonstrates that for up to 15% market penetration in the study area, the use of FWP in multi-unit dwellings would be expected to have small impacts on the sewage treatment system. If their adoption and use became more widespread, there would appear to be a need for additional investment in the sewage treatment system, however this is likely to be some time in the future given the presently low market penetration of these units.

Environmentally, correctly implemented Home Composting is the preferred option, however this may not be acceptable to residents of multi-unit dwellings for whom the FWP offers a practical, but much more expensive, alternative. The environmental cost of adopting this alternative would present a trade-off: the Energy, Global Warming and Acidification impacts are less than or equal to those of the Co-disposal or Centralised Composting options, however the Toxicity and Eutrophication impacts are higher.

ANNEX A. Summary of Results from the Sub-investigations

The conclusions from this study are presented below in terms of the stated aims of the investigation given in section 3. Conclusions reached with regard to the operational aspects of the sewerage system apply only to the *Waverley/Bondi Eastern Slopes Intercepting Sewer* and its contribution to the load on the Bondi STP. The methodology used in this study may be applied to other systems, however because of site specific design and construction criteria, care should be exercised in transporting all the results from Sub-investigation 1 to other sewerage systems.

Current and Anticipated Future Loads on the Sewerage System and Sewage Treatment System from the Use of FWP Units

- Conservatively, the specific daily water usage by each FWP unit is 6.2 liters per household, equivalent to 2.95 liters per person for the study area.
- For the study area, the marginal hydraulic load on the sewerage system is 0.004 ML per day at a FWP market penetration of 5%. This would rise proportionally to 0.037ML per day at 50% penetration.
- For the study area, FWP units will contribute 0.007% of the *Instantaneous Maximum Flow* within the sewerage system at 5% market penetration, rising to 0.07% at 50% penetration.

Positive and negative macro environmental impacts from the use of FWP units

The Occurrence of Sewage Overflows

- Flows contributed by FWP units in the study area would be very small compared to wet weather flows in the Waverley-Bondi Eastern Slopes Intercepting Sewer. At the highest market penetration level of 50%, the contribution would be less than 0.1% of the *Instantaneous Maximum Flow* in the sewer.
- While in principal FWPs could result in sewage overflows during wet weather if the sewer is flowing at full or very nearly full capacity, flows from FWP units at all market penetrations evaluated are extremely small compared with the increase in sewage flows that can result during wet weather.
- Problems with solids deposition or clogging in the sewer would not be expected at any of the FWP market penetrations examined.

The Sewage Treatment Process

Hydraulic Impacts

- The use of FWPs results in an additional water usage of 2.26 m^3 per household per year at the 5% market penetration level. This equates to approximately 1.3 ML per annum of additional water for study area.

- Flows contributed by FWP units in the study area at all market penetration levels examined would be very small compared to the flow treated at the Bondi STP which is attributable to the study area (the "scaled-down Bondi STP"): at 50% market penetration, FWP units would only contribute an extra 0.5% to the Mean Average Daily Flow.

- As with flow through the sewer, these small flow increases could in principal cause hydraulic capacities of the existing sewage treatment units and the allowable volume of treated sewage from discharged to the ocean to be exceeded. However, the flow increases caused by the operation of FWP units are extremely small compared to increases caused by wet weather.

Impacts of Pollutants

- The increased pollutant load on the Bondi STP resulting form FWPs should not cause operational problems for market penetrations of up to 15%.

- At a market penetration of 50%, FWP effluent would result in about 30% increase in hydrogen sulphide generation within the Waverley-Bondi Eastern Slopes Intercepting Sewer as a result of increased BOD_5, all else being equal. While lower increases in hydrogen sulphide generation would be expected at lower market penetrations, it is considered that any increase in hydrogen sulphide generation could lead to increased corrosion and odour problems, however this cannot be quantified.

Biosolids Reuse

- The small additional quantities of biosolids which would be produced by FWPs at any of the market penetrations studied are unlikely to affect the current contaminant grading or the reuse options for biosolids from Bondi STP.

Marine Environment in Disposal of Uncaptured Portion of Food Wastes

- Effluent from FWPs at all market penetrations evaluated would have negligible impact on effluent discharged to the ocean from Bondi STP in terms of the NSW EPA discharge criteria.

Energy Consumption

- Even at the maximum market penetration of 50%, transport and treatment of FWP effluent at Bondi STP would require only an additional 0.5% energy.

Loads diverted from municipal solid waste collection as a result of using FWP units.

- The use of FWP in the study area can be expected to divert 109 tonnes per annum of food waste from MSW collection system, at 5% market penetration.

- While this does represent a transport saving, this is partially offset by an additional 31 tonnes per annum of biosolids (at 5% market penetration) captured at Bondi STP requiring transport, an increase of 2.9%.

Environmental profiles of the food disposal options.

- *Energy consumption:* Home composting requires the least energy, FWP and co-disposal consume approximately the same and centralised composting has the highest energy demand.
- *Global Warming Potential*: Home composting generates the least CO_2-equivalents, followed by FWP, then centralised composting, with co-disposal the generating most.
- Energy recovery from biogas would have a marked positive effect.
- *Human toxicity, aquatic and terrestrial eco-toxicity*: Home composting is the best performing option, followed by co-disposal, centralised composting and then the FWP.
- *Acidification*: Home composting scores best, with FWP and co-disposal having higher impacts towards acidification and centralised composting the highest.
- *Eutrophication*: Home composting is the best performer, followed by co-disposal and then centralised composting. The largest contribution to eutrophication is caused by the FWP as a result of poor nutrient removal at the Bondi STP.
- On a normalized per capita basis, the energy consumption and acidification potential of the four options is a relatively small part of the annual average per capita contribution to these potential environmental effects, suggesting these impacts should be of lesser concern.
- A quantitative assessment of odour resulting from the four options is not possible. On a qualitative basis none of the options are expected to result in significant increases in odour, apart from increased (but not quantified) levels of hydrogen sulphide associated with the increased BOD_5 in the FWP effluent (see above).

Capital and operating costs of the food disposal options.

- The small flow increases resulting from FWPs at all market penetration levels would not require capital upgrades of the screens, grit tanks and the primary sedimentation tanks at Bondi STP.
- At a FWP market penetration in excess of 15%, additional chemical dosing may be required at Bondi STP to meet EPA discharge licence requirements.
- At a FWP market penetration in excess of 25%, the sludge digesters, dewatering centrifuges and biosolids handling and transport facilities at Bondi STP may require capital upgrades.

- FWPs in the study area would result in small increases in operating costs at Bondi STP, based on total operating costs. However, specific costs for individual process units could increase by up to about 30% at FWP market penetrations of 50%.
- Of the options studied, home composting is the least expensive for the householder.
- On the basis of either the total capital cost or the cost to the householder, the FWP option is the most expensive of the options studied.
- The co-disposal of waste does not involve additional capital expenditure as it is the system currently in place. The householder's cost for co-disposal is comparable with the high end of estimates for centralised composting.

The Social and Health Implications of the Food Disposal Options.

- There is a perceived need for a trade-off between a practice that is easily managed and one that is environmentally beneficial.
- For multi-unit dwellings, the two most attractive options are the FWP system and the separate food waste collection with centralised composting option.
- For both FWP and Centralised Composting, acceptance is based upon the level of waste processing planned and the ultimate re-use of the processed product.
- Provided there is an adequate level of waste treatment available for the FWP system, then it was judged to be 'ideal' for multi-unit dwellings, as it would preclude potential problems associated with localised storage of waste awaiting collection.
- Health risks associated with raw sewage overflows would be unacceptable, in the event of such overflows occurring.
- Potential salmonellae infections present the highest risks from the accidental ingestion of raw food wastes, but still at an acceptable level. Risk from the other microbial groups are very low from exposure to raw food wastes.
- Commercial composting does not appear to result in significant pathogen risks.
- Overall vector-based diseases were not considered significantly different due to the operation of FWP and on-site domestic composting in approved containers.

ANNEX B. Major Assumptions Made in This Investigation

Following is a list of the major assumptions made in this study.

- All of the FWPs were assumed to operate together every day for each of the adopted market penetrations.
- The current market penetration was assumed to be 5%.
- It was assumed that the latest available local data, as used in this study, will not change in the future.
- Pollutant load increases of less than 10% for pollutants at Bondi STP were assumed to be within the design and operational capabilities of the plant and would not result in operational problems or need capital upgrades.
- Sewage quality from Bondi STP was assumed to be the same as in the Waverley-Bondi Eastern Slopes Intercepting Sewer.
- The results from the laboratory investigation were assumed to be representative of the Waverley Catchment.
- The beneficial use of by-products, such as compost and biosolids (avoided products), was not considered within the LCA study.
- FWPs are operated correctly and require no maintenance over a 12 year lifespan.
- Home composting equipment is made from polyethylene and has a 12 year life.
- Home composting is correctly operated and maintained such that the food waste degrades under aerobic conditions.
- A Centralised Composting system for food and garden waste was assumed to run in parallel with the existing MSW system, at a capacity of 50,000 tpa.