INSTALLATION AND EVALUATION
OF
DOMESTIC GREYWATER REUSE SYSTEMS

A thesis submitted in fulfilment of the requirements for the degree of
Master of Engineering at the Victoria University of Technology

by

DIANA CHRISTOVA-BOAL, B.Eng. (Civil)

Supervised by
P. Lechte and R. Shipton

Department of Civil and Building Engineering
Victoria University of Technology
Victoria
Australia

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TABLE OF CONTENTS

CHAPTER 1 INTRODUCTION

CHAPTER 2 LITERATURE REVIEW

CHAPTER 3 PROJECT OBJECTIVES AND METHODOLOGY

CHAPTER 4 METHODS AND EQUIPMENT

CHAPTER 10 CONCLUSIONS AND RECOMMENDATIONS

LIST OF TABLES

LIST OF FIGURES

LIST OF DRAWINGS

LIST OF PLATES

Plate **Title**

SUMMARY

This study focuses on the installation and evaluation of domestic greywater reuse systems. The project was undertaken to assess the feasibility of reusing domestic greywater for irrigating lawns/gardens and for flushing toilets, to determine potential health and environmental impacts of such reuse, and to assess social attitudes towards reusing greywater in and around the house.

Greywater from bathrooms/laundries at four Melbourne properties with different soil types, slopes, house types and family characteristics was filtered, collected in tanks and distributed by gravity or pumping for subsurface irrigation and/or toilet flushing. Family water use activities, soil parameters and other environmental indicators were monitored, and flows were metered and sampled for microbiological, physical and chemical analyses. Preliminary risk analyses and two social surveys were also carried out.

The results of the extensive experimental program indicated that greywater quality, water savings, costs of the systems and general reuse practicability and success would vary substantially with specific site conditions and householder practices. A number of conclusions were drawn regarding technical difficulties of installation and maintenance of these systems, costs involved and the public perception of greywater reuse, but adequate assessment of environmental and public health risk will require further research.

The reader is referred to chapter 10 which contains a comprehensive review of the main conclusions and recommendations relating to the technical, economic, social, public health and environmental aspects of domestic on-site greywater reuse. These findings should serve as a useful guide for anyone contemplating the development and installation of greywater reuse systems or components for toilet flushing and/or irrigation purposes.

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CHAPTER 1: INTRODUCTION

1.1 GENERAL BACKGROUND

Greywater reuse has long a been practice in countries and areas with limited water resources, with application predominantly for watering gardens and lawns in the USA and for landscaping, fountains and toilet flushing in Japan. This form of wastewater recycling has proved to increase overall usage efficiency, reduce costs and conserve natural resources. It has been estimated (Lechte, 1992) that water savings in the range of 18%-29% for an average household could be achieved by reusing greywater. In addition greywater is regarded as a liquid fertiliser suppling easily available nutrients for vegetation (Milne, 1979). Despite these potential savings and benefits, greywater has been used in Australia only during severe droughts when current regulations have been temporarily relaxed to permit its reuse. Possible reasons for this limited greywater reuse are the lack of research in this area, and lack of suitable design guidelines and local regulations.

In recent years growing water demand and at the same time increasing constraints placed on supply have forced Australian water authorities to carefully assess available water resources and to develop a number of methods and measures for more efficient water use and conservation. In Victoria a number of reports prepared by Melbourne Water have raised the possibility of water shortages in Melbourne over the next 15 years unless the community now realise the economic, environmental and social costs associated with its water supply and the need to conserve this valuable natural resource. The Melbourne Water Resources Review Panel (Melbourne Water Resources Review, 1991) indicated that "the existing water resources available to Melbourne are finite and the current 2.2% annual increase in demand for water is not sustainable far into the next decade. Unless we plan and educate now for our future water needs, our children and grandchildren may not be able to enjoy a 21st Century water supply which is adequate in quality and quantity."

In the past the increasing water demand was met by constructing new dams and diverting more rivers. These options are no longer readily available, as the unused sources of surface water have become more remote and expensive. In order to meet future water demand, there is a need to consider redistributing Victoria's existing water resources or to resort to non-traditional alternative sources of water.

Since 1983 Melbourne Water has placed substantial emphasis on developing a demand management program, in which one of the key issues is the development of alternative supply sources. These alternative "non-traditional" sources of water include rainwater tanks, storm water, reuse of treated sewage effluent, greywater, groundwater, desalinated water and icebergs. The feasibility of using these alternative sources of water depends mainly on the geographic, climatic, topographic and other conditions of the region.

The potential economic benefit of supplementing water supply resources with the use of greywater is making it an issue of great interest to Water Authorities. In the Melbourne Water Resources Review (1992) it is concluded that greywater reuse in gardens has the potential to replace about 18% of the current domestic water demand. In the Melbourne Urban System this translates to overall savings of roughly 42 gigalitres a year. Greywater reuse could assist in meeting the growing water needs and at the same time would have the advantage of reducing sewage flows.

Another reason for research in this area is the apparent level of public support for greywater reuse. It was reported (Melbourne Water Resources Review, 1992) that various social surveys have indicated widespread general public interest and acceptance of greywater use as a reasonable water conservation measure. Some people have stated that they still use their diversion systems, which have been installed in times of severe drought, because they find them very efficient and wondered why the practice is not routinely encouraged. Furthermore some written and telephone submissions suggested that greywater distribution systems should be compulsory in all new homes, and that incentives should be offered to existing homeowners prepared to retrofit their properties with them (Melbourne Water Resources Review, 1992).

In a number of overseas countries such as Japan and the USA, where fresh reserves of surface water are not readily available, ongoing investigations and experiments with greywater reuse have been reported over many years. Some counties and states of the USA have already developed standards for the design, installation and control of greywater reuse systems, while in Japan greywater reuse is regulated by effluent quality guidelines set by the government.

Australia, being the most arid continent, is similarly limited in its water resources, and therefore greywater reuse should be an option of great potential. Overseas experience, conclusions and standards will be of value, but as Australia has some very specific and unique characteristics (such as different flora, acid soils, a multinational population, different industrial products, etc.) detailed research is required before any final conclusions can be drawn and any guidelines prepared. Up to now this option of water conservation has not been studied much in Australia except for some recently-undertaken research by Brisbane City Council (1993, 1994) which provides a starting point for further research in order to assess the feasibility of reusing domestic greywater in typical Australian conditions. The most important aspects that have to be addressed are technical, social, environmental, public health, regulatory and economic.

This research program focuses on greywater reuse as a water conservation and alternative supply option. The term "greywater" in this thesis refers to untreated household wastewater which has not been contaminated by any toilet discharge. Greywater includes wastewater from bathtubs, showers, bathroom washbasins, clothes washing machines, sinks and laundry tubs. Local and overseas reports indicate that greywater can be reused on residential allotments for the purposes of garden watering and toilet flushing, which do not require drinking water quality.

This thesis reports on an experimental program involving the design and installation of greywater systems at four Melbourne residential sites providing maximum variability in several experimental conditions including soil types, slopes, house construction and family characteristics. Experimental parameters investigated included components and operation of the systems, greywater flows, greywater quality and receiving soils characteristics. In addition possible public health and environmental impacts were studied, and two social surveys were conducted to determine social attitudes to the reuse of greywater.

1.2 GENERAL PROJECT OBJECTIVES

The broad objectives of this study are:

- To assess the feasibility of reusing domestic greywater from laundry and bathroom for irrigation of lawns and gardens and for flushing toilets.
- To determine potential health and environmental impacts which would occur if the people of Melbourne were given the opportunity to reuse their greywater.
- To determine the social acceptability of reusing greywater.

In order to fulfil these objectives a number of specific aims were established in four groups as follows: technical, economic, social, public health and environmental. They are presented in detail in Chapter 3.

1.3 OUTLINE OF THESIS

In Chapter 2, typical greywater volumes produced in homes, water savings and water quality parameters found in the literature are described. A review of different types of greywater reuse systems and their components is presented. An overview of health and environmental concerns associated with greywater reuse and a summary of the relevant sections of existing wastewater standards are also included.

The specific aims and objectives of the project are presented in Chapter 3 together with a review of the methods and techniques used in each particular area of the experimental work: technical, economical, social, public health and environmental.

Design considerations, equipment used and installation of the experimental greywater reuse systems are presented in Chapter 4. This includes schematic presentation of the components of each system at the four experimental sites.

Details about the monitoring program for parameters investigated and results of experimental work performed as part of this study are presented in Chapter 5 and Chapter 6 respectively. The greywater quantity and quality, the characteristics of the receiving soils and the performance of the systems are amongst the principle factors examined in order to assess the feasibility of greywater reuse. Evaluation of the greywater systems has been carried out by analysing the practical issues involved in their design, installation, operation and maintenance. To assess the results of the physical, chemical and microbiological greywater tests, quality parameters have been compared with corresponding ones for tap water, with values from existing standards for wastewater reuse, and with results of previous studies.

Costs of the greywater experimental systems, including installation, operation, maintenance and instrumentation costs are presented in Chapter 7. Cost analyses have been carried out for each of the sites to identify the economic difference introduced by such factors as: level of automation of the systems, new or existing house greywater installations, and other specific characteristics of the sites.

Chapter 8 covers the methodology and results of two social surveys aimed at assessing the public's perception of greywater reuse. In addition, the opinions of the homeowners where greywater systems have been installed are presented. A summary of the education needs for the general public to become familiar with and/or proficient in running a greywater system is provided.

Public health and environmental issues associated with greywater reuse are discussed in Chapter 9. Risk assessment methodologies used overseas are reviewed and the four main steps involved in a health risk assessment are described. A number of risk exposure pathways resulting from reuse of greywater for garden watering and/or toilet flushing are presented.

The experimental results are reviewed and key conclusions and recommendations are outlined in Chapters 10. Areas for further research and investigation are also included in this chapter. Additional experimental data not contained in the body of the thesis are included in Appendices.

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

This chapter presents a review of the literature on greywater. Its purpose is to provide background information and data from other studies on greywater systems, treatment (primary filtration and disinfection), and quality and quantity of greywater for comparison with the results of the present study. As indicated in Chapter 1, this research study comprises four parts. Accordingly, a review of the relevant literature can be divided into several broadly corresponding sections: technical, economic, social, public health and environmental.

2.1.1 BACKGROUND

By definition the term "greywater" stands for household wastewater which has not been contaminated by any toilet discharge. Greywater includes wastewater from bathtubs, showers, bathroom washbasins, clothes washing machines, sinks and laundry tubs. The kitchen sink wastewater is a possible source but because it can be highly contaminated (eg. food particles, cooking oil and grease) and since it accounts for only 5% of the 'average' household consumption its use as a greywater source is almost negligible and not recommended.

There are a number of spellings of the term used in different publications: (1) grey water, (2)greywater, (3) gray water, and (4) graywater. For the purpose of this study the spelling "greywater" was adopted unless quoting from other sources.

2.1.2 CONCEPTS FOR GREYWATER REUSE

In general, there are two concepts for safe reuse of greywater (Lechte, 1992):

- The first involves using only bathroom and/or laundry greywater, virtually as it is produced, allowing for minimum treatment (eg. coarse screening and/or simple filtration) and storage.

- The second involves using greywater from all sources after comprehensive treatment (eg. screening, sedimentation, biological treatment, sand and/or carbon filtration, membrane techniques and disinfection) aiming to achieve high quality of the treated greywater and allow its storage for a substantial time if necessary.

Minimisation of any health risk associated with greywater reuse can be achieved (1) by avoiding human contact with greywater or (2) by treating the greywater to a safe level. Consequently, greywater systems can be classified in two broad groups:

- **Primary greywater systems** - these are systems directly reusing virtually untreated domestic greywater from a single family dwelling for sub-surface lawn and/or garden watering. These systems do not allow storage or treatment, apart from some surge storage and coarse screening/filtration which removes hair, lint and coarse particles.
- **Secondary greywater systems** - these systems allow greywater to be treated and stored for toilet/urinal flushing and/or lawn and garden watering (including surface watering methods). Secondary greywater systems may be used for multiple occupancy buildings.

Greywater systems for irrigation, even with a higher automation level, can belong to the primary greywater systems group if there is no treatment and storage allowed. In contrast, even the simplest greywater systems for toilet flushing have to allow for some treatment and storage of greywater, therefore they belong to secondary greywater systems.

2.1.3 OVERSEAS EXPERIENCE

The United States of America and Japan are the two leading countries in the world in the sphere of greywater reuse. The following section briefly covers their experience, reasons for greywater reuse, methods adopted, current legislation and its development, and existing standards.

The USA has a long history of experience in greywater reuse. It dates back to 1925 when treated effluent was reused for toilet flushing and lawn irrigation at the Grand Canyon tourist facilities. Since then ongoing experiments, research and numerous evaluation projects have been carried out into most aspects of greywater reuse. Unfortunately, many of the conclusions made by scientists and research institutes are contradictory, a fact which may be attributed to the very heterogenic nature of greywater.

On-site greywater reuse is one of the water conservation methods used in the Western States of the USA. California (especially the southern part) and Southern Arizona (Tuscon) are areas with very arid desert terrain, where the climate and the water shortage are the main motivations for the widespread interest in greywater reuse. A possible additional factor for this is that 60% of houses in the USA are unsewered, and occupants already rely on on-site treatment of their household wastewater. Another facilitating element is the widespread general perception, although incorrect, that greywater is totally harmless.

In the 22 western states of the USA on-site reuse of residential greywater is predominantly for the purpose of irrigation. Most of the guidelines for untreated greywater reuse allow only sub-surface irrigation with an additional restriction in some jurisdictions that the use of greywater is restricted to single family dwellings. There are other forms of greywater reuse in the USA implemented on a larger scale: (1) in motels and hotels, where sophisticated technologies of greywater treatment are used - eg. pressure media filters, reverse osmosis unit, ultraviolet steriliser (Maki, 1994), and (2) more recent investigations were carried out for possible greywater reuse at university campuses and institute buildings (Venhuizen, 1990). In this case greywater quality has to meet the requirements for treated effluent for the corresponding type of reuse.

Residential greywater reuse was not included in the Uniform Plumbing Code (UPC) or the State plumbing laws (regulating the plumbing in the 22 western states and of each state respectively) until 14 July 1992, although a survey in 1977 in California indicated that there was an unquantified number of on-site greywater reuse systems illegally installed and operating throughout the state and probably thousands of them throughout the whole country (Milne, 1979). The first step for legalising greywater reuse was taken in 1989 by Santa Barbara County where the first "Greywater Regulations" were introduced. This example was followed shortly by other regulatory authorities and in 1992 there were 11 counties and cities in California where greywater reuse was legal. A severe drought in May 1991 and increased public interest led to the formation of the California Ad-Hoc Greywater Committee, which after an investigation of the safety of greywater reuse, prepared guidelines to be included in the UPC. On 29 September 1992, the greywater guidelines were included in the Uniform Plumbing Code as Appendix W. Based on these guidelines, a State plumbing code standard, known as Appendix J, permitting installation of greywater reuse systems in residential buildings was then developed.

The greywater reuse according to Appendix W is restricted to "**untreated domestic greywater reuse from single family dwellings for direct re-use in sub-surface irrigation of lawns and gardens**" which sets the requirements regarding greywater quality and minimising the potential health risk. The Code specifies "**untreated**" greywater because studies have shown that more than 80% of owners would not provide adequate maintenance of the treatment facilities. Consequently the use of treatment systems in on-site situations is unreliable. The term "**domestic**" restricts the use only to domestic greywater as its constituents are generally well known and believed not to pose any adverse effects when used for appropriate irrigation of lawns and gardens. The greywater reuse is specified to be "**from single family dwellings**". This practice is intended to minimise the risk of spreading pathogens, as family members are expected to have developed immunity to the pathogens they shed. The requirement of "**direct re-use**" aims to minimise possible pathogen regrowth by immediate reuse of greywater, and thus to minimise the potential health risk. The application only by "**sub-surface irrigation**" is an effective way to avoid human contact and reduce health risk. Toilet flushing or other uses of untreated greywater are prohibited as posing an unacceptable risk to human health.

In Japan the term "greywater" is used to define "treated wastewater effluent" supplied (1) by a second reticulation system from a local wastewater plant or (2) by an on-site treatment plant using the building's own wastewater. The only form of untreated greywater reuse in Japanese homes is the hand basin toilet. This incorporates a hand basin in the top of the cistern with a tap for hand washing. The tap operates automatically when the toilet flushes, simultaneously refilling the cistern and allowing hand washing (Brisbane City Council, 1994).

The main reason for wastewater reuse in Japan is the shortage of potable water. In most of the high rise buildings treated wastewater is used for purposes such as: (1) toilet flushing, (2) ornamental ponds and fountains, (3) landscape watering. Typically the on-site treatment of wastewater includes an aerobic process followed by membrane filtration and disinfection, which have high installation and operational costs and can be economically justified only in commercial buildings, apartment complexes or office blocks. Greywater reuse in single family dwellings is limited to hand basin toilets. These are also installed in commercial areas where potable water is still used for toilet flushing.

The wastewater quality guidelines are set by the government in a form of effluent quality standards recommended by the Tokyo Water Re-use Promotion Centre (see Table 2.1). It is the responsibility of the owner of the building to ensure that the on-site wastewater quality meets these standards. For greywater reuse in the hand basin toilets there are no quality requirements as it is believed that handwashing water is not heavily contaminated and does not pose significant health risks.

Table 2.1 - Effluent Quality Standards Recommended by the Tokyo Water Re-use Promotion Centre

Item	**Landscaping**	**Dabbling**
Coliform group count	< 1000/100 ml	< 50/100 ml
BOD	< 10 mg/l	< 3 mg/l
pH	5.8 - 8.6	5.8 - 8.6
Turbidity	< 10	< 5
Odour	Should not be unpleasant	
Colour Unit	< 40	< 10

Source: Brisbane City Council (1994)

2.2 TECHNICAL ASPECTS OF GREYWATER REUSE SYSTEMS

In general, the design of a greywater system has to comply with relevant standards and guidelines approved by authorities, which set the design considerations and principal requirements for the different components (eg. tanks, filters, pumps, backflow prevention, etc.). However, a greywater system for any household would have unique features because of the specific factors involved at a particular site. Furthermore, because of different levels of automation possible for such systems, the range of alternatives may be quite extensive.

2.2.1 PRELIMINARY INVESTIGATIONS

A review of the literature (California Dept. of Water Resources, 1993; Olkowski et al., 1979) identified a number of factors that have to be included in the preliminary investigation of sites for possible greywater reuse:

1. Suitability of the site - assessment of type of soil, size of land, house construction, flood level, ground water level, vegetation for irrigation, etc.
2. Greywater production - depends on the size of family, fixture flow rates, personal hygiene habits. However, water usage patterns are likely to change with time, which may lead to implications for the sizing of the system.
3. Greywater reuse - depends on the size of area for irrigation and the soil characteristics of the site and/or on the toilet flushing water demand.
4. Preference of greywater sources - based on the balance between greywater production and greywater demand, a decision can then be made about which sources of greywater to use. The first preference is shower, bathtubs and bathroom sink, second preference is laundry trough and washing machine, and third preference is kitchen sink and dishwashers (Olkowski et al., 1979). This ranking is based on the volume of water and the percentage of total solids produced by each source (see Table 2.2).

Table 2.2 - Preferred Greywater Sources

Greywater source	Gallons* of waste water generated per day	Percentage of total solids production
Bath/shower/bathroom sink	88	27 %
Washing machine/l'dry sink	35	23 %
Kitchen sink	25	50 %

Source: Olkowski et al. (1979) * - US gallons.

2.2.2 COMPONENTS OF GREYWATER SYSTEMS

In general the components of greywater systems described in the literature can be summarised as follows:

(a) **for irrigation**: a greywater diversion arrangement, screening and filtering elements, a surge tank and an irrigation distribution system. In cases where there is not sufficient head for gravity irrigation, a pump is included.

(b) **for toilet flushing**: a greywater diversion arrangement, a coarse screen and filter to remove solids, a storage tank to balance volumes between greywater production and greywater demand, a pump to transfer greywater and a disinfecting unit usually using chlorine tablets or a liquid disinfectant.

More specifically these components depend on the level of automation. For irrigation, this range starts from the most simple gravity fed system (County of Santa Barbara, 1991) to a system with fully automatic operation, control and maintenance, and using drip irrigation (City of Los Angeles, 1992). For toilet flushing, the range starts from a hand basin toilet (Brisbane City Council, 1993) to a system with two storage tanks, automatic backwashed sand filter, disinfection unit and control panel (Crawford, 1994).

2.2.3 DIVERSION ARRANGEMENTS

The first element of a greywater system is a diversion arrangement. This typically involves a branch pipe and a 3-way diverter valve which can be manual or electronic (County of Santa Barbara, 1991; California Dept. of Water Resources, 1993) or a double sanitary tee and one or two valves (Olkowski et al., 1979; Kourik, 1993). In general, wastewater pipes should be tapped after the P or S traps and downstream from the vent pipe(s) (Olkowski et al., 1979; Kourik, 1993). The same authors recommend the use of ball-valves, as gate valves (though about 50% less in cost) tend to become clogged with lint and hair and fail to shut off completely. Valves are a vital component for controlling the operation of the system and cheap ones should not be used. Metal valves are identified as the best option (Kourik, 1993).

Depending on the existing pipe configuration, the greywater diversion point can be on a vertical, horizontal or inclined section of the existing drain pipe (see Drw. 2.1). Each of the diversion arrangements has some limitations:

- A three-way valve arrangement is comparatively expensive.

- A tee and two valves arrangement (Drw.2.1, Pos.3) can be very confusing for people unfamiliar with plumbing and valves. It might lead to flooding of the house if by mistake both valves are left shut and no failsafe by-pass is provided (as in the case shown as Pos.2).

- A tee and a valve on the existing drain pipe arrangement (Drw.2.1, Pos.1) has the same limitation of possible flooding of the house in the event of a blockage on the greywater line. This limitation can be avoided by using a bypass (Drw.2.1, Pos.2), although this has extra components and requires more vertical space for installation. It is important to note that the tees positioned on the vertical pipe are in the reversed position so that no flow will be diverted into the branch even when the valve on the vertical pipe is open.

- A tee and valve on the greywater reuse line is the diversion arrangement typically used for existing pipes in the horizontal position (Drw.2.1, Pos.4). This is the simplest and safest arrangement as it allows an unrestricted overflow to the sewer.

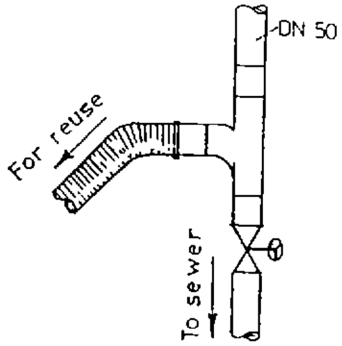
2.2.4 COLLECTION/SURGE TANKS

The main function of the collection/surge tank is to act as a temporary holding storage in the case when greywater is discharged from the fixtures faster than the pipes of the irrigation system can distribute it. Surge tanks therefore normally provide only minimal storage, as high rate flows are captured and then rapidly distributed by gravity to the irrigation lines. If the outflow has to be pumped, it is possible that a longer period of storage for at least some of the discharge might occur. Storage is not recommended for untreated greywater because of the microbial growth that may occur. Rose et al. (1991) has reported that the number of total bacteria SPC (as measured by Standard Plate Count) and coliform bacteria in stored greywater increased by one order of magnitude in the first 48 hours and then became fairly stable. Additional treatment and disinfection of greywater will be necessary if storage tanks are to be used.

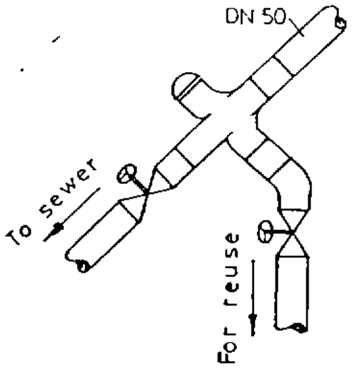
Diversion Arrangements

for following positions of the existing pipe:

① Vertical

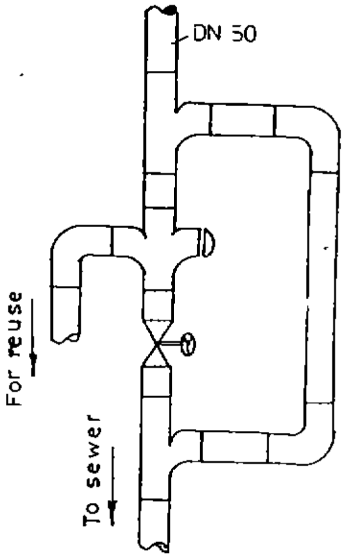


③ At an angle



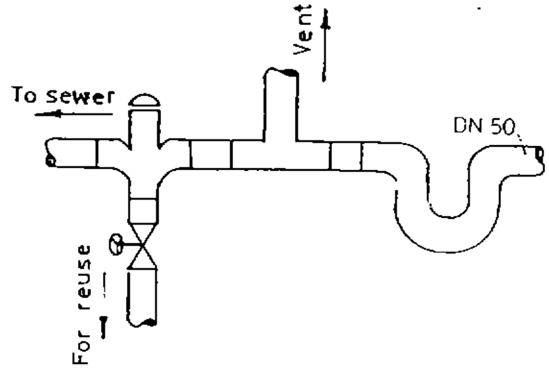
Source: Kourik, 1993.

② Vertical

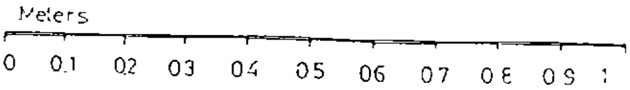


Source: Olkowski, 1979.

④ Horizontal



Source: Olkowski, 1979.



Dr No:	2.1

Collection/surge tanks have to meet a number of requirements. They should

- have an overflow and a scour to sewer,
- be appropriately vented,
- be mosquito and vermin proof,
- have a lockable access opening,
- have warning signs regarding non-potable water quality, and
- be anchored against overturning, or floating up.

Collection/surge tanks described in the literature are of different materials, forms and shapes. In general, the volume of the tanks depends on the greywater quantities produced, but most often they are 45-55 U.S. gallon tanks. They can be steel, plastic, fibreglass or any other material approved by relevant standards to hold wastewater (California Dept. of Water Resources, 1993).

According to Kourik (1993) the easiest drums to work with are metal with one bung on the top and one on the side, and with a top which is removable by loosening a metal ring. This makes it very convenient for installing a pump inside. However, in time the metal drums might rust and create problems. This should be avoided by the application of an appropriate protection layer both internally and externally.

2.2.5 PUMPS

In homes where the wastewater discharge plumbing is too close to ground level and no efficient gravity irrigation can be achieved, or where the garden is located above house floor level, a pump must be used for distributing greywater for irrigation. The choice of pump (including the maximum required head and flow rate) depends on site specific conditions: eg. distance from the collection/surge drum to the furthest point in the landscape, the maximum discharge rate of the greywater sources used, etc. Recommended pumping rates are between 20 and 40 litres per minute at the highest point of discharge (County of Santa Barbara, 1991;Olkowski et al., 1979).

To prevent back flow from the irrigation lines, a check-valve should be installed immediately after the pump. Another important requirement is that the pump should be equipped with an inlet screen or grate which will prevent clogging of the pump mechanism by solid matter and particles in the greywater.

No literature sources have discussed the use of pumps when greywater is used for toilet flushing. In general, greywater needs to be pumped from a surge tank to a toilet flushing tank, as the latter is elevated to gravity feed the toilet cistern. In a newly built house the clothes washing machine pump can be used to pump directly into a toilet flushing tank, providing the clothes washing machine is suitably positioned not to overload the head capacity of the pump.

2.2.6 SCREENING AND FILTERING DEVICES

Several sources stress the importance of preventing solid matter, lint, hair and excess soap suds from entering the greywater system, as these impurities can cause severe clogging of pipes, valves, pumps and orifices, and a lot of effort is then necessary to restore their normal operation. This is especially important for mechanisms or parts that are particularly susceptible to clogging such as the emitters of a subsurface drip irrigation system. A very comprehensive review of both simple and more complicated and automated filtering devices has been presented by Milne (1979). He described the mechanism, operation, cost and maintenance of a number of screens and filters that can be used for greywater; eg. cloth bags, drain filters, in-line filters, slow sand filters, mixed media filters, clivus multrum filters, high-flow rate filters, pressure vessel filters, cartridge filters and diatomite filters.

The type of filter (mesh size and volumetric capacity) depends on:

(a) **Daily production of greywater**. For small volumes up to 220 L per day, small low-technology arrangements can be sufficient, but for volumes of 330 L or more recycled each day a higher capacity and more sophisticated filtration apparatus is required (Milne, 1979);

(b) **Type and method of reuse.** Coarse screening of greywater is a basic requirement regardless of the type of its reuse. As a first measure removable thin mesh plastic screens or metal grates can be used to prevent solids from entering the greywater flow. They can be installed in bathtub, shower or trough where it is easy to inspect and clean them regularly (Olkowski et al., 1979). At the next level fine nylon mesh bags (75 micron) or ladies stockings can be installed on the inlet pipe of a surge tank (or at the end of the irrigation hose if surface irrigation is permitted) (Kourik, 1993). Other possible devices recommended are a shallow basket made of a quarter-inch hardware cloth hung inside the top of a surge tank (Kourik, 1993) or a filtration unit employing sand and gravel (Olkowski et al., 1979). The above described coarse screening and filtering techniques are considered sufficient for irrigation methods such as mini-leach fields or clay pots (Kourik, 1993).

If a drip irrigation system is used, the filtration requirements are more stringent. Finer filtration is required for removal of any particles which might block the emitters. For wide flow path wastewater emitters (size 1200 - 2000 microns) the recommended mesh size is 120 or greater in screen or disk filters (Geoflow Inc., 1992). A minimum of 140 mesh (or maximum aperture size of 100 micron) is recommended by the California Dept. of Water Resources (1993).

2.2.7 DISINFECTION OF GREYWATER

When reused for toilet flushing, in addition to screening and filtering, greywater needs to be disinfected to minimise potential health risks. Research carried out by the NASA Langley Research Institute (USA) in the 1970s identified the processes of diatomaceous earth filtration followed by heat and chlorination as the most suitable, low cost and operationally simple method to treat greywater for toilet flushing. It was reported that counts of coliform organisms in greywater can be reduced to zero or near zero by heating the water to a temperature of 335.9 K (62.9°C) for 30 minutes or by chlorinating the water to a chlorine concentration of 20 mg/L (Brisbane City Council, 1994).

Another study carried out in the United Kingdom (Crawford, 1994) on greywater reuse for toilet flushing identified chemical disinfection treatment followed by filtration as the most suitable method for removal of microbiological contaminants such as bacteria, viruses and parasites. Substances that could be used for disinfection are chlorine, bromine, and ozone, as well as electro-chlorination or ultraviolet light. The preferred types of filtration reported were: diatomaceous earth, sand, reusable and disposable cartridge filtration, ultrafiltration and reverse osmosis. In this study electro-chlorination and pressure sand filtration, which were already used for domestic applications such as swimming pools, were adopted as the simplest method of treatment. Most of these methods of treatment would require high-technology equipment which would substantially increase the cost of the greywater reuse systems.

2.2.8 OTHER DESIGN CONSIDERATIONS

Besides the requirements for the specific components of a greywater reuse system there are a number of general considerations related to cross connection prevention and accidental ingestion which are of major importance. Some relevant Australian Standards are: AS 1319 (1983) - Safety signs for the occupational environment, AS 1345 (1982) - Identification of the contents of piping, conduits and ducts, AS 2845 (1991) - Water Supply - Mechanical Backflow Prevention Devices and AS 3500 (1992) - National Plumbing and Drainage Code.

Some specific preventive measures that can be taken to minimise the risk of accidental ingestion are:

- Greywater pipes should be suitably coloured and marked. The international standard for dirty water is the colour purple.
- Irrigation outlets, hose points and greywater tanks have to be clearly and permanently labelled to prevent drinking or other uses requiring potable water.
- Greywater tanks should have tightly fitted lids, which can be locked if necessary.
- Backflow prevention devices should be used at properties with greywater systems.
- Hose point couplings and threads of the greywater fittings should be non-compatible with those for potable water.

Another essential criterion in the design and installation of a greywater system is to minimise the risk of cross connection of greywater and the potable water plumbing lines. The above mentioned requirements for accidental ingestion cover most of the cross connection prevention measures. In addition, if potable water is used as make-up water for the greywater collection tanks, appropriate air gaps should be provided to prevent cross connection.

Another general requirement is that all the lines and components of a greywater system should be watertight. The whole system has to be filled with water and tested before covering the irrigation line or any other elements of the system.

Greywater should never be allowed to pond on the surface or run off the property.

2.2.9 IRRIGATION SYSTEMS

Several sources recommend that greywater can be used for irrigating ornamental plants, lawns, trees and shrubs. Most authors recommend subsurface irrigation as being the safest method for applying greywater. However, there are some authors that describe surface methods of irrigation with greywater. Sprinklers with large orifices are described as a possible method by Kourik (1993). Olkowski et al. (1979) identifies as temporary methods (1) using a bucket to transfer greywater from the bathtub or laundry trough for reuse or (2) siphoning greywater with a garden hose for irrigation. Subsurface irrigation methods described for greywater reuse include: clay pots, mini-leach fields (County of Santa Barbara, 1991), dual pipe tubing, evaporation beds (Milne, 1979) and drip irrigation systems (Foster et al., 1988; City of Los Angeles, 1992; California Dept. of Water Resources, 1993).

The design of greywater reuse systems, although similar in some respects to that for on-site greywater disposal (which in unsewered areas has been a long term practice), has several different requirements. The purpose of disposal systems is to dispose the maximum volume of effluent using a minimum area as quickly and safely as possible at an approximately uniform rate throughout the year. The aim of irrigation with greywater is to optimise its use over as large an area as possible with allowance for a wide variation in the usage of water in summer and winter.

Geoflow Inc. (1993) indicates that there are two main requirements associated with greywater reuse for irrigation: (1) to ensure a high level of safety for public health and environment and (2) to make the maximum use of greywater (ie, irrigate with it rather than dispose of it). Subsurface application of greywater satisfies both criteria because

(a) the layer of soil above the discharge points provides a safety barrier to minimise public health and environmental risk, and

(b) application close to the rootzone ensures the best conditions for moisture intake by plants and less evaporation losses.

The rate of applying water for irrigation depends on a number of factors such as nature of soil and its characteristics, type of vegetation to be irrigated, climate, etc. In general during the warmer months (November to March) about 40%-60% of the evaporated moisture has to be replaced to provide an adequate amount of water for lawns and ornamentals (Handreck, 1986). In general, when calculating water application rates for different climatic conditions there should be a relevant adjustment to these figures. For Melbourne, an average application rate of 1.5 mm/d should be adequate for lawns and gardens, when taken in conjunction with typical monthly rainfall.

The sizing of the irrigation areas has to be based on the maximum hydraulic loading for the corresponding type of soil determined by percolation tests or other methods approved by the Administrative Authority (Geoflow Inc., 1993). A detailed procedure for sizing an irrigation area is provided in AS - 1547 Disposal of Sullage and Septic Tank Effluent from Domestic Premises (draft), based on soil permeability and design irrigation rate. The aim is to supply only the water needs of the vegetation irrigated. The California Department of Water Resources (1993) requires that a minimum buffer zone (horizontal distance) of 1.5m, 1.5m and 2.4m should be provided from the irrigated area to a property line, on-site domestic water service line or buildings, respectively. No other sources present such requirements.

For the mini-leach field type of systems the depth of trenches recommended is a minimum of 300 mm and a maximum of 400 to 450 mm, and the width of the trenches from 125 mm to

450 mm (Kourik, 1993; County of Santa Barbara, 1991; California Dept. of Water Resources, 1993). The minimum diameter advised for gravity irrigation pipes in the trenches is 50 mm (California Dept. of Water Resources, 1993). For drip irrigation systems the recommendations regarding depth and spacing are: water to be applied 150 mm-250 mm below the soil surface with emitters located on 600 mm centres throughout the disposal area (Geoflow Inc., 1993). There is still ongoing research in this area for optimising the efficiency of the irrigation systems using different spacing and depths (Rauschkolb et al., 1990).

Although it is recognised that pressurised subsurface drip irrigation systems combine the advantages of high irrigation efficiency and water economy with those of safe underground application and uniformity of flow distribution, opinions about using such systems for greywater reuse are contradictory. Kourik (1993) advises not to use drip irrigation equipment for greywater as it will clog very quickly. He considers that it would be far too expensive to filter greywater sufficiently to be able to use it for drip irrigation. The City of Los Angeles (1992) conducted a pilot project evaluating eight greywater systems, of which six were drip using wide flow path turbulent emitters. Several filtration systems were used, ranging from a bag filter to an automatically backwashed sand filter. Disinfection was not involved during the test period of one year. In contrast to the conclusion of Kourik (1993), the City of Los Angeles researchers reported that some plugging of the drip systems did take place but with proper maintenance all the systems except one were kept operating.

Carlile and Sanjines (1993) state that because of the amount of impurities contained in wastewater there is potential for emitter blockage and/or bacterial growth in the lines. To avoid this problem, emitters with relatively larger diameter outlets were designed, but then root intrusion becomes a major constraint. To solve both problems, GEOFLOW ™ trickle irrigation lines were developed with a bactericide incorporated into the tube material to inhibit the growth of bacterial slime on the walls, and to stop root intrusion the ROOTGUARD process was developed in which an environmentally safe herbicide (TREFLAN R) was impregnated into the emitters to protect them from root intrusion for many years (Geoflow Inc., 1993).

2.3 ECONOMIC ANALYSIS OF GREYWATER REUSE SYSTEMS

2.3.1 THEORETICAL GREYWATER SAVINGS

2.3.1.1 Domestic Water Consumption in Melbourne

The average Melbourne household of approximately 3 people has an average annual water consumption of about 250 kL(or 685 L/day), with about 5% used in the kitchen, 15% in the laundry, 20% in the toilet, 26% in the bathroom and 34% for outdoor use (see Table 2.3). Thus the average daily ex-house and in-house consumptions are 235 litres and 450 litres respectively. Around these averages there is a large variation in actual consumption due to water supply differences, climatic conditions, and other factors, but these figures will be used in the following analyses. The total domestic water usage within the Melbourne and metropolitan area accounts for approximately 53% of the total water consumption (Beith and Horton, 1989).

Table 2.3 - Domestic Water Consumption in Melbourne for 1992**

	Average household consumption in		Annual consumption per average household	Percentage of the total annual consumption
Units	L/day	%	kL/a	%
Kitchen	33	5 %	12	3 %
Laundry	104	15 %	38	8 %
Toilet	135	20 %	49	10 %
Bathroom	178	26 %	65	14 %
Garden/outdoors	235	34%	86	18 %
TOTAL	685	100 %	250	53 %

**Source: These figures were reported by Melbourne Water representatives at the Annual Conference of Australian Water and Wastewater Operators Association (Sep.1994)

2.3.1.2 Domestic Water Consumption in Australia

Information about the domestic water usage of major urban centres (Table 2.4) has been published by Brisbane City Council (1993). The figures for Perth and Melbourne were based on comprehensive research, while the remainder have been estimated. The author indicated that the variations in total use and external use figures can be due to the difference in climatic and geographic conditions.

Table 2.4 - Major Urban Centres - Domestic Consumption

Urban Centre	In-House	Ex-House	Total Usage
	L/d (%)	L/d (%)	L/d
Adelaide	466 (50%)	466 (50%)	932
Brisbane	586 (48%)	646 (52%)	1232
Darwin	959 (50%)	959 (50%)	1918
Melbourne	450 (66%)**	235 (34%)**	685
Perth	473 (53%)	423 (47%)	896
Sydney	680 (75%)	226 (25%)	906

Source: Brisbane City Council (1993)

** - The figures for Melbourne have been updated to conform with the 1992 analysis of domestic consumption.

According to these figures it might be expected that water savings resulting from greywater reuse will vary substantially between different cities. The following discussion on water saving will focus on the possible water savings for Melbourne.

2.3.1.3 Sources of greywater

The sources of greywater focused upon in this study are from the bathroom and laundry. The volumes can vary considerably between different households depending on number of occupants, hygiene habits, climatic conditions, etc. Based on the volumes of water used in the average Melbourne household (Table 2.3), the average volume of greywater available for reuse is as follows:

(1) The combined greywater from **bath tubs, showers and hand basins** accounts for about 26% of the total household consumption. Of this amount, the shower accounts for about 20%, the bath for 3%, and the basin for 3% (Beith and Horton, 1989).

(2) The greywater from **laundry troughs and clothes washing machines** accounts for about 15% of the total household water consumption. Of this amount the washing machine accounts for about 12%, and the trough for 3% (Beith and Horton, 1989).

Based on these figures the total amount of greywater available for reuse in an 'average' household will be about 282 L daily and 103 kL annually, which corresponds to 41% of the total household water consumption.

2.3.1.4 Potential Use of Greywater

Residential reuse of greywater is potentially feasible for watering gardens, trees, shrubs, lawns, landscapes and for toilet flushing, none of which require a drinking water quality supply.

Watering gardens and lawns accounts for around 34% of the total household water usage but this demand is highly seasonal and for Melbourne's temperate climate may only be needed for five to six months of every year.

Water for toilet flushing comprises about 20% of the total household water usage but this percentage is reducing over time as more dual flush and water economising toilets are installed. Water for toilet flushing is a relatively constant requirement throughout the year. The potential for savings depend as well on the number of the toilets in the house, as it may not be feasible to provide greywater to all toilets in the house.

The amount of water needed for these two applications is 370 L daily and 135 kL annually, which corresponds to 54% of the total household water consumption.

2.3.1.5 Theoretical Water Savings

Comparison of the above figures for greywater supply and demand shows that the potential reuse volumes exceed the quantity of greywater production. Various reuse options: garden watering only, toilet flushing only, different seasonal combinations and the corresponding potential savings are indicated in Table 2.5. The figures are based on the average water consumption for a Melbourne household of three people. In case 3 (greywater reuse for irrigation watering and toilet flushing) it is assumed that for six months all the greywater generated is reused for watering, and in the remaining six months for toilet flushing. The last column of Table 2.5 presents the percentage that these volumes represent of the total annual water consumption in Melbourne.

Table 2.5 - Potential Greywater Reuse Options and Corresponding Savings

	GW demand	GW supply	Period of time	Max GW reuse	Household Consumption % of annual	% of total annual consumption
	kL/a	kL/a		kL/a	%	%
1. Garden use only	86	103/2 = 52	1/2 year	52	(20.5%)	11%
2. Toilet flushing only	49	103	1 year	49	(20%)	10%
3. Garden and Toilet flushing	135	103	1/2 yr-gw 1/2 yr-tf	(103+49)/2=76	(30.5%)	16%

It can be concluded that reuse of bathroom and laundry wastewater for garden watering and/or toilet flushing has the potential to reduce the annual household potable water consumption by about 20% - 30%.

Similar figures for the potential water use reduction were indicated by:

-(1) Lechte (1992) - 18%-29% of the annual household consumption,

-(2) Melbourne Water Resources Review (1992):

- 18% replacement of the current domestic demand, if greywater is used for garden watering only,
- 13.5% water savings, if greywater is used for toilet flushing only, and
- 30% water savings, if greywater is used for both above mentioned options.

These authors have identified the possible water saving attributable to greywater reuse, but have not fully considered a number of current trends that might effect the future savings that can be achieved by reusing greywater. One factor affecting greywater production is the installation of water efficient (water saving) household appliances, which will subsequently reduce the volume of greywater produced. It was estimated that if good to maximum efficiency water conserving devices were installed in a house, a reduction in the daily wastewater flow of the order of 25% could be achieved (Lechte, 1992). Households with other than three members will also produce substantially different volumes of greywater than the average referred to above.

There are a number of factors affecting possible greywater reuse options as follow: (1) Different types of home foundations eg, concrete slabs/stumps, and floor clearances will influence opportunities for installing reuse systems, particularly in retrofit situations; (2) An increase in the density of population in Melbourne suburbs due to dual occupancy will reduce the lawn and garden area available for irrigation; (3) Any significant replacement of English type gardens with native Australian type plants which are resistant to dry conditions will reduce the need for irrigation; (4) The introduction of water efficient gardens using mulch and compost will reduce the evaporation rate and the need for irrigation; (5) The installation of water efficient toilet cisterns will reduce substantially the demand of greywater for toilet flushing.

For example, Beith and Horton (1989) demonstrated that replacement of the traditional 11 litre single flush cistern with any of the new water efficient options could lead to a reduction in water usage of up to 67.3%, as indicated in Table 2.6 below. The volumes they have calculated are based on the ratio of 4 half flushes to one full flush per person per day.

Table 2.6 - Water Volumes and Savings for Different Toilet Cisterns

Flushing volume	Volume used per person per day	Reduction in the water usage
11 litre flush	55 L	
9 litre flush	45 L	18.2 %
11/6 litre flush	35 L	36.4 %
6 litre flush	30 L	45.5 %
9/4.5 litre flush	27 L	50.9 %
4.5 litre flush	23 L	58.2 %
6/3 litre flush	18 L	67.3 %

Source: (Beith and Horton, 1989)

For the reasons above, actual water savings attainable from a greywater reuse installation at any particular house might differ substantially from those calculated as being theoretically possible.

2.3.2 GREYWATER QUANTITIES AND SAVINGS REPORTED IN PREVIOUS STUDIES

Volumes of reused greywater reported in the literature vary from area to area and also vary according to the definition used for greywater (whether or not including kitchen waste water). In the "Casa del Agua" study (Foster et al., 1988) the expected theoretically estimated savings were 38%, while at the end of the experiment it was reported that recycled greywater (reused for toilet flushing and landscape irrigation) supplied 25% of the water used in the house.

According to the City Of Los Angeles (1992) report the potential greywater supply varies from 53% to 81% of the total household water use and the estimated potential demand for greywater ranges from 13% to 65%, or the average potential demand is about 46%. Based on this data it was concluded "that if the total available gray water is used in a household, the amount of water savings may be about 50%". This statement is based entirely on estimated figures, not on actual achieved savings.

The above figures when compared with the figures of water consumption in the major urban centres of Australia (see Table 2.4) demonstrate that the pattern of water usage in the USA differs substantially. For example, the total in-house water usage in Australia varies from 48% to 75% of total water use, and the possible greywater supply would be less than this. The ex-house usage of water in Australia varies from 25% to 52%, which would suggest that savings of 50% are theoretically possible.

2.3.3 WATER SAVINGS AND COSTS OF SYSTEMS

Kourik (1993) indicated that the savings in water consumption and cost over time would be expected to cover the cost of installing a greywater reuse system. An analysis of the costs of various systems from a number of studies was carried out. It was concluded that the cost of a greywater system depends greatly on its complexity, capabilities and level of automation. Approximate price ranges and capabilities of different systems are presented in Table 2.7.

Table 2.7 - Prices Ranges of Different Greywater Systems

Type of GW system	**Santa Barbara 1991**	**Kourik 1993**		**City of Los Angeles 1992**		**Crawford 1994**
For irrigation	do-it yourself	do-it yourself	professional job	do-it yourself	professional job	
Low tech.system for CWM* greywater	**$ 480**	**$ 274 - $ 377**		**$ 548**	**$ 1096**	
Low tech. system with pump for CWM* greywater	**$ 754**	**$ 411 - $ 685**	**$ 3425**			
Low tech. system for all sources				**$ 1370**	**$ 2055**	
Fully autom. system for all sources				**$ 3425**	**$ 6850**	
For toilet flushing						
Fully automatic system						**$ 2200 - $4400**

** Costs have been converted to Australian dollars. ($=1.37 x USA$; $=2.2 x Eng.pound)

* CWM - clothes washing machine

It is possible to incorporate a number of devices to make the system less time, control and maintenance demanding. But the greater the level of automation and complexity of a greywater system are, the higher is the cost of greywater reuse and less people would be interested in using these systems. Therefore minimum levels of complexity and automation for optimum performance without compromising public health or environmental safety need to be determined.

2.3.4 CONCEPTS ADOPTED FOR THIS RESEARCH PROJECT

For this project the following concepts of greywater reuse systems were adopted:

- on-site greywater reuse in a single family dwelling;
- immediate reuse of untreated greywater for irrigation;
- provision of only coarse screening/simple filtration to ensure long term safe functioning of the system;
- disinfection in the case of toilet flushing to minimise health risk;
- exclusion of kitchen greywater as a source for reuse due to high contamination;
- and use of only subsurface irrigation methods to minimise health risks.

2.4 PUBLIC ATTITUDE TO GREYWATER REUSE

Public interest in saving water has been growing in recent years. The public are demanding a greater input into decision making generally, and especially so in water planning and management (AWWA, 1992).

2.4.1 IMPORTANCE OF CUSTOMER ACCEPTANCE

The attitude of the general public, the potential user of greywater reuse systems, is a major factor affecting the success of this water conservation option. Community consultation and education is a vital component in the development and implementation of this reuse option, and of major importance in influencing public opinion and addressing community concerns.

2.4.2 FACTORS FORMING ATTITUDES TOWARDS GREYWATER REUSE

The main factors affecting the general public's perceptions about greywater reuse can be summarised in three groups:

- Availability of potable water and need of reuse,
- Price of potable water, cost of greywater systems and economic motivation,
- Education and traditions in the society regarding reuse.

In the "Casa del Agua" study (Foster et al., 1988) it was concluded that: "Public acceptance of water conservation and reuse systems will be influenced by dependability of the systems, ease of maintenance, and efficiency of treatment". A factor that has not been considered in this statement is the cost of the systems which will be of great importance for the market penetration of the systems.

In general, to make reuse systems more consumer friendly, the following design objectives can be outlined:(1) Safety, (2) Simplicity, (3) Low cost, and (4) Ease of maintenance.

2.4.3 RESULTS FROM PREVIOUS SURVEYS

A number of surveys have been conducted regarding the value of reuse in conserving potable water resources. The results of an 18 month community consultation program were reported by the ACT Electricity and Water (1994). The reuse of effluent for irrigation enjoyed a very high level of support from all sectors of the community (ref. Table 2.8).

Table 2.8 - Community support for Reuse of Treated Effluent for Irrigation.

Response	Total (%)	Age group Preference		
		20s & 30s	40 yrs	50 + yrs
Totally Support	79	78	87	87
Support a Little	18	19	12	10
Disinterested	-	-	-	-
Against a Little	-	-	-	1
Totally Against	-	-	-	1
Don't know	2	3	-	2

Source: ACT Electricity and Water, 1994.

This study mainly addressed the reuse of treated effluent, but not any of the other water conservation options.

The concept of greywater reuse was endorsed throughout the consultation process for conserving Melbourne's water (Melbourne Water Resources Review, 1992). It was found that greywater reuse was rated as a medium preference as a conservation option. A telephone survey that mentioned greywater as an alternative source of supply indicated that 83% of people felt that "it was a reasonable water conservation action to re-use bathroom and laundry water on gardens". In general, in the Melbourne Water Resources Review (1992) it was concluded that there was widespread public acceptance of the concept of greywater reuse (particularly from bathroom and laundry) predominantly for use on the garden or for toilet flushing. The general findings of this research are important as a first indicator of public opinion; however more detail and in depth analysis is necessary to address issues of concern, the level of information and education needed, and the segment of consumers most interested in greywater reuse.

A Melbourne Water survey into Garden Watering Systems found that 5% of customers were currently practising recycling as a means of watering their gardens (see Table 2.9). According to the report (Brisbane City Council, 1994) commenting on these results, recycled water was more likely to be used for productive plants and pot plants.

Table 2.9 - Number of People Using Different Type of Watering Method

Watering Method	**Year**	**Region**		
	1993 (1015)	**Maribyrnong (225)**	**Yarra (455)**	**South East (335)**
Hand held hose	60%	55%	59%	65%
	627	128	275	225
Hose end sprinkler or soaker hose	27%	17%	32%	26%
	278	40	147	90
Bucket or watering can	20%	18%	18%	25%
	213	41	83	88
Fixed sprinkler system	20%	18%	22%	19%
	208	42	101	65
Drip watering system	6%	4%	6%	7%
	62	8	29	24
Recycled water	**5%**	**5%**	**5%**	**5%**
	50	**12**	**22**	**16**
Total dwellings watered garden last summer	81%	74%	83%	83%
	848	172	388	288

The number in brackets is the number of people surveyed.
Source: Adapted from Brisbane City Council, 1994.

Reuse policies and programs need to be responsive to community needs and concerns. A consumer study (Melbourne Water, 1994) indicated that the concept of effluent reuse in general is likely to raise a number of key issues. In particular:

- The concept has a poor image with many consumers and this will affect the demand for reuse,
- Many consumers will hold serious health and safety concerns about the concept,
- Others will believe that it is an expensive method of saving water,
- Some will not see the need to re-use effluent as a means of conserving a scarce resource.

The above study focused mainly on treated effluent reuse. Similar information is needed on greywater reuse. For this purpose two social surveys were carried out. Details on the methods and procedures used are presented in Chapter 8.

2.5 PUBLIC HEALTH AND ENVIRONMENTAL IMPACTS ASSOCIATED WITH GREYWATER REUSE

2.5.1 GREYWATER QUALITY REPORTED IN PREVIOUS STUDIES

Characteristics (physical, chemical and microbiological) of household greywater are expected to show substantial variation due to factors such as type of family (number and age of members), individual lifestyles and customs, sources of greywater, detergents and other cleansing products used, etc. Hypes (1974) stated that the characterisation of household greywater can produce as many profiles as there are family units generating it.

2.5.1.1 Physical and Chemical Quality

Many studies have addressed the physical and chemical quality of greywater and data from several of these is summarised in Table 2.11.

Traditional concerns regarding physical and chemical quality of wastewater for reuse include BOD, suspended solids, nitrogen and phosphorus. Different sources of greywater in the household contribute differing amounts of these contaminants. A study done by Siegrist et al. (1976) concluded that laundry and kitchen wastewaters were major contributors of pollutants, while the bathroom contribution was a minor one (see Table 2.10). There was a significant difference between the laundry wash and rinse water, with 70% of the pollutants contained in the wash cycle and 30% in the rinse cycle. The results indicated that greywater can be heavily contaminated with pollutants. Laundry greywater, for example, has the highest concentration of phosphorus and suspended solids compared to the other sources, while bathroom water appears to be the less contaminated source.

Table2.10 - Mean Wastewater Contributions from Household Events as a Percentage

Source	Unfiltered BOD_5	Suspended solids	Total Nitrogen	Total Phosphorus
L'dry greywater	29.8 %	31.2 %	11.9 %	54.1%
B'rm greywater	6.2 %	6.4 %	5.0 %	1.0 %
Kitchen greywater	42.3 %	26.7 %	15 %	31.2%

Source: Siegrist et al., 1976.

Table 2.11 - Greywater Physical and Chemical Characteristics reported in the Literature

Parameter	Unit	Rose et al. (1991)	BCC (1991)	Brandes (1978)	Boyle (1982)	Enferadi et al (1986)	Sherman (1991)	Siegrist (1977)	Karpiscak (1992)	City of L.A. (1992)
		range	mean	range	range	range	mean	mean	mean	range
pH		5 - 7	7.4	6.5 - 7.3	7.1 - 8.7					5.7 - 9.9
ECs	µmho/cm		580	330 - 510		443				
Turbidity	NTU	20 - 140	90		42 - 67				56, 63*	
Suspended solids	mg/L		120	25 - 510	36 - 160	20 - 1500		155	90, 150*	
Total dissolved solids	mg/L		350	284 - 854	686 - 925	420 - 1700				140 - 5960
Alkalinity	mg/L	149 - 198		125 - 169	382					
Hardness	mg/L	112 - 152		26 - 54						
Chloride	mg/L	3.1 - 12								
Nitrite Nitrogen	mg/L		< 0.2	1.01 - 0.24						
Nitrate Nitrogen	mg/L	0 - 4.9	0.3	< 0.1 - 0.2	0.1 - 0.6					
Ammonia	mg/L	0.15 - 3.2	5.5	0.1 - 8.1	0.6 - 4.5					
Total Kjeldahl N	mg/L	0.6 - 5.2	12	5.5 - 18	5.7 - 18.4	2 - 50	1.9	17	1.16, 6.68*	
Phosphorus	mg/L	4 - 35	8	0.8 - 3.2	0.3 - 11.9		3.4	23		
Sulphate	mg/L	12 - 40	30	4 - 19						
Potassium	mg/L			4.5 - 13						
BOD_5	mg/L		175	35 - 245	125 - 291	40 - 620	33	260	229, 1489*	
COD	mg/L			119 - 870	242 - 622	60 - 1610	52		539, 597*	
TOC	mg/L			30 - 375						
Aluminium	mg/L		0.67	0.02 - 0.27						
Calcium	mg/L		30	4 - 18						20 - 824
Chloride	mg/L	3.1 - 12		20 - 88						6 - 136
Copper	mg/L		0.15							
Iron	mg/L		0.79	11 - 28						
Lead	mg/L		< 0.05							
Magnesium	mg/L		15	1 - 6						
Sodium	mg/L		70	59 - 90						32 - 1090
Zinc	mg/L		0.38							

Source: Brisbane City Council (1994). Details of references provided there-in. * - Kitchen sink wastewater only.

The comparison between tap water and greywater septic tank effluent undertaken by Siegrist and Boyle (1987) indicated that tap water possessed negligible organic matter, nutrients, and solids while greywater possessed substantial concentrations of these materials. Greywater septic tank effluent, compared to domestic septic tank effluent, had lower concentrations of total suspended solids (TSS) and total nitrogen, but higher concentrations of total solids and sodium. Based on these findings it appears that sodium might be of major concern with greywater reuse for irrigation.

Milne (1979) gave a more detailed comparison between greywater and tap water quality. Chemicals found in significantly higher concentrations in greywater were copper, lead, sodium, nitrates/nitrites, ammonia, chloride, phosphate and sulphate. In his opinion the likely excessive amounts of chloride and sodium, and their potential damage to plants, were of particular concern.

A number of metals can have elevated concentrations in greywater. A study carried out in the Adelaide metropolitan area by Lock (1994) investigated the pollution load of metals and organics in domestic sewage (as compared to that from commerce and industry). The results indicated that the metals with significant loadings in the laundry and bathroom greywater were copper, aluminium and zinc. About 30-45 % of aluminium was already present in the water supply, and about 60-80% of the copper load came from household plumbing. The remainder of the aluminium was mainly attributed to the laundry products, and the copper to bathroom products. Zinc was identified as a significant part of the metal load with the main source being bathroom water. Total boron load was similar to that of aluminium with contributions from both bathroom and laundry. This study, apart from the general categorisation of the sources of metal pollution from kitchen, bathroom or laundry greywater, did not identify any particular products which should be avoided in order to reduce the metal loads. In contrast, the City of Los Angeles (1992) reported that boron was not detected in the 92 greywater samples tested. This fact once again confirms the high variability of greywater quality and its dependence on personal habits, soaps and detergents used, and other site or area specific factors.

With regard to the two possible applications of greywater, its physical and chemical quality is likely to present a number of concerns. One of the concerns with greywater is the high turbidity which affects the efficiency of disinfectants(e.g. chlorine, ultraviolet light) and this might be of concern mainly for toilet flushing. For irrigation, elements of particular concern in greywater according to Brisbane City Council (1994) are boron, sodium, total salts, chlorine and alkaline chemicals. Household detergents are identified as a main source of sodium, phosphorus, potassium, chloride, boron and other elements, but water softeners could also contribute a substantial amount of sodium and chloride.

Some of these elements (eg. phosphorus, potassium) are essential for the growth of plants and greywater can be considered as a liquid fertiliser. Other elements like boron, zinc and chloride are beneficial for healthy plant development when provided in small amounts, but in higher concentrations they can be detrimental. Appropriate selection of bathroom and laundry products suitable for the purpose of greywater reuse for irrigation is essential but not easy. The labelling of the contents of the products on the package does not provide enough information about the concentration of the different components. Manufacturers are reluctant about releasing this information for commercial reasons.

Phosphorus is one of the main elements in detergents, and although it does not usually pose a problem when disposed to land since it is normally a plant requirement, phosphorus can be a source of contamination when soils become phosphate-saturated and there is a potential for leaching to groundwater or run-off to a watercourse. The Albury Sewage Treatment Works Laboratories have conducted tests on the levels of phosphorus in some laundry detergents (Dreyfus, 1994). The results shown in Table 2.12 provide valuable information that can be used as a guide for selecting appropriate detergents.

Manufacturers are beginning to reduce the amount of phosphorus in detergents. A number of alternatives to phosphorus compounds are emerging, eg. zeolites, nitrilotriacetic acid, and sodium carbonate, but none of them possesses all of the useful properties of pentasodium tripolyphosphate, which is a builder with proven toxicological safety and is commonly used in many detergents. Furthermore, not much is known about the effect of some of these alternatives on the environment.

Table 2.12 - Phosphorus Levels in Laundry Detergents

Bushland laundry powder (P)	0.05%	Castle (P)	1.70%
Savings (P)	0.05%	Plus (L)	1.70%
Velvet (P)	0.05%	No Frills liquid (L)	2.30%
Aware (P)	0.05%	Surf (L)	2.90%
Blue Advance (P)	0.05%	Spree (P)	3.00%
Excel Blue (P)	0.05%	Surf (P)	3.00%
Bio Z (P)	0.05%	Fab (L)	3.00%
Down to Earth (L)	0.05%	Spree (L)	3.20%
Country Homestead wool mix (L)	0.05%	Softly liquid (L)	3.40%
Greencare liquid (L)	0.05%	Home brand (safeway) (P)	3.40%
Savings laundry detergent (L)	0.05%	Omo (L)	3.60%
Aura (L)	0.05%	Cold Power liquid (L)	3.70%
Puren (P)	0.05%	Caring (P)	3.70%
Pental (P)	0.05%	Drive (L)	3.80%
Lux (P)	0.05%	Softly (P)	3.90%
Hurricane (P)	0.05%	Savings concentrate (P)	3.90%
Amway Kool Wash (L)	0.05%	Dynamo (L)	3.90%
No Frills soap (P)	0.05%	Cold Power (L)	4.00%
No Frills detergent (P)	0.05%	Gows (P)	4.30%
Earth's Choice (L)	0.05%	Shift (P)	5.10%
Drive Power liquid (L)	0.05%	Cold power (P)	5.60%
Dominant Booster (P)	0.05%	Omo Free (P)	6.00%
Dominant laundry (P)	0.05%	Omo (P)	6.10%
Black and Gold (L)	0.05%	Fab 3 (P)	6.10%
Bushland laundry detergent (L)	0.06%	Dynamo (P)	6.50%
Aware concentrate (P)	0.09%	Omomatic (P)	6.70%
Preservene soap (P)	0.12%	Power wash (P)	6.90%
Amway SA8 super (L)	0.20%	Drive (P)	7.30%
Savings wool wash (L)	0.43%	Cold Power Ultra (P)	7.50%
Scotts lemon (L)	0.60%	Amway Tri Zyme (P)	8.60%
Omo micro (P)	0.90%	Dynamo Ultra (P)	8.90%
Lectric soap powder (P)	1.20%	Dynamo (P)	9.00%
Morning fresh (L)	1.20%	Amway SA8 plus (P)	9.40%
Embassy wool wash (L)	1.30%	Radiant (P)	10.40%
Love 'n' Care (L)	1.60%	Amway Smashing (L)	10.40%

The values are - % total phosphorus by weight of sample. Source: Dreyfus, 1994.
* (P) = powder; (L) = liquid.

As part of an investigation on the safety of greywater for reuse on the garden, Burke's Backyard (C.T.C. Productions, 1994) commissioned a number of tests on leading soap powders as well as those claiming to be 'green' and 'environmentally friendly' for levels of phosphorus, sodium, boron, pH and conductivity. Laundry washwaters and rinsewaters were tested separately. The tests were performed at the Australian Government Analytical Laboratories at Pymble, NSW. A summary of the results is presented in Table 2.13.

Table 2.13. - Detergents Recommended for Garden Use of Greywater

Product tested	Safe to use wash water regularly	Wash water for emergency use	Wash & rinse water together	Rinse water only
FAB Lemon Fresh	No	No	Yes	Yes
OMO Micro Concentrate	Yes	Yes	Yes	Yes
Down to Earth	No	Yes	Yes	Yes
AWARE Concentrate	No	Yes	Yes	Yes
ARK Concentrate	Yes	Yes	Yes	Yes
FAB Lemon Ultra Concentrate	No	No	No	Yes
Surf Laundry Powder**	No	No	No	No
Radiant Concentrate	No	No	No	Yes
Cold Power**	No	No	No	No
Omo Powder	No	No	Yes	Yes

** - not recommended for any garden use.
Source: C.T.C. Productions, 1994.

On the basis of these tests OMO micro-concentrate and ARK concentrate were recommended as the most suitable detergents when laundry greywater was to be reused for irrigation as they presented the least problems with pH, salinity and alkalinity.

2.5.1.2 Microbiological Quality

There is a wide range of results reported in the literature. Comparatively low values were reported by Rose et al. (1991) for total and faecal coliforms in bathroom greywater of 10^5 and $6x10^3$cfu/100mL, in laundry wash of 199 and 126 cfu/100mL, and for laundry rinse of 56 and 25 cfu/100mL, respectively. Both total and faecal coliform concentrations were higher in shower and bath than in laundry waters for all families. It should be noted that the analysis was done with grab samples, collected before the greywater passed through fixtures, water traps or household drainage, and this could be an explanation for the low levels. These samples are not representative of greywater which has travelled through fixtures, pipes and surge tanks before reaching the point of reuse. Microbial populations in the combined (composed from all sources) greywater samples obtained from a sump were 100 to 1000 times higher than at any of the individual greywater collection sites. Total coliforms numbers fluctuated only slightly and averaged 2.8×10^7 cfu per 100mL. In contrast, numbers of faecal coliforms varied from 1.83×10^4 to 7.94×10^6 cfu per 100 mL.

Regarding the variation in microbiological quality of greywater due to family type, in the same study Rose et al. (1991) reported that total coliforms and faecal coliforms in the greywater were low from families without children and averaged between 6 and 80 colony forming units (CFU) per 100ml. In contrast, faecal coliform and total coliform counts were significantly higher in greywater from families with young children and averaged 1.5×10^3 and 3.2×10^5 cfu per 100ml, respectively.

A greywater pilot project carried out in 1992 by the City of Los Angeles investigated the quality of combined greywater from surge tanks. Monthly sample sets were taken over a year from each of eight pilot sites. The faecal coliform levels measured in 92 samples were in the range from 17 to 1.6×10^5 MPN/100mL, and averaged $>3 \times 10^4$ MPN/100mL. In 7 samples no faecal coliforms were detected. The samples were also tested for presence of four disease causing organisms (Salmonella, Shigella, Entamoeba hystolitica and Arscaris lumbricoides), but none of these were found in any sample.

A summary of the results reported in a number of studies is presented in Table 2.14. The levels of faecal coliforms reported in all of these studies indicate the possibility of greywater containing significant levels of pathogenic microorganisms, and the need for selecting an appropriate method of reuse(eg. subsurface irrigation) to avoid human contact.

Table 2.14 - Faecal Coliform Concentrations in Greywater prior to Storage

Source of greywater	**Rose et al (1991)**	**Calif.DHS (1990)**	**Brandes (1978)**	**Siegrist (1977)**
units	cfu/100 mL	(MPN)		
Bath/shower	6×10^3	4×10^5	<10 to 2×10^8	330 to4.4×10^3
L'dry wash	126	2×10^3 to 10^7		
L'dry middle of wash cycle				28 to 405
L'dry rinse	25			
Combined greywater	6 to 80 (a) 1.5×10^3 (b)		8.8×10^5 1.3×10^6	

(a) - families without children; (b) - families with children

Source: Brisbane City Council (1994) and Siegrist (1977).

Novotny (1990) expressed the opinion that greywater quality "is not much different from typical household combined sewage containing black water". Discussing the problems of on-site reuse, Novotny stated that organic pollution (BOD and COD) and bacterial contamination are very high, and that the warm temperature of greywater may provide optimum conditions for growth of bacteria, including pathogens. The same author presented a number of typical greywater characteristics and compared them with sewage characteristics (see Table 2.15). It should be noted that these results refer to greywater from several sources, including the kitchen sink. These results show once again how strongly greywater quality depends on its source.

Table 2.15 - Some Typical Wastewater Characteristics

	Concentration ranges in			
	Domestic greywater		Commercial laundry*	Typical total domestic sewage
	with in-sink garbage disposal	without in-sink garbage disposal		
BOD$_5$,mg/L	200 - 650	125 - 380	118 - 1300	200 - 300
COD, mg/L	280 - 830	210 - 620	560 - 5000	680 - 800
Susp. solids	70 - 180	30 - 80	120 - 1000	200 - 300
pH	6.9 - 8.5	6.9 - 8.5	7.5 - 10	
Total N, mg/L	1 - 8	1 - 8		25 - 50
Total P, mg/L	6 - 10	5 - 15	140 - 275	5 - 20
Total coliform log no/100 mL	7 - 8	7 - 8		9 - 11
Faecal coliform log no/100 mL	6 - 7	6 - 7		7 - 9

* - commercial greywater includes effuent from public restrooms, restaurants, laundries, etc., from which black water is eliminated.

Source: Novotny, 1990.

Rose et al.(1991) studied the effects of storage on microbiological quality of greywater and found that faecal coliforms increased by a factor of 10 to 100 in the first 48 hours and then declined slowly, but even after 12 days the numbers remained higher than those initially present. This indicated that there was a growth of microorganisms in stored greywater and emphasised the need for immediate reuse before the quality of water deteriorates. It appears likely that regrowth potential is governed to some extent by the nutrient and temperature conditions maintained in a particular storage tank.

2.5.2 HEALTH CONCERNS ASSOCIATED WITH GREYWATER REUSE

Concern has often been expressed about possible adverse health effects associated with the microbial content of greywater when its reuse has been considered. Data reported from the literature indicates consistently that greywater contains a significant concentration of pathogenic indicators and potential pollutants. Greywater may contain microbiological agents which will represent a public health hazard if its use is unrestricted. Researchers generally warn that these concerns should be given serious consideration when selecting the method of greywater application.

According to Rose et al. (1991) "The presence of Eschericia coli and other enteric organisms in water indicates fecal contamination and possible presence of intestinal pathogens such as Salmonella or enteric viruses. Fecal coliform is a pollution indicator and may be used to assess the relative safety of graywater. Generally, a high fecal coliform count is undesirable and implies a greater chance for human illness to develop as a result of contact during graywater reuse".

The same study examined the survival of Salmonella, Shigella and poliovirus type 1 in greywater. The results showed that Salmonella and Shigella persist in greywater for at least several days, while the poliovirus added to greywater decreased 99% and 90% at 25°C and 17°C, respectively. However, due to the low dose of viruses required to cause infection, even low concentrations would be of concern.

The survival of pathogens in water, soil or on plants varies from a few hours to months, depending on factors such as type and number of organisms, pH, humidity, rainfall, exposure to sunlight, temperature, type of soil and soil moisture content, competition with other micro-flora (Brisbane City Council, 1994). Watering with greywater will elevate the moisture content and the organic matter in soils, conditions which promote the survival of enteric viruses and bacteria.

These findings raise some concerns about potential health risks associated with greywater reuse. However, there are some opposing opinions to the effect that greywater may not present an excessive risk to public health. For example, Farwell (1990) stated that:

> "Today, as it has been for generations, greywater is used by millions of Americans in rural and semi-rural areas. ...And, as far as anyone has been able to determine, there is not a single recorded instance of anyone in the United States becoming ill from exposure to greywater."

In the final report of City of Los Angeles (1992), it was stated that when greywater is used for irrigation, it helps promote plant growth by introducing nutrients. At the same time greywater is naturally purified by biological activity in the top soil. Soil microorganisms break down organic contaminants including bacteria, viruses, and biodegradable cleaners. The results of the study showed that faecal coliforms in greywater-irrigated soils were not significantly different to levels in soils irrigated with fresh water. The general conclusion of the City of Los Angeles study was that "the results indicated that there may be minimal additional risk of exposure from use of greywater for irrigation of landscaping". An opinion was expressed that either an entirely healthy population was participating in the test program or there was a mechanism for deactivation of pathogens. This last hypothesis is highly unlikely considering the findings of Rose et al. (1991) concerning regrowth of pathogens in the storage tanks and the soil conditions promoting the survival of enteric viruses and bacteria (Brisbane City Council, 1994).

Ruskin (1993), while evaluating the potential health risk of using reclaimed water (including greywater), stated that although most researchers report no incidents of pathogens in the soil, the experimental areas are very small compared to the potential areas to be irrigated. "A very small risk repeated over a very large area may result in some human disease infection". The author presented data on pathogen removal by treatment (Table 2.16) and pathogen survival on grass and expressed the opinion that this small risk would be nearly eliminated by using subsurface irrigation. It appears that subsurface irrigation could be the most suitable method of applying greywater, as it will minimise the potential health risk.

Table 2.16 - Pathogens Removal by Wastewater Treatment

Effluent	Viruses	Bacterial Salmonella	Parasitic Giardia
Raw	500,000	42,500	104,500
Primary	129,250	935	59,405
Secondary	117,700	288	30,462
Tertiary	42	2	784
Infective Dose	1	> 1,000	25 - 100

Source: Ruskin, 1993.

In general, most authors recommended that greywater should be applied by subsurface irrigation. Further general recommendations are that greywater should not be allowed to come into contact with the edible portion of fruits and vegetables, to pond on the surface of the ground, or to run off the property (City of Los Angeles, 1992). Based on the findings regarding the potential presence of viruses and pathogens in greywater and their survival in the environment, surface irrigation with greywater might present a potential health risk. A layer of soil could be used as a barrier which would reduce the chances of contact with greywater and thus would minimise the potential health risk. A detailed analysis of risk assessment literature is presented in Chapter 9.

2.5.3 ENVIRONMENTAL CONCERNS ASSOCIATED WITH GREYWATER REUSE

Greywater reuse has beneficial aspects in keeping the lawn green and providing nutrients for the plants. But there are a number of potential problems including high salinity hazard, degradation of the soil structure due to high sodium content in greywater, damage to plants due to the high concentration of boron and phosphate in greywater, change of soil pH and soil clogging.

2.5.3.1 Salinity

One of the main concerns when using greywater for irrigation is the salinity of greywater. The reason for this concern is the influence of salinity on (1) the soil's osmotic potential, (2) specific ion toxicity, and (3) degradation of soil physical conditions that may occur. All these result in adverse effects on the health and growth of plants. Plants are divided into four major groups, based on tolerance to irrigation water salinity, leaching fraction, and the respective root zone salinity (US-EPA, 1992 a). Salinity is usually determined by measuring the electric conductivity of the water, but may also be reported as TDS. An approximate equation used to convert EC to TDS is given below. It should be noted that EC of the water should be measured at 25°C as the conversion factor is temperature-dependent.

$$\text{T.D.S. (mg/L)} = 0.64 \times \text{EC } (\mu\text{mho/cm}) = 640 \times \text{EC (dS/m)} \qquad (2.1)$$

According to the TDS content irrigation water is classified in five classes; their ranges are presented in Table 2.19. An opinion was expressed that "Gray water may be limited for irrigation due to salinity" (Geoflow Inc., 1993). Salinity could reduce the water uptake of plants by lowering the osmotic potential of the soil. In turn, this causes the plants to use a substantial portion of their available energy on adjusting the salt concentration within their tissues to obtain adequate water (US-EPA, 1992 a). The problem is greater under hot and dry climatic conditions. The concentration of specific ions may cause one or more trace elements to accumulate in the soil and plants, and long-term buildup may result in animal and human health hazards or phytotoxicity in plants.

2.5.3.2 Effect of Sodium Absorption Ratio on soil permeability

Irrigation with water high in sodium and low in calcium and magnesium contents can alter the structure of the soil, reducing its permeability and aeration capacity. High sodium and low calcium in the water or in the soil may lead to waterlogging and permeability problems. The high sodium content in greywater can be due to water softening agents or certain powder detergents. Most of their components (eg. surfactant system, builders, bleaches, corrosion inhibitors and electrolyte fillers) are typically sodium compounds.

The potential influence sodium may have on soil properties is indicated by the sodium absorption ratio (SAR). SAR is the concentration of sodium in water related to calcium and magnesium and is calculated as follows:

$$\mathrm{SAR} = \frac{\mathrm{Na}}{\sqrt{[(\mathrm{Ca}+\mathrm{Mg})/2]}} \qquad (2.2)$$

where ion concentrations, Na, Ca and Mg are expressed in meq/L (US-EPA, 1992 a). Sodium does not impair the uptake of water by plants, but it impairs the infiltration of water into soil, and thus affects the plants' growth by affecting the availability of soil water.

In general, based on a salinity hazard diagram produced by the USDA (Richards, 1954), irrigation water with an SAR of less than 8 should be suitable for irrigation. Waters with an SAR between 9 - 15 are likely to be marginal, and those with an SAR of 16 or more are usually not suitable, although salinity values should be considered in conjunction with SAR values in order to draw firm conclusions.

SAR gives an indication of the effect of exchangeable sodium on the physical condition of the soil. In order to include a more precise estimate of calcium in the soil water following irrigation, for reclaimed water it is recommended to use SAR adjusted for alkalinity, ie. adj. R_{Na}.

$$\mathrm{adj.}\,R_{Na} = \frac{\mathrm{Na}}{\sqrt{[(\mathrm{Ca}_x+\mathrm{Mg})/2]}} \qquad (2.3)$$

where the Ca_x value can be determined from a table (US-EPA, 1992 a).

An excessively high concentration of sodium can be toxic to plants if it cannot be leached away from the root zone (Milne, 1979). Sodium effects can be counteracted by the addition of gypsum (calcium sulphate) directly to the soil. It should be noted that gypsum does not affect the alkalinity of the soil, and it is therefore safe to use it even when excessive soil alkalinity is a problem (Milne, 1979).

2.5.3.3 Trace Elements and Metals

Some of these elements are essential for plants and animals but all can become toxic at elevated concentrations. The large variation in concentration of trace elements in soils under natural conditions complicates the setting of general limits for application. It is important as a safeguard to sample and analyse the soils and vegetation before irrigation and to regularly monitor them (maybe yearly) during the period of irrigation with wastewater. Elements such as Cd, Cu, Ni and Zn might limit the use of wastewater for irrigation because of their potential toxicity to plants, but for domestic wastewater with typical trace element concentrations this appears to be unlikely (EPAV, 1991). Boron is another element that is essential for plant growth, but the margin between levels considered essential for plant growth and those considered toxic to plants is extremely narrow. The recommended limits for maximum concentrations in mg/L of some trace heavy metals in irrigation water is presented in Table 2.18 (Section 2.5.4).

2.5.3.4 Specific Ions

Plants vary greatly in their sensitivity to specific ion toxicity. When using greywater for irrigation the specific ions of most concern could be chloride, boron, and sodium. In general, excess concentrations of aluminium, phosphorus and nitrogen in irrigation wastewater can also be of concern.

Chloride

Chloride is one of the elements of concern as it can cause leaf burn in sensitive plants. Waters containing less than 100 mg/L are considered safe for spray irrigation and higher chloride levels can be tolerated in flood irrigation, but severe damage to plants can occur if chloride exceeds 350 mg/L (EPAV, 1991). For subsurface turf and landscape irrigation, it was reported (Ruskin, 1993) that water with 900 mg/L chlorides and average pH of 7.6 was successfully used. It appears that when applied subsurface the contact of water with plant leaves is eliminated and no harmful effects are observed even at higher concentrations.

Aluminium

Some soils are naturally high in aluminium and sensitive plants such as lucerne will not thrive (EPAV, 1991). Aluminium retards the root development of plants in strongly acid soils and it may also affect the availability of phosphorus. Recommended limits are shown in Table 2.20.

Nitrogen

Nitrogen is essential for plant growth. However, application of large amounts of nitrogen can result in soil acidification, groundwater contamination through leaching, and surface water contamination if there is runoff from the site. The total nitrogen load should generally not exceed 500 kg N/ha.yr. Greywater is unlikely to provide such high loadings of nitrogen.

Phosphorus

Phosphorus typically is not of concern as it is an essential element for plant growth. However, clay soils may become phosphate-saturated and there is a potential for leaching to groundwater or run-off to a watercourse. Excessive leaching of phosphorus to groundwater in sandy soils may be an even more significant problem. Phosphate can also be of concern to gardeners because of the possible damage it may cause to phosphate sensitive plants. Some native plants (not all) are injured or killed by excessive soil phosphate levels. These native plants should therefore not be watered with greywater, and most of them are in fact very drought tolerant (see Table 2.17).

Table 2.17 - Plants that Should Not be Watered with Greywater

Class/family	Name of plant	Reasons
Australian natives		
Proteaceae family	Banksias	Sensitive to phosphorus
	Grevilleas	Sensitive to phosphorus
	Hakeas	Sensitive to phosphorus
	Waratahs	Sensitive to phosphorus
Mimosaceae	Wattles	Sensitive to phosphorus
Rutaceae	Boronias	Sensitive to phosphorus
Acid loving plants		
	Azalieas	Sensitive to alkaline water
	Rhododendrons	Sensitive to alkaline water

Greywater is generally considered suitable for irrigation of ornamental trees and shrubs, flowers and other ornamentals, ground cover, lawns and fruit trees (Geoflow Inc., 1993). Plants which grow in acid soil, at pH below about 5.0, are likely to be quite sensitive to the alkaline character of greywater. It is recommended that greywater should not be used on such plants.

2.5.3.5 Soil Alkalinity

pH of the irrigation waters and the influence it has on soil pH are very important factors, as plants grow best when the soil is within specific pH ranges. Most plants prefer a slightly acid soil with pH between 6 and 7. Very few plants grow well in soil with pH in the range of 8 to 9 or above. According to Milne (1979), greywater tends to be slightly alkaline, with pH range typically between 6.5 and 9.0, and the extensive use of greywater for irrigation could ultimately cause soil to become progressively more alkaline. If the soil becomes alkaline, various minerals such as iron, manganese, and copper become fixed in chemical compounds and unavailable to plants. It is recommended that if the pH of soil rises above 7, iron sulphate should be added to the soil to lower pH (Kourik, 1993). In acid soils iron, manganese and aluminium all become more readily available, and sometimes toxic to plants. Important nutrients such as phosphorus may become fixed in compounds and unavailable to plants in either acid or alkaline soils. Phosphorus is most available in the pH range between 5.5 and 7 (Milne, 1979).

2.5.3.6 Soil clogging

One possible problem with using greywater for irrigation is soil clogging. The factors contributing to soil clogging are typically classified as chemical, physical and microbiological (Chen, 1974). A field investigation was conducted at the University of Wisconsin between 1979 and 1985 to evaluate the effects of wastewater composition and loading rate on soil clogging development in subsurface wastewater infiltration systems (Siegrist and Boyle, 1987). Greywater septic tank effluent was applied at the rate of 1.3, 2.6 and 5.2 cm/day to a structured silty clay loam subsoil. The results showed that soil clogging development was negligible under loadings at 1.3 and 2.6 cm/day. But under loadings at 5.2

cm/day severe soil clogging development led to continuous ponding of the soil infiltrative surfaces. Their hypothesis was that the reduction in infiltration rates was caused by accumulations, at and immediately beneath the soil infiltrative surfaces, of organic matter which underwent humification and gradually filled the soil pores. They concluded that soil clogging development is a long-term process with infiltration rate losses occurring over a period of a year or more. It was confirmed that soil clogging development is highly correlated with the cumulative mass density loadings of total BOD and TSS. This study investigated only the physical factors involved in soil clogging, but did not consider any of the chemical factors such as ion-exchange or deflocculation of the soil caused by high concentrations of sodium. The latter problem is expected to be of major concern with greywater reuse for irrigation, as has been previously indicated.

2.5.4 GUIDELINES FOR WASTEWATER REUSE

No standards are available for quality of greywater for reuse, but there are a number of guidelines regarding reuse of wastewater that could be considered relevant and were reviewed. A summary of the most important parameters regarding wastewater quality is presented in this section.

(i) NSWRWCC (1993) - Guidelines for Urban and Residential Use of Reclaimed Water

Reclaimed water meeting the NSW urban and residential reuse guidelines requires treatment to a high standard aimed at eliminating micro-organisms and can be used for open access urban and residential re-use. Among the number of permitted applications are garden watering and toilet flushing. The quality criteria are divided into three sections: microbiological, physical and chemical parameters (see Table 2.18).

With regards to disinfection, the NSW guidelines suggest that a free chlorine residual of 5 mg/L with 1 hour contact time should ensure virus kill.

Table 2.18 - Reclaimed Water Quality Requirements

Microbiological Quality	Physical quality	Chemical quality
(a) From the water recl.plant	(a) Turbidity	(a) General
Faecal Coliforms < 1 in 100 ml	< 2 NTU geometric mean .	Free residual chlorine at point of use
	< 5 NTU in 95% of samples	< 0.5 mg/L .
Coliforms < 10 in 100 ml (in 95% of the samples)		
	(b) pH	(b) Salt and Nutrients
Virus < 2 in 50 L	6.5 to 8.0 allowable range .	as recommended by SPCC's
	(7.0 to 7.5 desirable range)	publication WP-8 "Reuse of Treated
Parasites < 1 in 50 L		Wastewater by Land Application" .
(b) From consumer services	(c) Colour	(c) Heavy Metals and Pesticides
Coliforms < 22.5 in 100 mL geometric mean over 5 consecutive samples	< 15 TCU .	according to EPA requirements (SPCC, 1991)
< 25 in 100 mL . (in 95% of samples)		

Source: Adapted from information in NSWRWCC (1993).

These guidelines focus on the public health requirements which the treated wastewater quality should meet to be suitable for use in open access areas and in urban block situations. With regard to greywater reuse the guidelines are very useful for assessing the greywater quality for toilet flushing. As greywater for irrigation would be applied subsurface, more appropriate guidelines would be EPAV (1991) which address in detail the environmental issues associated with wastewater irrigation.

(ii) EPAV (1991) - Guidelines for Wastewater Irrigation

The salinity hazard of irrigation water is classified according to the TDS content into 5 classes. The TDS ranges of these classes and the possible application of the wastewater are presented in Table 2.19.

Regarding health criteria, the same guidelines have set the following quality requirements for wastewater that has received secondary treatment:

(a) BOD - median < 50 mg/L;

(b) Suspended solids - median < 50 mg/L;

(c)	Faecal coliforms	- median	< 1000 org/100 mL
		and 90%	<2000 org/100 mL.

Wastewater with this quality can be used for flood, furrow, drip or spray irrigation of trees, pastures and landscaped public recreation areas (subject to conditions). In regards to greywater reuse for subsurface irrigation these health standards could be too stringent, as they refer to spray irrigation and in public areas.

Table 2.19 - Salinity Classes of Irrigation Waters.

Class	TDS (mg/L)	Electrical Conductivity (μ m/cm)	Type of soil and plants suitable for irrigation
1	0 - 175	0 - 270	Can be used for most crops on most soils, some leaching is required.
2	175 - 500	270 - 780	Can be used if a moderate amount of leaching occurs, for plants with moderate salt tolerance.
3	500 - 1500	780 - 2340	Should not be used on soils with restricted drainage, and the salt tolerance of the plants must be considerable.
4	1500 - 3500	2340 - 5470	Soil must be permeable and drainage adequate, salt-tolerant crops should be selected.
5	> 3500	> 5470	Not suitable for irrigation except on permeable well-drained soils under good management, use restricted to salt-tolerant crops.

Source: EPAV (1991).

(iii) USEPA (1992 a) - Guidelines for Water Reuse

The most complete set of limits for trace elements and metals in irrigation water is found in the Guidelines for Water Reuse (USEPA, 1992 a). Identical levels for metal concentrations are recommended by EPAV (1991). The NSWRWCC (1993) has set more stringent requirement for two metals: Lead (0.20 mg/L) and Iron (1.0 mg/L).

With regard to TDS, for concentrations below 500 mg/L no detrimental effects are usually noticed. Between 500mg/L and 1000mg/L, TDS in irrigation water can affect sensitive plants. At 1000 mg/L to 2000 mg/L, TDS levels can affect many crops and careful management practices are recommended. Above 2000 mg/L, water can be used regularly only for tolerant plants on permeable soils (USEPA, 1992 a).

Table 2.20 - Recommended Limits for Trace Elements & Metals in Irrigation Water.

Metal	Max concentration (mg/l)	
	Long-Term Use	**Short-Term Use**
Aluminium	5.0	20
Arsenic	0.10	2.0
Beryllium	0.10	0.5
Boron	0.75 (sensitive crops)	2.0
Cadmium	0.01	0.05
Chromium	0.1	1.0
Cobalt	0.05	5.0
Copper	0.2	5.0
Fluoride	1.0	15.0
Iron	5.0	20.0
Lead	5.0	10.0
Lithium	2.5 (citrus 0.075)	2.5
Manganese	0.2	10.0
Molybdenum	0.01	0.05
Nickel	0.2	2.0
Selenium	0.02	0.02
Vanadium	0.1	1.0
Zinc	2.0	10.0

Other parameters	Recommended Limit
pH	6.0
TDS	500-2000 mg/L
Free Chlorine Residual	< 1 mg/L

Source: USEPA, 1992 a.

The above review of existing guidelines on wastewater reuse demonstrated that there are differences in the limits quoted in the different sources. For the purpose of this project it seems that NSWRWCC (1993) defines the most appropriate limits regarding reuse of wastewater where people can come in contact with it and is more relevant to health risk aspects. The guidelines providing most relevant information on trace element and metal limits in irrigation water and on environmental risks due to possible effects on soil, plants, groundwater, etc. are those in EPAV (1991) and USEPA (1992 a). This information will be used for assessing the quality of greywater used at the experimental sites.

2.5.5 RISK ASSESSMENT METHODOLOGY

Before any authorisation for greywater reuse could be given by relevant Authorities, an assessment must be made of potential risks involved in the various forms of reuse. Risk assessment analysis involves the four main steps of hazard identification, dose-response rate determination, exposure assessment and risk characterisation. A detailed review of local and overseas literature on risk assessment methodology is presented in Chapter 9.

CHAPTER 3: PROJECT OBJECTIVES AND METHODOLOGY

3.1 GENERAL

In 1993 Victoria University of Technology in conjunction with Melbourne Water commenced an investigation of the practicalities, costs and social attitudes of reusing domestic greywater. An industry-based committee consisting of representatives from Melbourne Water (MW), Victoria University of Technology (VUT), the Department of Health and Community Services Victoria (H&CS) and the Environment Protection Authority Victoria (EPA) was established to provide technical support and guidance throughout the two years of research.

3.2 FUNDING OF THE PROJECT

Initially the research project began with the main funding provided by Melbourne Water, and supplementary support for some of the experimental equipment given by Victoria University of Technology. In the second year significant financial assistance for the greywater sampling and testing program was provided by the Department of Health and Community Services Victoria. One of the greywater sampling and testing rounds was partially financed by the Environment Protection Authority Victoria.

3.3 AIMS AND OBJECTIVES OF THE PROJECT

As outlined in the introduction the general aims of the research are: **(A.)** To assess the technical and economic feasibility of reusing domestic greywater from laundry and bathroom for the irrigation of lawns and gardens (priority 1) and toilet flushing (priority 2), **(B.)** To determine what public health and environmental impacts would occur if the people of Melbourne were given the opportunity to reuse their greywater, **(C.)** To determine the social acceptance of reusing greywater. These aims have been expended into a range of specific objectives as follows:

3.3.1. TECHNICAL

- To determine suitable methods (if any) of using domestic greywater for garden watering and toilet flushing. As it is believed that most people will only use greywater if it is a cheap and simple proposition, greywater systems meeting these criteria will be the priority for investigation and assessment.
- To assess the practical issues involved in operating and maintaining a greywater reuse system, based on results from the experimental program.
- To make an assessment of the methods and practices that can be recommended and not recommended for greywater reuse systems.
- To provide practical experience and recommendations facilitating the development of guidelines for installing greywater systems and to assess the best way to regulate their use.

3.3.2 ECONOMIC

- To make an assessment of water and cost savings to be made for Melbourne's domestic water consumers under various water and sewerage tariff strategies.
- To assess the potential extent, costs and difficulties related to the use of greywater reuse systems in established and new homes in Melbourne Water's supply area.

3.3.3 SOCIAL

- To assess the general public's perception of greywater use;
- To assess the level of costs for installing greywater reuse systems for toilet flushing and garden watering acceptable to the general public;
- To assess the level of education required for the general public to become familiar with, or become proficient in, the use of greywater recycling systems;
- To identify sympathetic customer segments that can be effectively reached in a greywater marketing campaign.

3.3.4 PUBLIC HEALTH AND ENVIRONMENTAL

- To assess the quality of domestic greywater from laundry and bathroom, derived from local and overseas field research work.
- To make a comparison of domestic greywater quality with Australian wastewater quality guidelines and standards.
- To make a qualitative assessment of the environmental and health impact of greywater reuse systems, based on local and overseas experience.

3.4 METHODS AND TECHNIQUES USED

As a starting point of the research work an intensive literature review was carried out in order to provide the background information on greywater reuse systems and data from other case studies on quality and quantity of greywater for comparison with results of the present research. The review included analysis of information available from Australia and overseas relevant to the four main areas of the investigation program: ie, technical, economic, social, public health and environmental aspects.

In order to determine suitable methods of using greywater for garden watering and toilet flushing, experimental greywater delivery systems were designed, installed, monitored and assessed on four home sites which provided a range of conditions under which the systems would operate (eg. soil type, slope, house construction, family size, vegetation). The main objective was to develop types of greywater reuse systems which are cheap, simple to operate, acceptable to the user and safe for the environment.

In the process of assessing the suitability of the sites a number of factors were investigated and assessed - soil type, slope, area available for irrigation, vegetation, access to the existing plumbing and greywater production. Assessment procedures for some of the parameters under consideration are covered in Australian Standard AS 1547 (Draft), "Disposal of sullage and septic tank effluent from domestic premises".

Soil type and properties are key factors in the design and operation of greywater irrigation systems. The main characteristics necessary for evaluation of the soil for the purpose of greywater irrigation are soil texture, soil structure, infiltration rate through the topsoil and percolation rate in the sub-strata. Percolation rates were determined using percolation tests and compared with textural classification charts. Infiltration rates were determined using a cylinder infiltrometer.

The slope of the irrigation site (in combination with the soil parameters) is an important factor in controlling surface ponding and erosion. The topography of the sites and contours were established using standard surveying procedures. The size of the irrigation area and the buffer zones at each site were determined before the design of the layout of the irrigation pipes was made. A turf specialist inspected the sites and analysed the existing grass cover, trees, bushes and other plants in relation to the source and future use of greywater for irrigation.

A preliminary evaluation of access to the existing plumbing, the sources and quantities of greywater produced and of suitable space for placing the surge tanks was carried out for each site. Two procedures for estimating greywater volumes produced were used: (1) based on historic water use records for the particular family and (2) on typical figures for average daily water use per person.

The final design and construction of the greywater reuse systems were based on:

- Information from the intensive search of local and overseas literature (Milne, 1979; County of Santa Barbara, 1991; California Department of Water Resources, 1993; Kourik, 1993; Brisbane City Council, 1993) about design and installation of greywater systems;
- A number of relevant local standards:

  AS 3500 (1992) - National plumbing and drainage code(Part 1 and 2);
  AS 1547 (Draft) - Disposal of sullage and septic tank effluent from domestic premises
  AS 2698 (1984) - Plastic pipes and fittings for irrigation and rural applications;

AS 1319 (1983) - Safety signs for the occupational environment;

AS 1345 (1982) - Identification of the contents of piping, conduits and ducts;

AS 2845 (1991) - Water supply - Mechanical Backflow Prevention Devices;

- NSW Guidelines for Urban and Residential Use of Reclaimed Water.
- Findings from the preliminary investigation of the site conditions and estimated greywater volumes produced;
- Results for laboratory testing of some of the system components.

In order to ensure the proper functioning of the systems as well as meeting public health and EPA requirements, operation manuals were prepared for the residents of the experimental sites.

Applications for permits for the installation of the experimental systems were submitted to Melbourne Water, EPA and the relevant Municipal Councils. Melbourne Water inspectors approved the plumbing arrangements and inspected the sites after the greywater reuse systems were installed. Approval of the experimental subsurface greywater reuse systems was gained from EPA under Section 53 M(7) of the Environmental Protection Act 1970. Permits (in the form of a septic tank permit) for each system were obtained from the Municipal Councils.

After commissioning, close monitoring of the systems was undertaken on a weekly basis for a 14 months period. Special pro-forma sheets were designed for recording of weekly observations, aspects of operation and control of the greywater systems, household fixture usage, laundry and bathroom products used, plant development and difficulties or problems encountered that might require servicing or alteration to the system. In addition to investigating the practical issues involved in running a greywater reuse system the field study aimed to assess the level of training required for householders to become proficient in the use and operation of greywater reuse systems.

Detailed records of observations and expenses were kept during the construction and installation of experimental systems in order to identify costs and difficulties of installing reuse systems in existing and new homes in Melbourne. The weekly recordings of water consumption and greywater volumes were used to assess potential water and cost savings for consumers under existing water and sewerage tariff arrangements.

An assessment of the general public's perception of greywater reuse and the level of acceptable costs for garden watering and toilet flushing was made from social surveys conducted using several different approaches, ie telephone survey, mail survey and personal interview. The first survey consisted of 300 telephone interviews of randomly selected residents in the Melbourne metropolitan area. The second survey comprised 990 questionnaires distributed randomly amongst the residents of Melton, a town of 10119 households situated 39 km west of Melbourne. The results of the two surveys were coded and analysed using the software package Statistical Package for Social Science (SPSS) for Windows. Details of the testing methods and procedures are provided in Chapter 8. Personal interviews were conducted with the residents of the experimental sites in order to identify concerns, practical difficulties, and the need for additional information or recommendations associated with greywater reuse systems.

To assess the quality of domestic greywater from laundry and bathroom and any effects on receiving soils a program of sampling and testing of greywater and soil was developed. Six sampling rounds of the greywater from bathroom and laundry sources and four rounds of sampling of the receiving soils were made. Strict sampling procedures were followed to ensure the best possible representative results. Greywater samples were taken immediately after the greywater producing event, kept on wet ice at 4°C during transportation and delivered to the testing laboratories within 24 hours. Soil samples were taken before irrigation with greywater to establish a base line for comparison and after one season of irrigation to determine if there were any changes in the characteristics of the receiving soils. Details of the sampling procedures are given in Chapter 5. Authorities that conducted the testing were:

A./- For greywater

- physical and chemical testing - the Water Ecoscience Laboratory,

- microbiological testing - the Fairfield Hospital Laboratory.

B./ For soil

- physical and chemical testing - Turfgrass Technology Pty Ltd and the State Chemical Laboratory.

Chemical, physical and microbiological quality of laundry and bathroom greywater was compared with values reported in the literature, and with relevant Australian wastewater quality guidelines and standards. Regular reports of the physical and chemical properties of normal tap water were obtained in each locality to assist in the interpretation of greywater test results.

A number of tests were performed with different disinfectants and detergents in order to identify the most suitable ones in respect to public health and environmental safety.

Another aim of the project was to make a qualitative assessment of the environmental and health impacts of greywater reuse systems. A review of local and overseas methods and techniques used for risk assessment was carried out. Health risk assessment includes four main steps (hazard identification, dose-response rate determination, exposure assessment and risk characterisation), which affect the qualitative assessment of the possible health impacts associated with greywater reuse. For the environmental risk assessment, attention was focused on potential harmful effects on specific environmental elements such as soil, soil biota, plants, and ground water. A range of health risk exposure pathways for toilet flushing and garden watering was defined. A limited risk assessment, based mainly on literature and information from previous studies and experience, was carried out and identified the main risk factors and pathways.

Based on the analysis of the results from the experimental work, key conclusions related to technical feasibility, economics, social attitudes, and risk to the environment and the public of reusing greywater have been drawn. Recommendations were made regarding installation and maintenance of greywater reuse systems, and areas of future research were outlined.

CHAPTER 4 METHODS AND EQUIPMENT

4.1 EXPERIMENTAL REQUIREMENTS

In order to achieve the objectives of the project the first step was to select experimental sites to provide as much variation as possible in type of family, house construction and allotment characteristics. The next step included the design, supply and installation of greywater systems and equipment as indicated below to provide a range of layouts incorporating various devices for system control and performance monitoring.

(a) Diversion plumbing arrangements and associated equipment including:

- diversion systems for wastewater from laundry and bathroom,
- greywater screening and filtering devices,
- greywater collection/surge tanks from which water samples could be taken,
- greywater toilet flushing tanks, with provision for potable water make-up supply,
- pumps.

(b) Irrigation systems for distribution of greywater.

(c) Automatic control devices for the irrigation systems:

- rain sensors and automatic pump switch devices.

(d) Apparatus for system control and monitoring including:

- flow meters to measure greywater flows,
- pressure gauges to measure head losses across filters,
- rain gauges to aid in irrigation management,
- tensiometers to aid in irrigation management and give an indication of soil moisture levels near site boundaries.

4.2 SELECTION OF SITES

People who had made submissions to the Melbourne Water Resources Review regarding greywater reuse were contacted by telephone and interviewed in order to obtain preliminary information regarding their interest in participating in the experimental program. As a result arrangements were made to visit and investigate ten sites, and technical data were prepared for a preliminary assessment. It was decided to base selection of suitable experimental sites on the following desirable criteria:

- Sites should be within the Melbourne metropolitan area,
- A range of topographic and soil conditions should be investigated,
- A range of family types (number and age of members) should be included,
- A range of house types and construction should be studied,
- Both new and established dwellings should be represented,
- A variety of vegetation types should be irrigated.
- There should be no obvious problems such as inadequate area available for irrigation, site susceptibility to flooding, or excessive slopes.

During initial investigations a number of sites were eliminated because of the following constraints:

- slab on ground house and no access to divert greywater,
- attached terrace house and not enough area for irrigation,
- difficult access and inconvenient configuration of the sewer pipes under the house .

Representatives of the industry-based project steering committee visited the remaining six sites to consider the most appropriate locations. Three sites were then eliminated because of constraints including steep slopes and high flood levels. Experimental installations were designed for the remaining three sites but because of financial constraints it was initially possible to develop only two of the three sites. Later on a third site (not in the original group) was added when additional funding and the opportunity for a system to be built into a new house (as compared with retrofitted ones) became available. A year later a fourth site was added and a greywater diversion system designed and installed with the following objectives:

- to develop a prototype greywater reuse installation,
- to install a simplified diversion system,
- to take advantage of low cost, simple and easy to maintain equipment,
- to test and analyse the performance of additional types of filters and filter media,
- to take the opportunity to test additional distribution system arrangements, and
- to analyse the retrofitting process at a brick house.

Thus, by the time the project had been running for about eighteen months, there were four sites participating in the research, providing as much variation as possible in house type (eg. new/retrofitted greywater plumbing, ground clearance, storeys, brick/timber construction), allotment characteristics (eg. soil type, size of area for irrigation, topography, vegetation), and family type (eg. number of people, age group). Experimental sites and their characteristics are summarized in Table 4.1.

Table 4.1 - Experimental Sites and their Characteristics

CHARACTERISTICS	SITE 1	SITE 2	SITE 3	SITE 4
1. Location (suburb)	Balwyn	Clifton Hill	Malvern	Strathmore
2. Installation date (month)	December '93	December '93	August '94*	October '94
3. Family characteristics				
(a) adults**	2	2	2	2
(b) teenagers (13 - 18 yrs)	2	-	-	-
(c) children (3 -12 yrs)	-	2	-	-
(d) babies/toddlers (0 - 2 yrs)	-	-	-	1
4. Typ.quan.generated (L/wk)				
(a) bathroom	2450	1420	460	840
(b) laundry	1200	400	210	520
5. Allotment characteristics				
(a) size (m^2)	573	569	216	541
(b) soil type				
- top soil (150 mm)	silty sandy soil	bl. clayey silty soil	gr./br. silty sand	gr. silty top soil
- subsoil	silty fine/med.sand	bl./gr. silty clay	gr./br. silty sand	gr./br. clayey silt
(c) area irrigated (m^2)	130	160	34	97
(d) slope of area irr. (%)	5 - 7	< 1	< 1	3 - 4
(e) vegetation irrigated	lawn	lawn, some garden	native garden	lawn
6. House details				
(a) construction type /storeys	weatherboard/ 2	weatherboard/ 1	concrete brick/ 1	brick veneer/ 1
(b) approx.floor clearance (m)	0.20 - 1.10	0.25	slab on ground	0.25 - 1.35
(c) number of toilets	3	2	1	1
7. New or retrofit situation	retrofit	retrofit	new	retrofit

* - The toilet flushing part of the system reusing greywater was finished and commenced operation in January '94, but the whole project including the irrigation system using greywater was finalised in August '94.
** - It should be noted that at each site both adults were working outside the family home. At sites 1 and 3 one of the adults has part time employment.

An analysis (see Appendix A) was carried out to assess whether these sites represented a reasonable sample of typical Melbourne household types. It can be concluded that, although chosen on a voluntary basis, the four households involved in the greywater research program:

1. being detached houses, belong to the group of the most typical type of dwelling in the Melbourne Metropolitan Area;
2. and with families of 2, 3 or 4 members, have the most typical sizes of family for this type of dwelling.

4.3 EXPERIMENTAL DESIGN AND EQUIPMENT

The design of the experimental greywater reuse systems was carried out after extensive research of the local and overseas literature for existing practices, guidelines and plumbing codes. The following section gives an overview of devices, materials and equipment used for the experimental installations. Additional design considerations were presented in Section 2.2.

4.3.1 DIVERSION ARRANGEMENTS

Diversion will typically involve insertion of a tee and branch in the appropriate fixture waste pipe and the provision of one or more valves. Diversion of greywater for reuse in newly built houses will usually present fewer difficulties than in retrofitted cases as systems can be incorporated in the design of the dwelling. In retrofit situations diversion arrangements depend on factors such as type of house construction, type of foundations, access to plumbing, levels of existing sewer, storm and drain pipes, possible location of the collection/surge tanks, etc.

4.3.1.1 Design of a New Diversion Arrangement

As discussed in Section 2.2 the reviewed diversion arrangements have some limitations regarding installation space, failsafe protection and ease of control. A major design task was therefore to find the simplest, most economic and safest way to divert greywater. A new arrangement consisting of only one valve and a tee has been developed, tested in the laboratory and implemented at experimental site 4. The arrangement is for diverting greywater from a horizontal drain pipe which typically has minimal vertical ground clearance, a common situation for bathrooms in one storey houses. A schematic view of it is presented in Figure 4.1. The same design can be successfully used for diverting laundry greywater independent of the configuration of the existing drain pipes (see Fig.4.2). Laboratory tests were conducted on a model constructed of DN 50 pipe with a 45° tee installed as close as possible (75mm) after the S-trap. The arrangement demonstrated very good diversion capacity. Up to 50 L/min flow was completely diverted through the lateral part of the tee. There are a few other advantages of this diversion arrangement:

1) high level of safety - if there is a blockage or any other impediment in the way of the diverted greywater it will unrestrictedly overflow to sewer or into the laundry trough;

2) immediate indication of clogging or blockage - if a downstream in-line filter becomes clogged, the overflow is directed into the trough and gives an immediate warning;

3) a very small vertical clearance is required for installing this diversion arrangement;

4) it is easily accessible for diverting laundry greywater containing bleach or other undesired constituents to sewer,

5) it is a very economic and simple diversion arrangement, suitable for many greywater diversion designs.

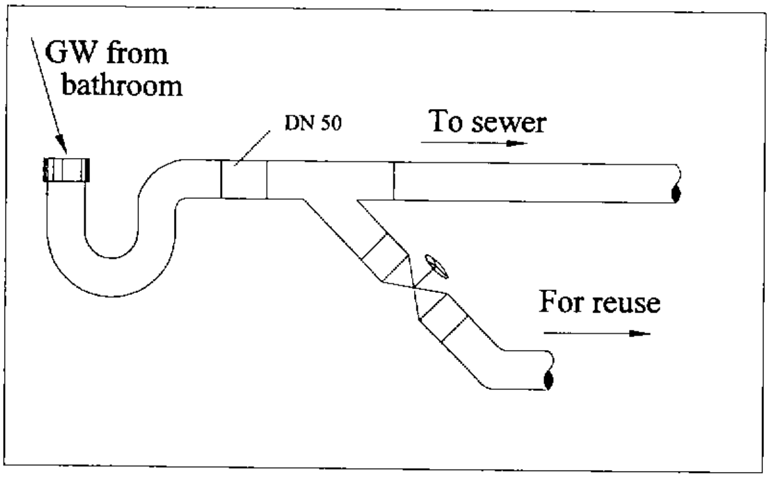


Figure 4.1 - Diversion arrangement for bathroom greywater

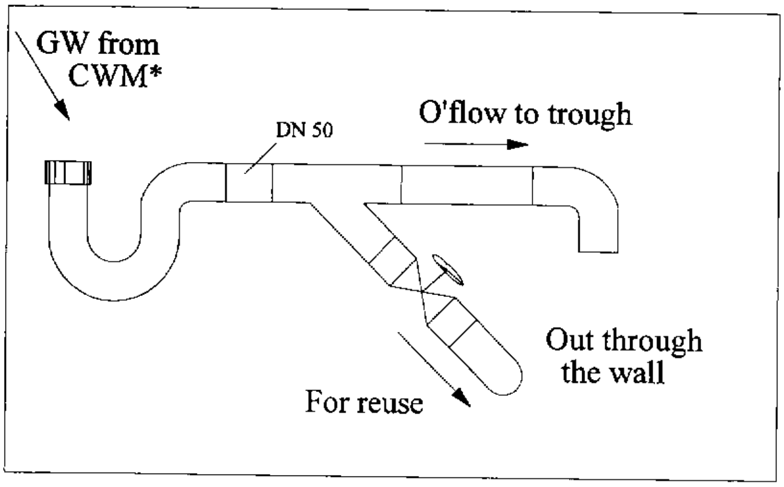


Figure 4.2 - Diversion arrangement for laundry greywater

* CWM - stands for "clothes washing machine".

4.3.2 SCREENING AND FILTERING DEVICES

At the experimental sites the removal of the suspended material was achieved by a three-stage filter system:

- Stage 1 - a strainer (pre-filter) in the laundry trough, shower or bath outlet to remove coarse sized materials. The devices used were a metal grate or a "Hair Share" thin mesh plastic strainer.

- Stage 2 - a mesh screen installed in the collection tanks or as an in-line filter to collect previously untrapped hair, soap particles, lint and body fats. The mesh screen was made of fly wire and fitted into a plastic basket attached to the pipe inlet stub of the tanks and drums. A view of this type of filter is shown on Plate 1. An additional stainless steel mesh screen was installed on the outlet pipe from the toilet flushing tanks. At site 4 where no tanks were involved, in-line "HI-FLO" and "Leaf canister" filters with large surface area mesh screens were used.

- Stage 3 - a fine filter on the supply line to the irrigation pipes or toilet cistern for removing settled materials and other fine particles still in suspension.. "Amiad" mesh filters and "Arkal" disk filters with housing and interchangable filtering elements were used. The 100 micron mesh and 110 micron disk elements initially installed became clogged very quickly and were subsequently replaced with 200 micron mesh and 170 micron disk elements respectively.

A number of disposable-type filters including "Cleaning cloth" filter-bags, "Geotextile" filtersocks and "Nylon stockings" were also tested. These were installed at the end of clothes washing machine hoses, on inlet pipes in the collection tanks, or in the "Leaf canister" filter.

An overview of the characteristics of the filters used is presented in Table 4.2.

Table 4.2 - Experimental Filters and their Characteristics

CHARACTERISTICS	Type of Filter	Mesh size	Filter device code*	Price (1994 $)
	REUSABLE FILTERS			
STAGE 1				
	Metal strainer	2.3 mm	1	$ 0.68
	"Hair share"	0.9 mm	5	$ 2.97
STAGE 2				
	Fly wire mesh screen	1.45 - 1.88 mm	2	$ 10.00
	"HI-FLO" filter	1.0 mm	9	$ 39.95
	"Leaf canister" filter	0.9 mm	10	$ 110.00
	Stainless steel screen	1.3 mm	3	$ 4.00
STAGE 3				
	"Amiad" mesh filter	0.2 mm	4	$ 29.25
	"Arkal" disc filter	0.17 mm	6	$ 38.24
	Irrig. tube filter-19 mm	0.3 - 0.5 mm	7	$5.27
	DISPOSABLE FILTERS			
STAGE 1, 2 or 3				
	"Cleaning cloth" bag	1 mm	-	$ 0.22
	"Geotextile "filtersock	0.18-0.43 mm	-	$ 0.50
	"Nylon stocking"	0.5 mm	8	$ 0.32

*Note: This coding of the filters is used in Figures 4.3 to 4.9.

4.3.3 COLLECTION/SURGE TANKS

The toilet flushing tank and collection/surge drums used in the experimental program were designed as holding tanks in accordance with AS-3500.2 Cl.10.8.

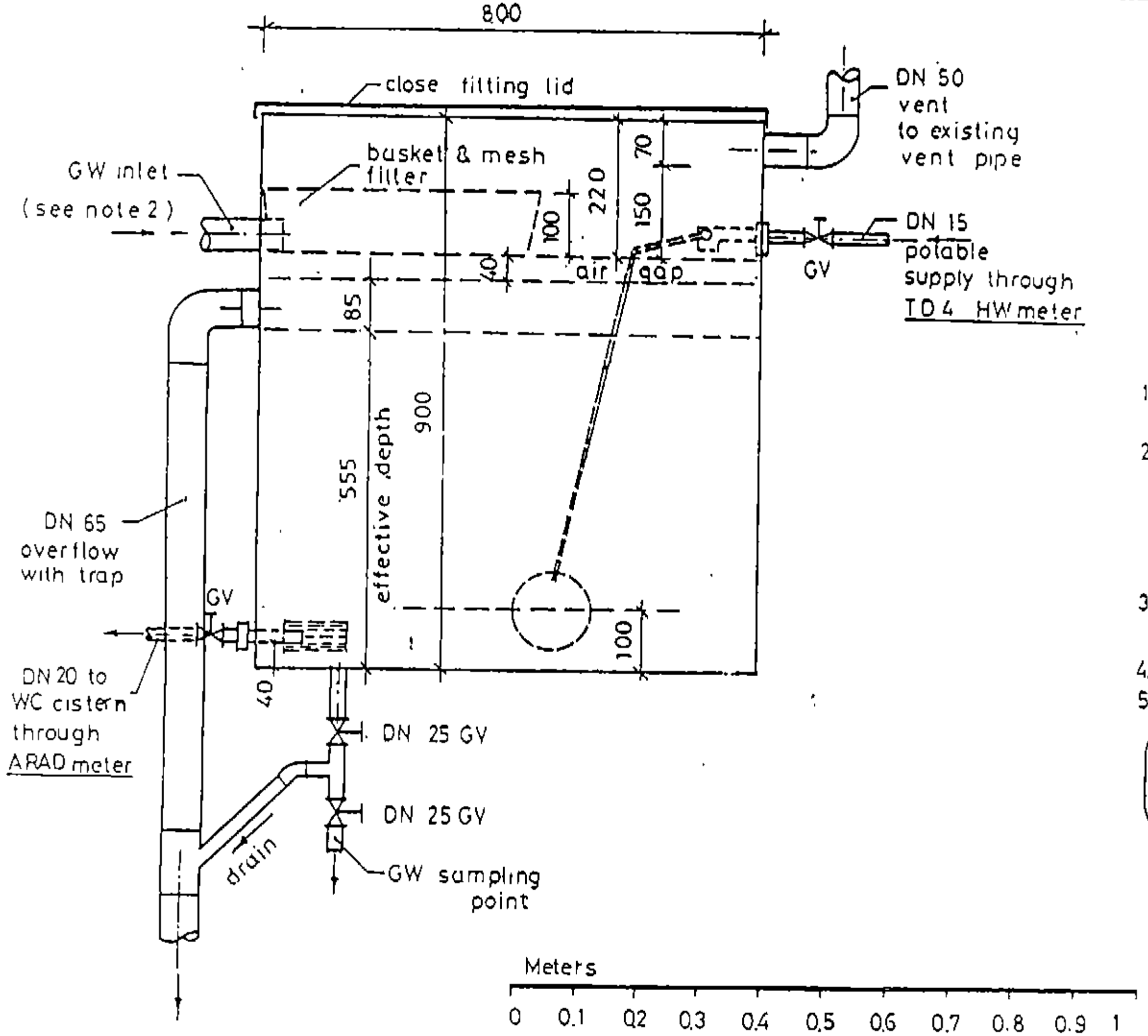
4.3.3.1 Toilet Flushing Tank Design

The greywater toilet flushing tank had dimensions 900 x 800 x 350 mm and effective capacity of 140 L (see Drw. 4.1). It was made of galvanised sheet steel and equipped with a number of connection stubs:

- a greywater inlet - DN 50 for gravity flow or DN 25 for pumped flow;
- a greywater outlet - DN 20 connected to the toilet cistern feed line;
- an overflow pipe - DN 65 for excess greywater to be directed to sewer(or irrigation);
- a scour - DN 25 installed on the bottom of the tank and directed to sewer;
- a vent pipe -DN 50 for ventilation and especially equipped with mosquito proof cap;
- an inlet pipe - DN 15 for potable water make-up in case of greywater shortage.

The float arm controlling the last-named inlet was adjusted to allow potable water entry to the tank when its water level fell to anywhere less than 100 mm depth, thus ensuring that the

Toilet Flushing Tank on Stand - Typical Details



GALV. STEEL TANK

900 x 800 x 350 mm
Eff. capacity = 140 litre

NOTE:

1 Tank is located on stand outside building
2 GW inlet:
   - DN 50 from shower by gravity (site 2)
   - DN 25 from laundry by pump (site 1)
3. Tank designed as holding tank (See AS- 3500·2 Cl.- 10 8)
4. Stand not shown
5. Warning sign on tank:

CAUTION NOT
FOR DRINKING

VUT - Footscray			
Project:	GREYWATER REUSE		
Drawing:	FLUSHING TANK		
Date:	Sep.'93	Dr. No:	4.1

flushing tank could always supply water to the toilet cistern. As the greywater was gravity fed to the toilet flushing cistern under low head, a new low pressure cistern inlet valve had to be installed, replacing the normal type suited for higher pressure. The basket mesh screen was attached to the greywater inlet stub. On the greywater outlet a small stainless steel screen was installed inside the tank, and outside on the same line there was a gate valve, an in-line "Amiad" filter and an "Arad" water meter. A TD-4 flow meter was provided for the potable water line. The toilet flushing tank was designed with an air gap complying with AS 3500 to prevent any possible contamination of potable water, and was fitted with a removable tightfitting and lockable lid. Tanks were located outside houses on stands secured to the house walls. Warning signs "Caution do not drink" were designed for the front sides of the tanks.

4.3.3.2 Collection/Surge Drums

Standard 200 L capacity steel and Mauser plastic drums were used as collection/surge tanks. Lockable lid openings and connection stubs for greywater inlet, greywater outlet, overflow and vent similar to the ones in the toilet flushing tank were provided on each drum(see Drw.4.2). The locations of pipe connections and the incorporation of a basket mesh inlet screen reduced the effective capacity of the drums to about 150 L. At sites 1 and 2, two drums were interconnected to provide a larger collection volume. The drums were placed under the house (site 1) or beside it (site 2) and depending on the required levels they were installed in a vertical or horizontal position, on the ground or semi-buried. A sign "Caution do not drink" was designed for each drum.

4.3.4 PUMPS

Onga multi purpose portable submersible pumps were used in the project where necessary to pump greywater from collection/surge tanks to toilet flushing tanks or the irrigation systems. The two models used had the following characteristics:

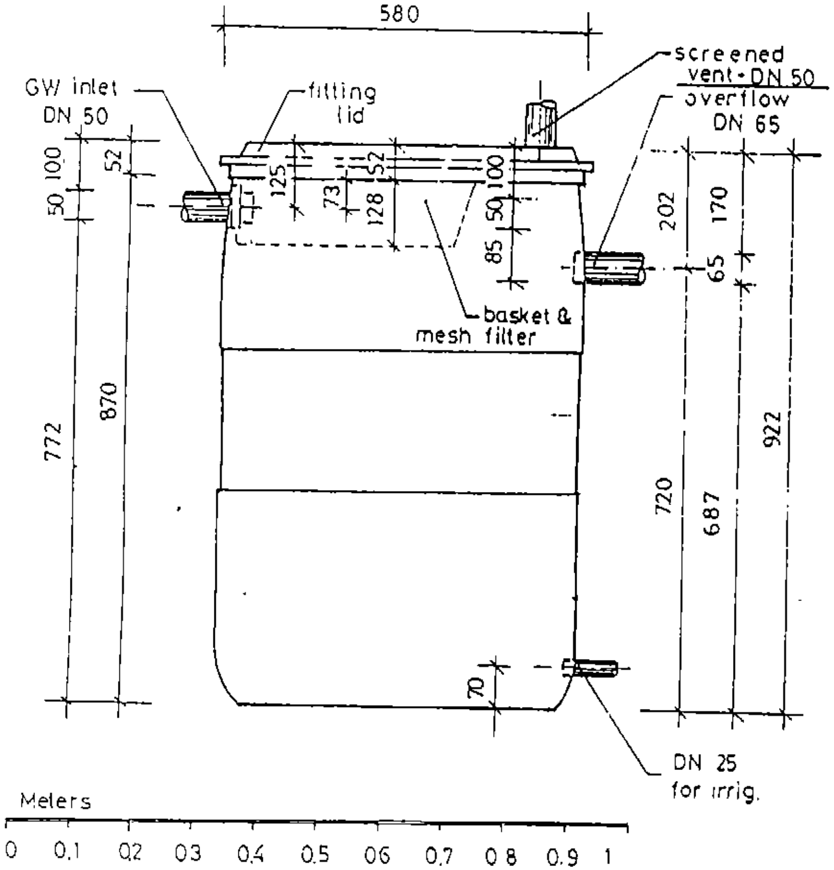
Baby-Sub 2000: $Q = 240$ L/min ($H = 1$m); $Q = 40$ L/min ($H = 10$m)

Baby-Sub 2002: $Q = 80$ L/min ($H = 1$m); $Q = 25$ L/min ($H = 7$m).

GREYWATER

Collection Tank -

Typical Details



STANDARD MAUSER DRUM -

200 LITRE

H = 922 mm
D = 580mm
Eff. V = 150l

NOTE:

1. Warning signs must be installed on every collection tank!

CAUTION NOT
FOR DRINKING

2. Tank designed as holding tank
(See AS - 3500·2 Cl. 10·8)

VUT - Footscray			
Project:	GREYWATER REUSE		
Drawing:	COLLECTION TANK		
Date:	Sep '93	Dr No:	4.2

4.3.5 IRRIGATION SYSTEMS

The irrigation systems installed at the experimental sites can be divided broadly into two groups:(1) drip irrigation and (2) mini-leach field. Different pipe spacings and depths were used in order to determine the optimum depth and spacing of drip and corrugated piping for the purpose of subsurface irrigation of lawns and gardens on different soils. Appropriate pipe spacing and depth are essential to ensure that the plants receive adequate water to avoid differential growth patterns and to minimise the installation cost of the irrigation system. Piping was installed at spacings ranging from 0.6 to 1.6m, and at depths ranging from 50 mm to 160mm below the soil surface. Details about the zoning at each site, pipe type, spacings, depths and the trench cross sections used are summarised in Table 4.3 and on Drw.4.3 and Drw. 4.4.

Two types of piping were used for sub-surface irrigation systems at the experimental sites:

-For gravity irrigation - 25 mm dia PE irrigation pipe (with 2.5 mm holes drilled every 0.5 m along the pipe) or corrugated slotted pipe of several diameters (50mm, 80mm and 100mm).

-For pressure irrigation - "Dripmaster-17" drip tubing with emitters at 0.6 m, 0.8 m and 1.0 m spacing and discharge rate of 2.3 L/h to 3.5 L/h;

A summary of the characteristics of the distribution systems at the four experimental sites is presented in Table 4.3.

"Dripmaster-17" drippers are specially constructed with wide water passages based on the NETAFIM patented labyrinth pattern and free floating diaphragm designed to vary the volume of water. This dripline maintains a constant discharge rate over pressure ranges from 5 to 40 m and uniform discharge along lines of up to 800 m.

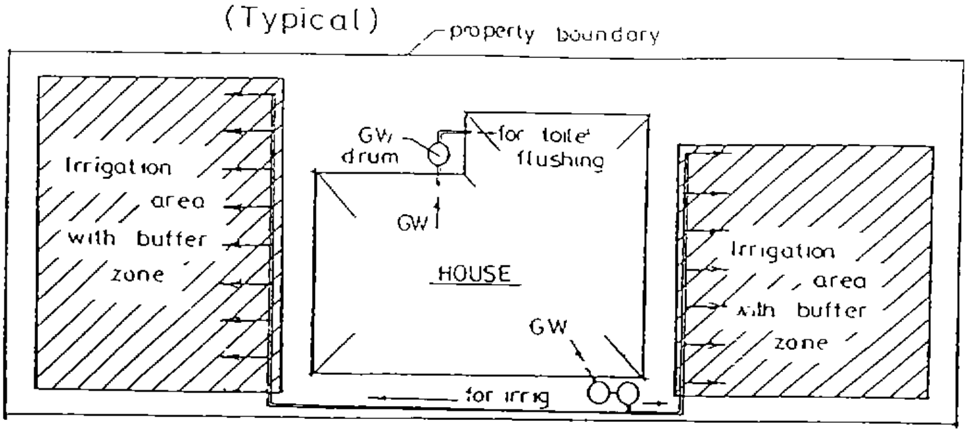
One of the biggest challenges in gravity irrigation systems is the uniform distribution of water. Maximum effort was made to achieve uniform greywater distribution by using a range of techniques. At site 1 (zone E) the distribution pipes were progressively reduced in size in the direction of flow. At site 2 (zone M and N) symmetrical fittings were used at the

Table 4.3 - Summary of Greywater Distribution Systems Characteristics

SITE	BALWYN			
	Pressure irrigation			
Zone	Zone A	Zone B	Zone C	Zone D
Type & dia. of pipes	Dripmaster 17 mm	Dripmaster 17 mm	Dripmaster 17 mm	Dripmaster 17 mm
Spacing b/n lines	0.6 m	1.0 m	0.8 m	0.6 m
Spacing b/n emitters	1.0 m	0.8 m	0.6m	1.0 m
Emitting rate	2.3 L/em/hr	3.5 L/em/hr	2.3 L/em/hr	2.3 L/em/hr
Cross section (drw 4.3)	Y	X	X	Z
Vegetation irrigated	lawn	lawn	lawn	garden
	Gravity irrigation			
Zone	Zone E	Zone F		
Type & dia. of pipes	Corr. sl. pipe 50 mm	Poly pipe 25 mm		
Spacing b/n lines	1.6 m	1.0 m		
Spacing b/n emitters	-	-		
Cross section (drw 4.3)	B	D		
Vegetation irrigated	lawn	lawn		
SITE	CLIFTON HILL			
	Pressure irrigation			
Zone	Zone P	Zone Q	Zone Q (one line)	
Type & dia. of pipes	Dripmaster 17 mm	Dripmaster 17 mm	Dripmaster 17 mm	
Spacing b/n lines	1.0 m	0.8 m	0.8 m	
Spacing b/n emitters	1.0 m	1.0 m	1.0 m	
Emitting rate	2.3 L/em/hr	2.3 L/em/hr	2.3 L/em/hr	
Cross section (drw 4.3)	X, Y	X, Y	Z	
Vegetation irrigated	lawn	lawn	garden	
	Gravity irrigation			
Zone	Zone M	Zone N		
Type & dia. of pipes	Poly pipe 25 mm	Corr. sl. pipe 50 mm		
Spacing b/n lines	1.0 m	1.3 m		
Spacing b/n emitters	-	-		
Cross section (drw 4.3)	D	C		
Vegetation irrigated	lawn	lawn		
SITE	MALVERN			
	Pressure irrigation			
Zone	One zone			
Type & dia. of pipes	Poly pipe 25 mm			
Spacing b/n lines	-			
Spacing b/n emitters	0.3 m			
Cross section (drw B-4)	R			
Vegetation irrigated	native garden			
SITE	STRATHMORE			
	Gravity irrigation			
Zone	Zone A	Zone B	Zone C	Zone D
Type & dia. of pipes	Corr. sl. pipe 80 mm	Corr. sl. pipe 80 mm	Corr. sl. pipe 100 mm	Corr. sl. pipe 80 mm
Spacing b/n lines	0.8 m	1.0 m	1.2 m	-
Spacing b/n emitters	-	-	-	-
Cross section (drw 4.4)	L	L	N	M
Vegetation irrigated	lawn	lawn	lawn	shrubs

Distribution System Arrangements - pipe size DN 17-50

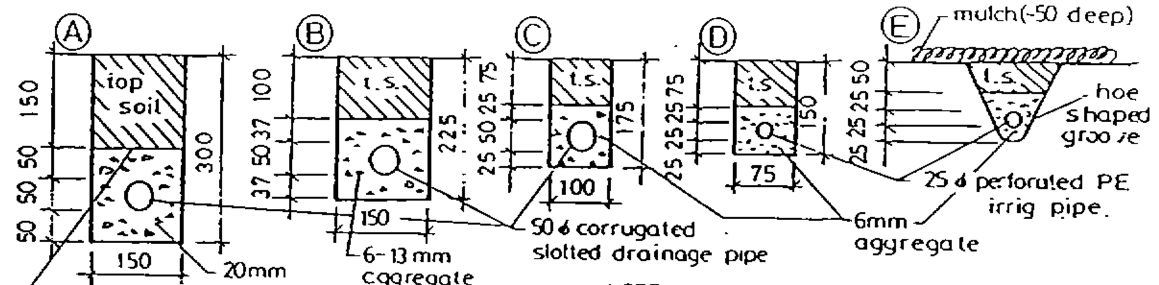
(Typical)



NOTE: Each property to have 2-4 irrigation zones, with appropriate subareas
Min buffer distance to bldgs, boundaries from piping = 1.0 m

Typical Cross Sections:

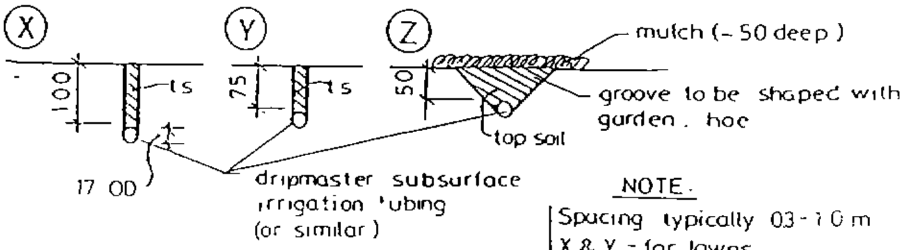
For Gravity Irrigation:



*filter layer to be used in each of Ⓐ to Ⓔ (building paper or similar)

NOTE: A - D - for lawns.
Spacings typically 0.8 - 2.0 m.
E - for garden area application.

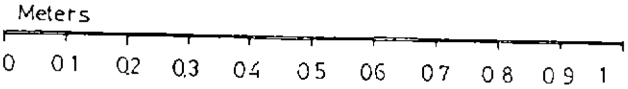
For Pressure Irrigation:



NOTE:
Spacing typically 0.3 - 1.0 m
X & Y - for lawns.
Z - for garden areas.

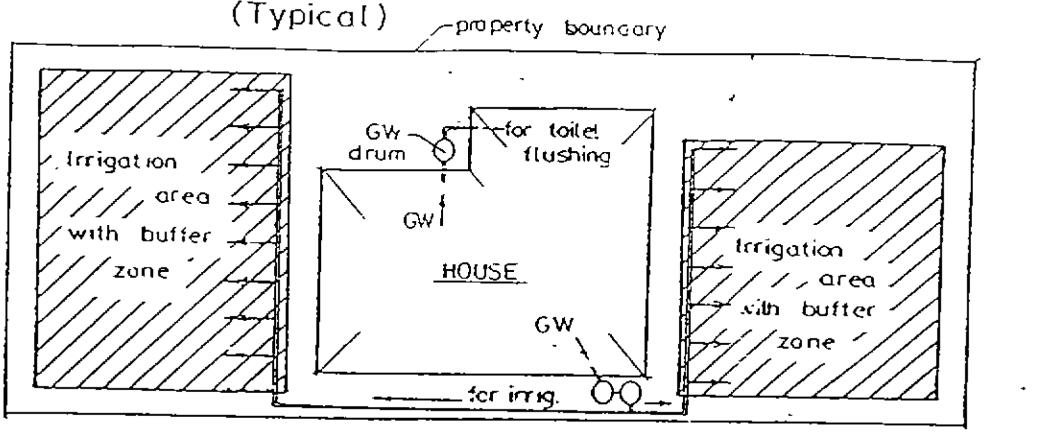
Water Quality

1. For gravity systems, water to be screened through multilayer flywire mesh in drums.
2. For pressure systems, water to be screened as above & then passed through 155 mesh (100 μm) screen / disk filter.
3. "Treflan" or similar to be used periodically as root inhibitor.



VUT - Footscray			
Project.	GREYWATER REUSE		
Drawing	DISTRIBUTION SYSTEM		
Date	Sep' 93	Dr No	4.3

Distribution System Arrangements-pipe size DN50-100 (Typical)

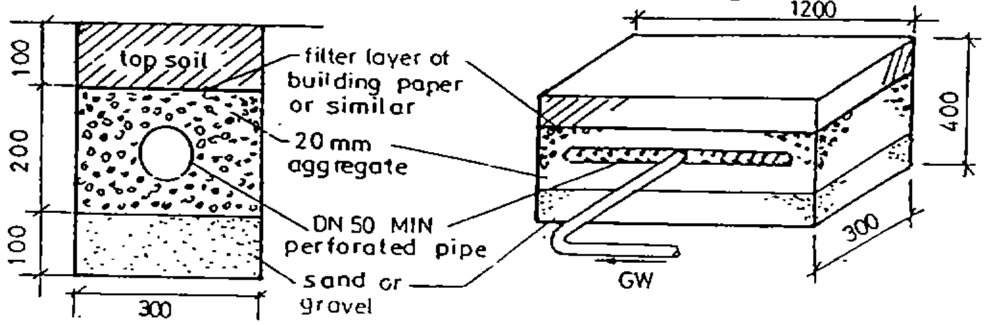


NOTE: Each property to have 2-4 irrigation zones, with appropriate subareas
Min buffer distance to bldgs, boundaries from piping = 1.0 m

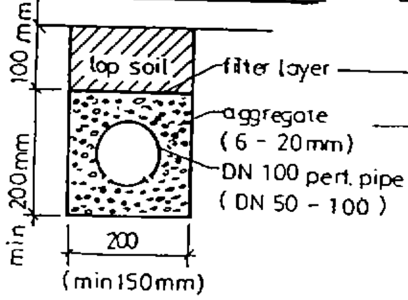
Typical Cross Sections:
For Gravity Irrigation:

Cross section M

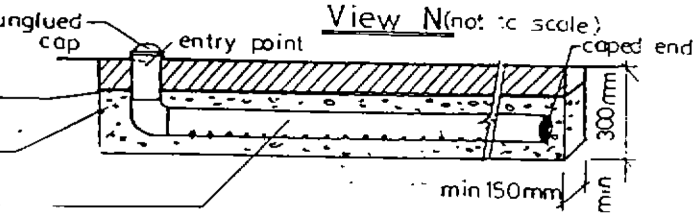
View M (not to scale)



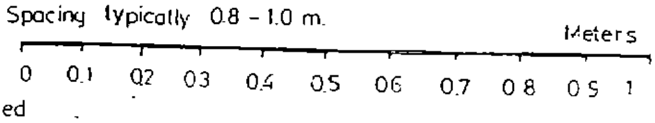
Cross section N,L



View N (not to scale)



NOTE:
System M - for irrig. trees & shrubs.
System N - for irrig. lawn.
Spacing typically 0.8 - 1.0 m.



Water Quality

1. For gravity systems, water to be screened through in-line filter
2. Treflan or similar to be used periodically as root inhibitor.

VUT-Footscray			
Project:	GREYWATER REUSE		
Drawing:	DISTRIBUTION SYSTEM		
Date	Jul '94	Dr. No.	4.4

points of diversion in an attempt to divide the flow equally. At site 4 two different methods were implemented to regulate the flow (1) by manually controlled valves on each line (zone A) or (2) by using one valve for two lines and an overflow arrangement connecting these lines (zone B). Gravity irrigation methods using a number of typical trench cross sections and mini-leach fields adopted in the United States were used at site 4 to assess their feasibility under local conditions(see Drw. B-5).

4.3.6 AUTOMATIC CONTROL DEVICES FOR PUMPED IRRIGATION SYSTEMS

"Rain bird" type rain sensors (automatic pump shutoff devices) were installed at two sites (1 and 2). The mechanism was adjusted to switch off irrigation pumps if rainfall was higher than 6 mm. The function of the pumps would restore automatically when the water in the sensors' rain collector pan fell (evaporated) below 6 mm. Thus automatic contol was provided so that in days with high rainfall the pumps would not operate and the soil would not be overirrigated. This is an important preventive measure against possible water-logging or ponding of greywater on the surface.

All of the submersible pumps were placed on the bottom of the surge tanks and were automatically controlled by a float mechanism. This activates the pump when the water level in the tank reaches a preset level and shuts off the pump when the tank is pumped down to within 50mm of the bottom. This pumping arrangement allows enough time for greywater to mix and cool and at the same time ensures that most of the greywater will be discharged from the tank quickly, thus avoiding significant storage and deterioration in the tank.

4.3.7 EQUIPMENT FOR SYSTEM CONTROL AND MONITORING

"Arad" type flow meters suitable for low pressure water flow were installed on the irrigation lines to the different zones and TD-4 (hot water type) flow meters were used on the toilet cistern feed lines to measure greywater flows. Pressure gauges were placed before and after the filters on the irrigation lines to measure head losses across filters and thus indicate the level of clogging of the filters.

"Nylex" type rain gauges (models 1000 and 600) were provided as an aid for greywater system operation and irrigation management. Tensiometers (depth 300mm, 600mm and 900mm) were also used to aid irrigation management and give an indication of soil moisture levels near site boundaries. At each site two or three tensiometers at different depths were grouped together and installed at two locations: between the irrigation lines and in the buffer zone around the irrigated area.

The diversion of greywater for reuse or to sewer was controlled by manually operated gate valves. At site 4 gate valves were installed on every line (zone A) or every second line (zone B) of the subsurface irrigation system, allowing controlled greywater supply to each line.

4.4 DESCRIPTION OF THE EXPERIMENTAL SYSTEMS AT THE FOUR SITES

For each of the four sites a greywater system was designed and installed making the best use of the individual features of the site and experimenting with different methods and equipment. The first two sites were retrofitted and designed as experimental systems, equipped with a number of monitoring and metering devices. The third greywater system was incorporated in the original design of a newly built dwelling. The fourth site system was developed more as a prototype installation than an experimental one. The following section gives a more detailed description of the installations at each site.

4.4.1 SITE 1 - BALWYN

The double storey house at this site provided the opportunity to divert greywater flow from the upstairs bath and shower by gravity to a toilet flushing tank and to use it for flushing a toilet on the ground floor. The overflow from the toilet flushing tank was directed for irrigation in summer and to sewer in winter. As preliminary investigations indicated that this overflow was likely to be substantial, two interconnected metal drums were provided to collect it and a pump (Onga model "Baby-sub 2002") installed to deliver it to the drip irrigation lines. A rain sensor was provided to control the function of the pump and prevent unnecessary irrigation during rainy days in summer. The second source of greywater was a clothes washing machine and laundry trough, from which the greywater was directed to a horizontally installed (due to space restrictions) metal drum and then to a gravity-fed irrigation system. A number of screening and filtering devices were used as indicated in Section 4.3.2 and flow meters were installed on the lines to the toilet cistern and to all irrigation zones. The overflow pipes from all drums were directed to sewer. Fully opened gate valves were used to allow unwanted winter greywater to flow directly to the sewer. Mosquito-proof vents complying with AS-3500 were designed and installed on the toilet flushing tank and on each group of drums. Schematic views of the installation and its main components are presented in Figures 4.3 and 4.4. The irrigation system at site 1 consisted of four zones (A,B,C and D) with pressure irrigation and two zones (E and F) with gravity irrigation. Details of systems used are presented on Drw.B-1 in Appendix B and summarised in Table 4.3.

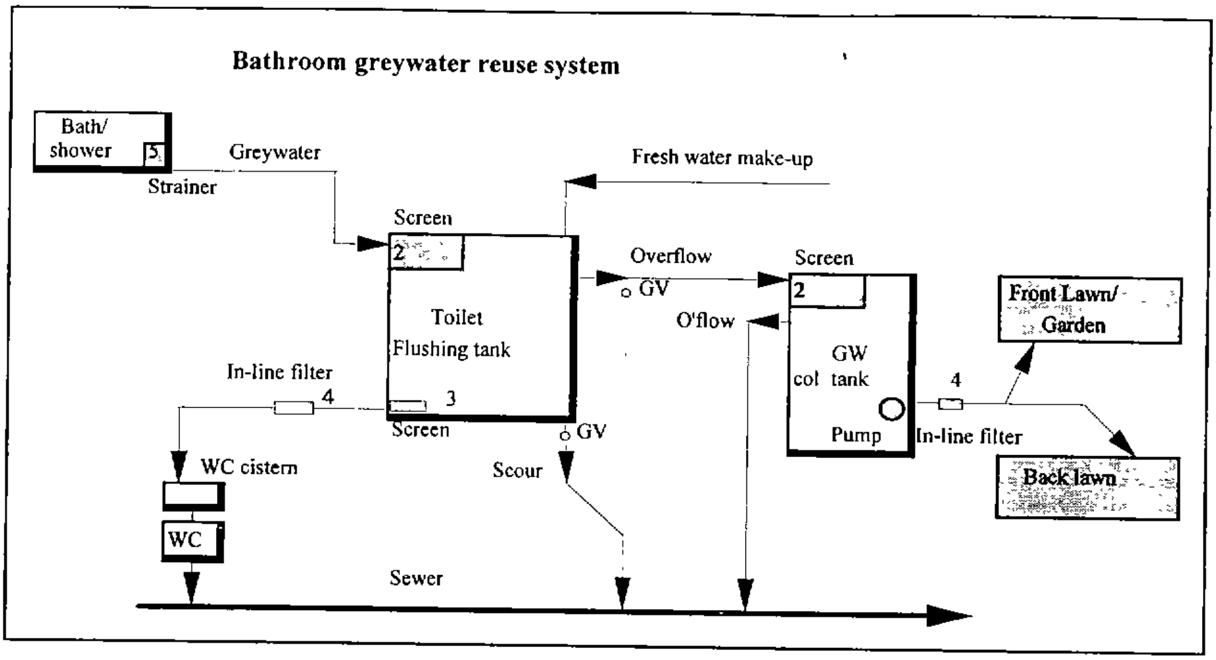


Figure 4.3: Schematic view of bathroom greywater reuse system at Site 1 - Balwyn

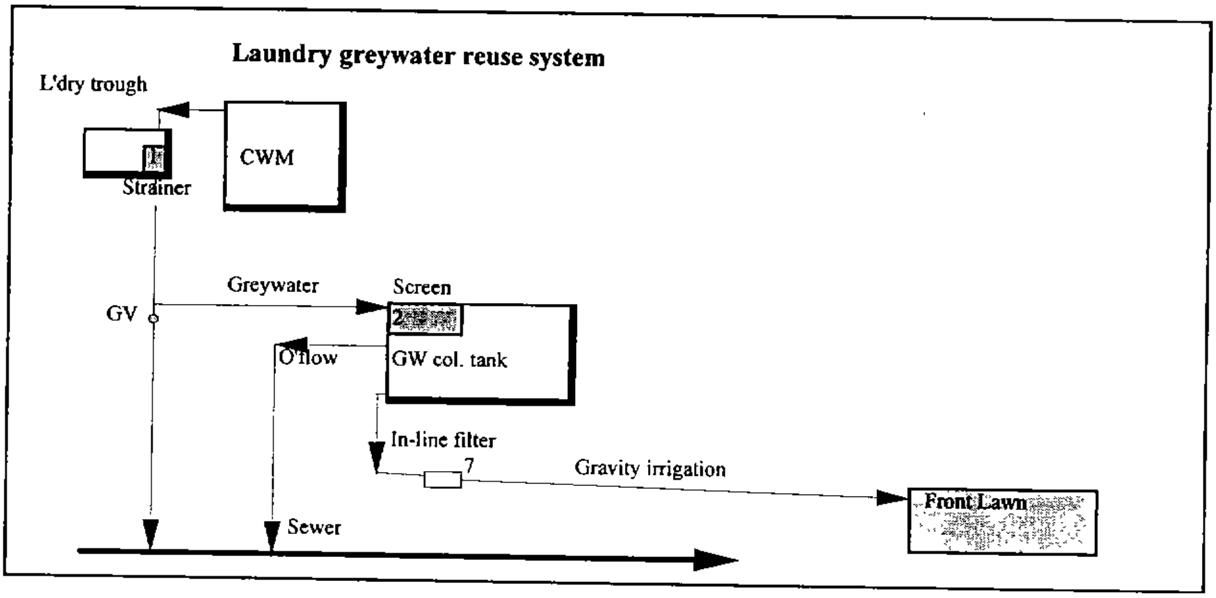


Figure 4.4: Schematic view of laundry greywater reuse system at Site 1 - Balwyn

Note: For the filter device codes in Figures 4.3 to 4.9 please refer to Table 4.2.

4.4.2 SITE 2 - CLIFTON HILL

At site 2, in order to assess the feasibility of using the two sources of greywater (laundry and bathroom) for different types of application in contrast to site 1, laundry greywater was used for toilet flushing and bathroom greywater was diverted for irrigation. The house is on a flat site and is single storey with low ground clearance necessitating the use of pumps (Onga model "Baby-sub 2000") for each of the applications. Greywater from bath and shower was diverted to two interconnected semi-buried metal drums. A pump was provided to direct the collected greywater to drip irrigation lines or to a slightly elevated plastic drum, from which greywater was used for gravity irrigation. A rain sensor was used to control the function of the pump and prevent unnecessary irrigation during rainy summer days. The greywater flow from a clothes washing machine and laundry trough was diverted to a plastic collection drum outside the building and then pumped to a toilet flushing tank. A number of screening devices were installed as in Section 4.3.2 and flow meters were installed on the lines to the toilet cistern and to irrigation zones. Greywater overflows from the drums and the toilet flushing tank were directed to sewer. Mosquito-proof vents were installed on the toilet flushing tank and on each group of drums. Schematic views of the installation and its main components are presented in Figures 4.5 and 4.6.

The irrigation system at site 2 consisted of two zones (P and Q) with pressure irrigation and two zones (M and N) with gravity irrigation. Details of the systems are presented on Drw.B-2 and Drw.B-3 in Appendix B and summarised in Table 4.3.

4.4.3 SITE 3 - MALVERN

This site has two unique features: (1) the greywater installation was incorporated in the design of the new dwelling, and (2) the only source of fresh water for the house is the rain water collected in a concrete tank of 20000 L under the concrete floor slab of the house. It is an excellent example of a water conserving, water efficient and greywater reusing home. The laundry greywater is pumped to a toilet flushing tank using the pump of the clothes washing machine. The latter was especially elevated about a meter from the floor to accommodate the

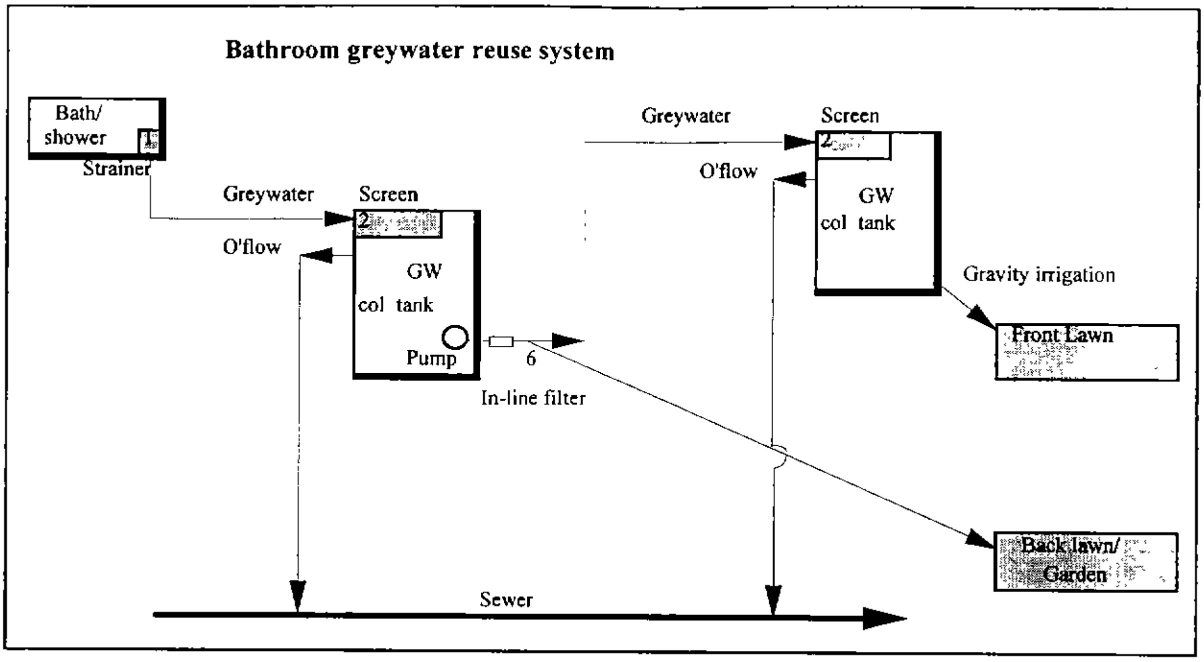


Figure 4.5: Schematic view of bathroom greywater reuse system at Site 2 - Clifton Hill

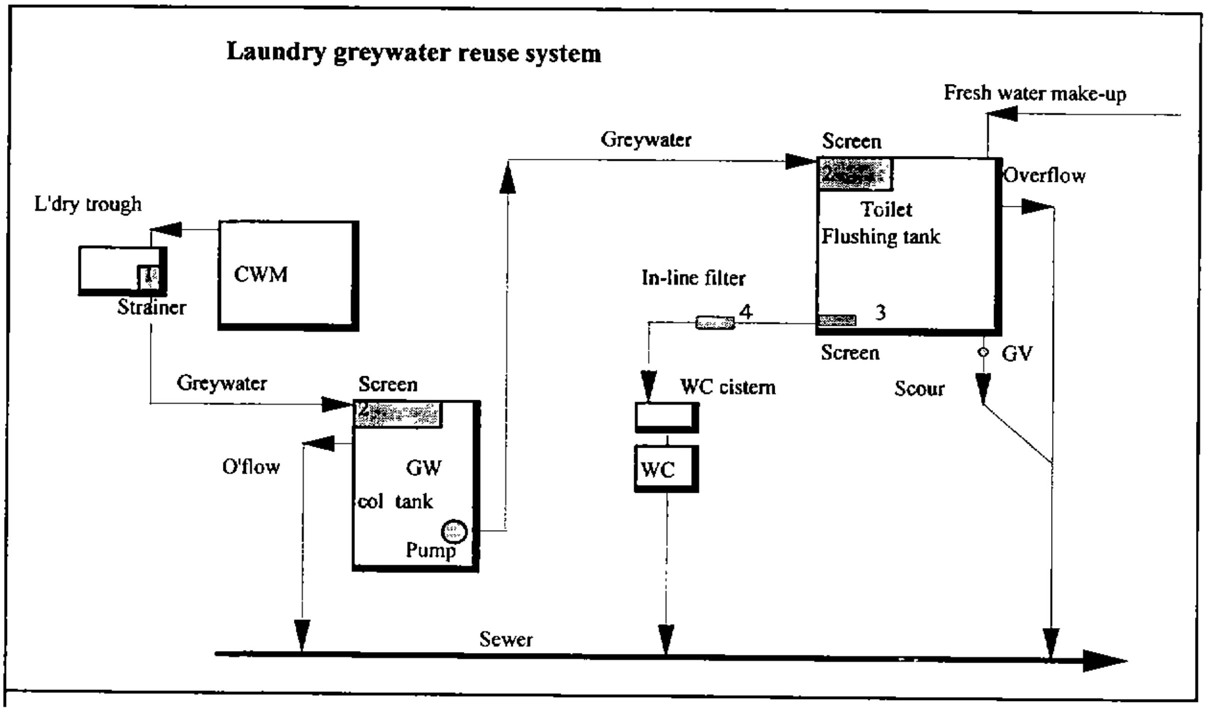


Figure 4.6: Schematic view of laundry greywater reuse system at Site 2 - Clifton Hill

limited head generated by the pump. Screening devices were installed in the tank and in the pit preceding the entry to the irrigation lines. The overflow from the tank was directed to pit No.1, from where it could be directed to sewer or for irrigation by a removable circular weir. Fixtures in the bathroom (hand basin, bath and shower) provided another source of greywater. These flows were directed to pit No.1 and in accordance with the seasonal demands the greywater could be diverted to sewer or used for irrigation after gravity flow to pit No.2. In this pit a pump was installed to direct the water to the irrigation lines. A schematic view of the installation and its main components is presented in Figure 4.7.

At site 3 the pressurised distribution system was laid on an irregular pattern specifically suited for the layout of the ornamental native garden covered with mulch. The system was a pressure irrigation system. Details of the pipe layout, cross section and materials used are presented on Drw.B-4 in Appendix B and in Table 4.3.

4.4.4 SITE 4 - STRATHMORE

This installation for greywater reuse was designed as a possible prototype of a cheap, simple and easy to maintain system. Both laundry and shower flows were used for gravity irrigation, avoiding the use of pumps and collection tanks. A simple and compact type of diversion arrangement as shown in figures 4.1 and 4.2 was designed and installed for testing. The greywater flow can be directed to sewer in winter by closing two gate valves. Two in-line filters ("HI-FLO"filter and "Leaf canister") providing a large filtering surface were installed for trial. Four different types of irrigation systems (see Table 4.3) were installed to test the distribution and control of greywater flows using manually operated valves. Schematic views of the installation and its main components are presented in Figures 4.8 and 4.9.

Site 4 had a gravity distribution system with four zones (A, B,C and D). Details of the cross sections, depth of irrigation lines and materials used are presented on Drw.B-5 in Appendix B and summarised in Table 4.3.

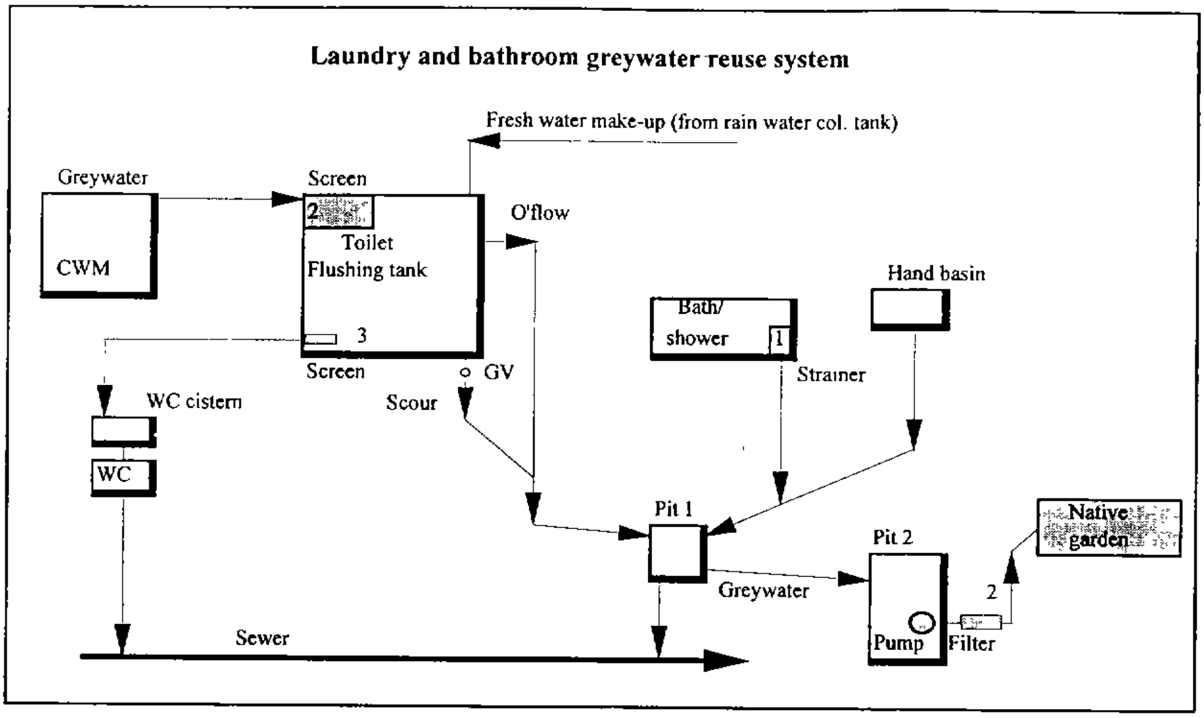


Figure 4.7: **Schematic view of the laundry and bathroom greywater reuse system at Site 3 - Malvern.**

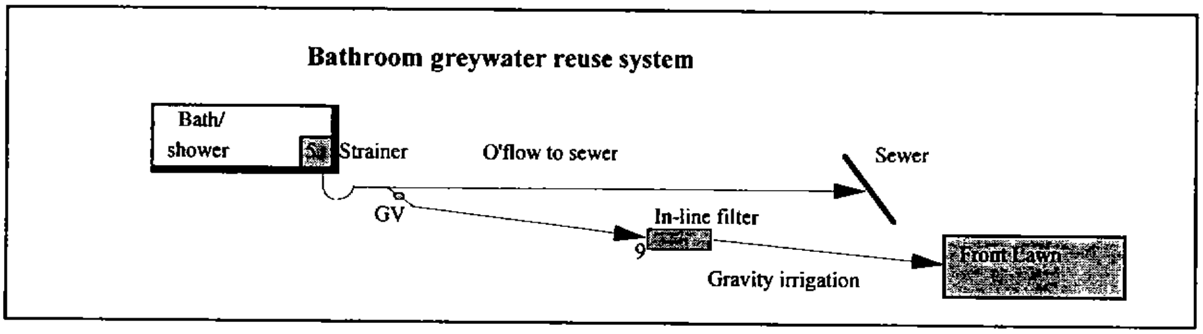


Figure 4.8: **Schematic view of the bathroom greywater reuse system at Site 4 - Strathmore.**

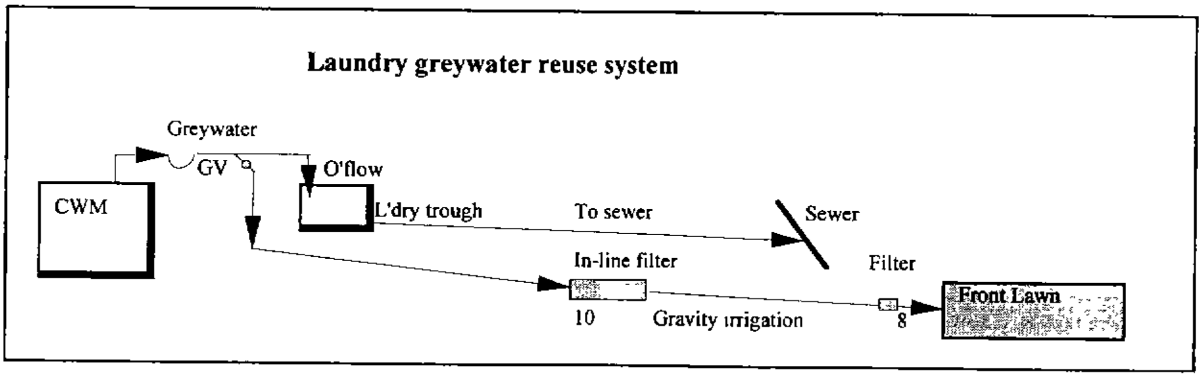


Figure 4.9: **Schematic view of the laundry greywater reuse system at Site 4 - Strathmore.**

CHAPTER 5: SYSTEM OPERATION AND MONITORING

5.1 INTRODUCTION

Regular monitoring of the experimental greywater systems was undertaken for a period of fourteen months from February, 1994 to April, 1995. Research activities and experimental field work focused on :

(a) Monitoring household water use in order to quantify potable water consumption and savings, greywater production and reuse;

(b) Maintaining a greywater quality sampling program to determine the characteristics of the greywater produced and the potential for impact on public health and the environment;

(c) Conducting a sampling program on the receiving soils to determine if there were any impacts;

(d) Testing products such as detergents, disinfectants and disposable filters to determine their suitability for use in conjunction with greywater reuse;

(e) Continuing evaluation of system components to improve the design and performance of the systems.

5.2 MONITORING HOUSEHOLD WATER CONSUMPTION

Weekly recordings of the main house water meter and all the flow meters (see Section 4.3.8) installed on the lines to the toilet cistern and the irrigation pipes were taken in order to calculate water usage and saving, and greywater production and reuse. Pro-forma sheets were designed and the householders were asked to keep detailed diaries of all water consuming activities. This information was the main data source for estimating the water savings at site 4 (which was not equipped with flow meters) and provided complementary data to the water readings for sites 1, 2 and 3. Water bills for the preceding years, which provide a history of water consumption, were also used in the final analysis of the water savings achieved at the experimental sites.

5.3 GREYWATER QUALITY PROGRAM

A greywater quality sampling and testing program was developed to determine the typical quality of greywater and any potential impact associated with greywater reuse. The selection of physical, chemical and microbiological parameters for the tests is presented later in this section. Six rounds of sampling were performed for sites 1 and 2 and four rounds for sites 3 and 4. Strict sampling procedures were followed for taking, storing and transporting the greywater samples to the testing laboratories. The following sampling procedure was adopted:

1. The surge tanks were emptied using a submersible pump.
2. Fresh samples of laundry and bathroom waste water were generated and collected in their respective surge tanks to obtain separate composite samples from each source.
3. The sampling bottles were filled immediately after the completion of the greywater producing event from the surge tank and labelled with the sample source and other unique identification.

The samples were delivered to the Testing Laboratories within 24 hours. All the samples were kept on wet ice at a temperature of 4°C during transportation.

For every sampling round all the products used during the greywater producing events were recorded. For additional information about the factors influencing the greywater quality the residents were asked to record in their diaries the soaps, shampoos and detergents used in laundry and bathroom.

5.3.1 SELECTION OF PARAMETERS

The following physical, chemical and microbiological parameters were determined for each of the greywater samples collected:

1. Physical Parameters: Solids, Colour and Turbidity were analysed for the purpose of comparison with tap water characteristics, results from previous studies, and to facilitate the choice of methods of filtering and disinfecting greywater.

2. Chemical Parameters: A number of organic and inorganic parameters were analysed. For most of these parameters there are recommended limits to be observed if the water is to be used for irrigation. The aim of the analysis was to assess the quality of greywater in regard to these limits.

2.a Inorganic Parameters.

Based on common practice in pollution studies and on information relating to wastewater reuse contained in publications by the NSWRWCC (1993), the EPAV (1991) and the USEPA (1992 a), it was decided to analyse greywater samples for the range of inorganic chemical parameters shown in Table D2. Alkalinity, pH, and Electrical Conductivity were also determined, and Sodium Absorption Ratios (SAR) calculated from relevant values to assess any possible adverse effects of greywater reuse on the structure of the receiving soils.

In the case of Phosphorus, the aim was to indicate any high levels due to detergents used in the laundry. Nitrogen is the other essential element for plant growth and uptake of nutrients and the purpose of the analysis was to provide information about nitrogen levels in greywater.

2.b Organic Parameters.

BOD was analysed as it is the most widely used indicator of organic pollution. Other organic substances included in the analysis were Oil, Grease and Azure- A Active Substances (used in household detergents).

3. Microbiological Parameters

Tests were conducted to evaluate the microbial quality and safety of greywater for reuse purposes.

3.a Total and Faecal Coliforms and Faecal Streptococci.

The first two were included as being traditional indicators of biological contamination. The last is reported to be a reliable indicator of virus contamination in sludges (Gibbs and Ho, 1993).

3.b Campylobacter, Giardia and Salmonella.

These pathogens are of significant importance for assessing the safety of greywater reuse. A study on the reported enteric infections in Melbourne indicated that these are the dominant enteric pathogens (Gibbs and Ho, 1993).

3.c Cryptosporidium.

This is a microorganism of high potential risk, as it is very difficult to destroy because of its resistance to strong disinfectants such as chlorine. A very low dose (eg. 2 organisms) may cause infection, for which no effective treatment has yet been found.

5.4 RECEIVING SOILS ANALYSIS

A sampling program was developed to determine if any of the characteristics of the receiving soils might be affected by using greywater for irrigation. There were four rounds of samples for sites 1 and 2 and two rounds for sites 3 and 4. The first samples at each site were taken before the start of irrigation with greywater for establishing the baseline conditions of the soils. A special design tool was used to collect the surface samples and a 100mm hand auger was used for the sub-soil samples. Plastic bags with seals were used to store the samples and preserve their moisture content. The samples were delivered to the testing authority as soon as possible. The samples of the first and fourth rounds were immediately tested, while the samples of the second and third rounds were stored by the testing laboratory for a period of six months before being tested. This delay was due to unavailability of funds at the time the samples were collected.

The following parameters were tested to assess the risk of soil structure decline: Total Cation Concentration (TCC), Electrical Conductivity (EC), Exchangeable Sodium Percentage (ESP), Exchangeable Cations, and Ratio of Calcium to Magnesium.

5.5 SUITABILITY OF PRODUCTS FOR GREYWATER REUSE

Products analysed for suitability and efficiency for greywater reuse systems were: detergents, disinfectants and disposable filters.

5.5.1 POTASSIUM BASED DETERGENT

A special potassium based detergent (product of "Back to Basics" Ltd.) was tested for the purpose of greywater reuse to assess its suitability and to compare its qualities with the sodium based detergents routinely used at the experimental sites. The product was introduced in a number of samples of laundry greywater, which were tested as a part of the greywater sampling program. The resulting greywater parameters of main interest were Sodium, Phosphorus, pH, and Electrical Conductivity.

5.5.2 DISINFECTANTS

The action of two chemical agents was investigated regarding their efficiency for disinfecting greywater: (1) chlorine in the form of swimming pool tablets, and (2) a disinfectant ("Process 946N") based on quaternary ammonium compounds (product of Gibson Chemicals Ltd).

The trials were carried out at the toilet flushing tank (details in Section 4.3.3.1) at site 2 where the greywater source was a laundry trough. The possible greywater producing events were clothes washing machine operation, hand washing, and washing of shoes, floors and other typical household washing activities. The detergents routinely used in the laundry were "Cold Power" and "Lux Soap Flakes".

Extra long-lasting chlorine tablets were used having an active constituent of 850 g/kg available chlorine present as trichloro isocyanuric acid. The tablets were placed in several locations to identify the best method of introducing the disinfectant. The locations were: on the basket mesh filter; in a floating dispenser, semi-submerged in greywater; and in a floating dispenser, fully submerged in greywater. Regular weekly monitoring for a period of six months was carried out to determine the levels of free chlorine, total chlorine and pH of the greywater in the tank. Tests for total and faecal coliforms were carried out using Oxoid Dip Slides (code DS 102). To confirm these weekly measurements, two samples for complete analysis were provided to the microbiological laboratory at Fairfield Hospital.

The second chemical disinfectant tested was "Process 946N". One of the components of "Process 946N" was a quaternary ammonium compound in the proportion of 10% to 30% by weight. The product was a dark blue powdered concentrate especially formulated to act as a bacteriostat and odour counteractant in aircraft toilet systems. It was safe on stainless steel, aluminium, rubber and plastics. The recommended dosing rate was one to two sachets (of 32 g) for each 120 litres of water. The sachets dissolved almost instantaneously. The pH of the solution (Process 946N and water) was 9. Several steps were implemented in order to determine the appropriate dose and contact time for applying Process 946N. To assess the disinfecting effect microbiological testing of the greywater was carried out before and after introducing the sachets. The following procedure was used:

1. Two sachets were dissolved in the toilet flushing tank and two hours contact were allowed before the sampling of the disinfected greywater.

2. Two sachets were dissolved in the toilet flushing tank and four hours contact were allowed before the sampling of the disinfected greywater.

For the microbiological testing Oxoid Dip Slides (code DS 102) were used. They carry Red MacConkey Agar on one side and Green C.L.E.D. Agar on the other. Faecal coliforms appear as red colonies on MacConkey Agar. The greywater samples were diluted to 1/10, 1/100 and

1/1000 to determine the best dilution ratio. The 1/100 dilution ratio proved to be the most convenient one for counting the faecal coliform colonies. Regular weekly microbiological testing was carried out for a period of two months.

5.5.3 DISPOSABLE FILTERS

Three different types of disposable filter were tested to identify the most inexpensive, efficient and easy to change: "Cleaning cloth" filter-bag, "Geotextile" filtersock and "Nylon stockings" filter. These filters were installed on the inlet pipe to the toilet flushing tanks or greywater collection tanks. At site 4 the disposable filters were installed in the "Leaf canister" and at the end of the irrigation hose (DN 40). This hose transported greywater to the subsurface pipes of the "Kourik" type of irrigation system. The disposable filters were changed as soon as they showed signs of clogging. All of these filters were weighed before and after being used to establish their filtering effectiveness. A summary of their characteristics is presented in Table 4.2. (see Section 4.3.2)

5.6 MONITORING THE OPERATION OF THE SYSTEMS

Weekly monitoring and servicing of the experimental greywater systems and continuing evaluation of the performance of their components were carried out for the 14 months period. The monitoring data included: frequency of changing filters & their performance; condition of grass in relation to irrigation system operation; moisture content of soil, possible ponding, efficiency of distribution of water; rainfall measurements for control of irrigation needs; any problems such as odour, scum, clogging of filters, mosquitoes, and surface run off of greywater.

The regular servicing of the systems consisted of at least fortnightly changing and washing of the mesh on the basket screens. The in-line irrigation filters ("Amiad" and "Arkal") required weekly cleaning of the filtering elements. The initially installed 0.1mm mesh and 0.11mm disk element spacing suffered almost instantaneous clogging and had to be replaced at a very early stage of the research program with the next larger size of 0.2mm mesh and 0.17mm disk elements.

The moisture content of the soil was monitored with tensiometers at 300mm, 600mm and 900mm depth located between the lines (for estimating the efficiency of irrigation) and in the buffer zones (for monitoring possible subsurface lateral seepage of greywater). Weekly recording of the readings and servicing of the tensiometers were carried out.

To supplement the observations of the researcher the residents were asked to record in the pro-forma sheets any problems associated with the greywater reuse that they observed such as odour, scum in the toilet bowl, filter clogging, ponding of greywater on the surface, etc.

CHAPTER 6: PRESENTATION AND EVALUATION OF TECHNICAL RESULTS AND OBSERVATIONS

6.1 INTRODUCTION

This chapter summarises and analyses the results of the greywater reuse program, and presents findings and conclusions of various aspects of the field research work. More specifically the chapter presents: greywater savings and the factors influencing them; greywater quality test results and analysis and an assessment of greywater suitability for reuse; soil test results and changes in soil characteristics; results and recommendations from tests on disposable filters, detergents and disinfectants; an assessment of performance of greywater system components; and a discussion of difficulties and problems encountered during design, installation and operation.

6.2 GREYWATER QUANTITIES AND WATER SAVINGS

Regular greywater reuse commenced at sites 1, 2 and 3 (toilet flushing) at the start of February '94, at site 3 (irrigation) at the start of August '94 and at site 4 at the start of January '95. Water savings achieved at sites 1, 2 and 3 were calculated based on the meter readings for a twelve months period from March'94 to Feb.'95. At site 4 the estimated water savings were based on records of the number of greywater producing events, their duration and rates of fixture discharge for the period January'95 to March'95. A summary of the total water consumption, greywater reuse and savings achieved is presented in Table 6.1. The fourth row in the table shows the amount of potable water inflow measured by the household water meter. Row seven shows the amount of water that has been reused as greywater. In row eight is the total water consumption at each site, calculated as the sum of potable water and greywater used. All the percent figures presented in the table are calculated as a ratio to the total water consumption (potable water + greywater). The total amount of greywater reused represents the achieved water savings, the percentages were calculated using formula (6.1):

$$\% = (\frac{GW}{GW + PW}) \times 100 \qquad (6.1)$$

where GW = is the greywater amount reused

PW = is the measured potable water inflow.

Table 6.1 - Water Consumption and Savings at the Four Experimental Sites

Site	Site 1	Site 2	Site 3	Site 4	
Period of time	one year	one year	one year	three months	one year
Method	measured	measured	measured	estimated*	calculated**
Potable water consumption kL (%)	280.1 (88 %)	121.5 (81 %)	62.2 (72 %)	52.7 (72 %)	210.8 (83 %)
Greywater for irrigation kL (%)	29.3 (9 %)	18.6 (13 %)	13.3 (15 %)	20.9 (28 %)	41.8 (17%)
Greywater for toilet flushing kL (%)	8.1 (3 %)	9.6 (6 %)	11.0 (13 %)	-	-
Total greywater consumption kL (%)	37.5 (12 %)	28.2 (19%)	24.3 (28 %)	20.9 (28 %)	41.8 (17%)
Total household water consumption kL (%)	317.6 (100%)	149.8 (100%)	86.5 (100%)	73.6 (100%)	252.6 (100%)

* - Potable water use measured, the remaining figures estimated for three months period (Jan.'95-Mar.'95).
** - Calculated amounts for twelve months period, based on extrapolation.
Note: Some numbers were rounded.

6.2.1 SITE 1 (BALWYN)

Average annual usage for the three years prior to October'93 was about 377 kL, but in the following twelve months total usage dropped to about 301 kL. This can be attributed firstly to the wet summer of 93/94 (in which rainfall averaged 83mm/month compared with 51mm/month for normal avarage rainfall) and secondly to the fact that a tenant living in the house (in the period Feb.'93 -Oct.'93) left. The total amount of water used for the period of March'94 to Feb.'95 was 317.6 kL. Of this amount approximately 29.3 kL (9%) and 8.2 kL (3%) were greywater used for irrigation and toilet flushing respectively, so total savings were approximately 37.5kL (12%). Figure 6.1 shows the total water consumption at site 1, and Figure 6.2 shows the monthly water use of potable water, greywater for irrigation and greywater for toilet flushing.

At this site the greywater diverted for reuse from laundry was the whole amount, while from the bathroom was only from the shower used by two out of the four residents of the house. To achieve more precise estimates of how efficiently each greywater source was used, an analysis was carried out for the six months (March'94 - April'94 and Nov.'94-Feb.'95) when greywater was used for both toilet flushing and irrigation. The results showed the total amount of water used for this period was 187.9 kL. Of this amount approximately 21.1 kL (11%) and 11.8 kL (6%) were greywater from the bathroom and the laundry respectively. This indicated that the bathroom greywater diverted for reuse was completely utilised in the six months period, but not all of the diverted laundry greywater was used.

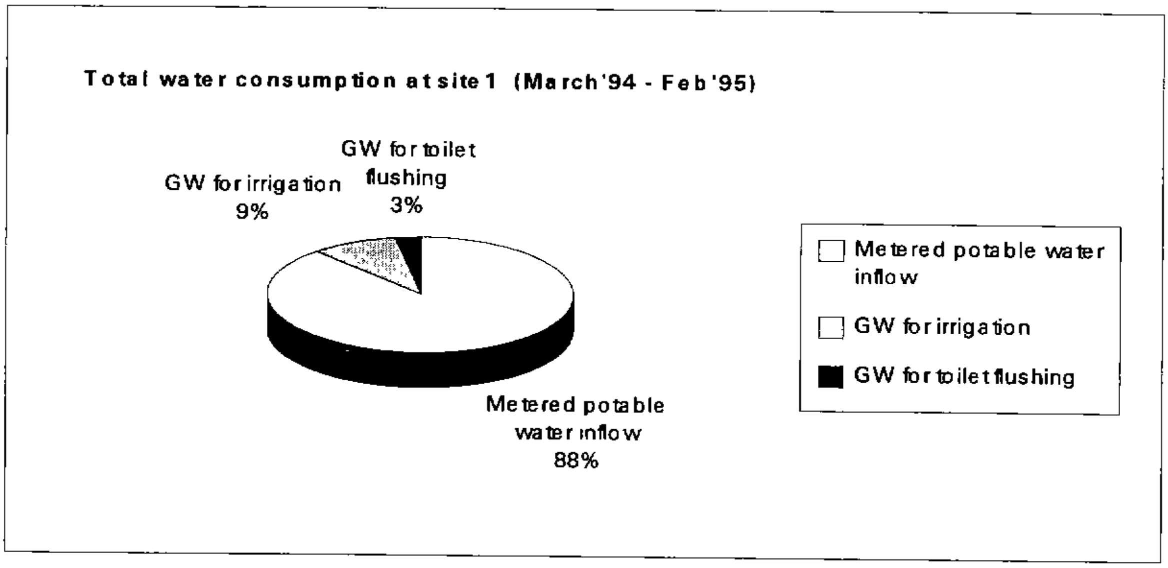


Figure 6.1: Total water consumption at site 1 (Balwyn)

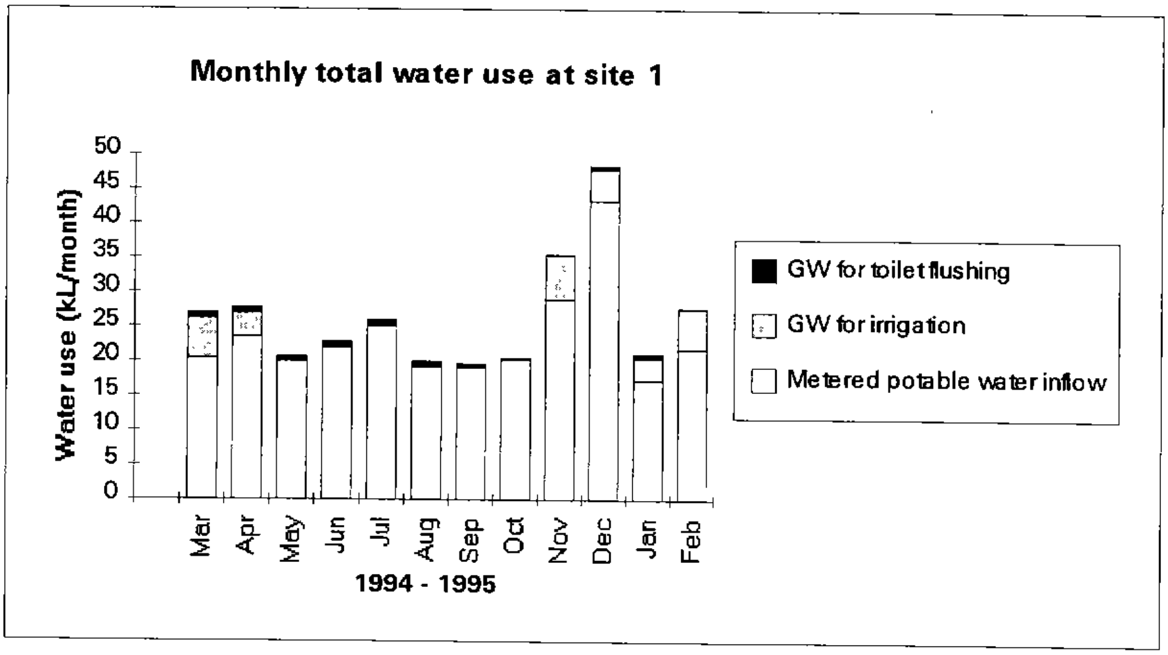


Figure 6.2: Monthly total water use at site 1 (Balwyn)

The difference between the theoretical possible water saving for an average household of 20%-29% (see Section 2.3.1.5) and the actual water savings achieved (12%) at site 1 is due to the following factors:

(1) Greywater from only one shower used by two out of the four members of the family was diverted for reuse. The water from the bathroom handbasin and from the second bathroom of the house was not diverted due to inaccessibility.

(2) Only one toilet was supplied with greywater for flushing. There are two other more frequently used toilets in the house to which greywater could not be diverted.

(3) The irregular pattern of clothes washing activities (3 to 14 washes/week) creating extremely high volumes at times, exceeded the capacity of the gravity irrigation in-line filter.

(4) The nature of sport activities of the family members and the type of clothing used generated a lot of lint (eg. from pullovers for a football team) which clogged the in-line filter in less than a week, causing greywater to overflow to the sewer.

6.2.2. SITE 2 (CLIFTON HILL)

Average annual usage for the three years prior to October'93 was about 142 kL, and was similar in the following twelve months at 139 kL. The total amount of water used for the period of March'94 to Feb.'95 was 149.8 kL. Of this amount approximately 18.6 kL (13%) and 9.6 kL (6%) were greywater used for irrigation and toilet flushing respectively, so total savings were approximately 28.2 kL (19%). Figure 6.3 shows the total water consumption at site 2, and Figure 6.4 shows the monthly water use of potable water, greywater for irrigation and greywater for toilet flushing.

The total water used for the six months (March '94-April '94 and Nov '94-Feb '95) was 87.1 kL, of which approximately 18.6kL (21%) and 4.4kL (5%) were greywater from the bathroom and the laundry respectively. This indicates that the bathroom greywater diverted was completely utilised, but not all of the diverted laundry greywater was used.

The difference between the actual water savings achieved (19%) at site 2 and theoretical water savings of 20%-29% can be attributed to the following factors:

(1) Only one of the two toilets was supplied with greywater for flushing. The savings would be higher if both toilets were using greywater.

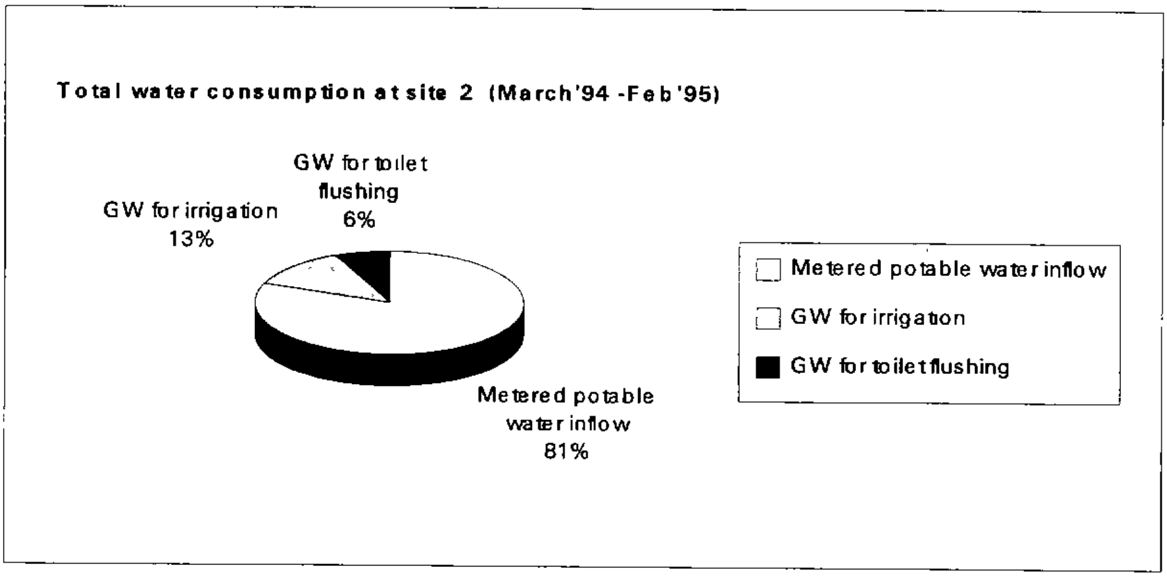


Figure 6.3: **Total water consumption at site 2 (Clifton Hill)**

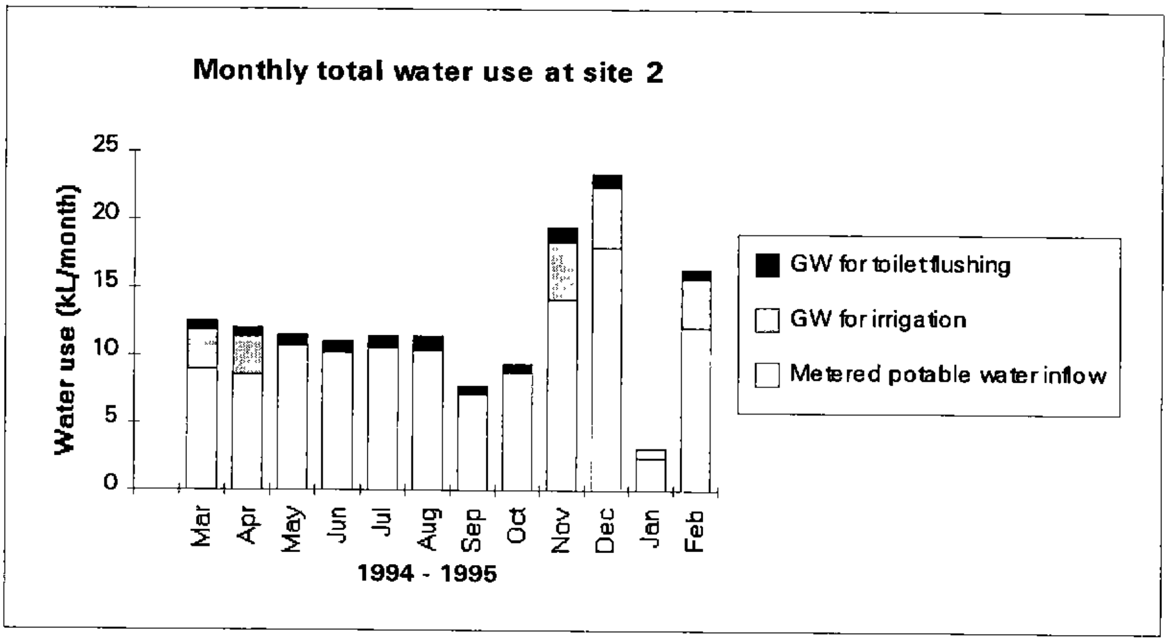


Figure 6.4: **Monthly total water use at site 2 (Clifton Hill)**

(2) The amount of laundry greywater exceeded the demand for toilet flushing. The unused excess greywater, having a high dose of chlorine for disinfection, was not suitable for irrigation.

6.2.3 SITE 3 (MALVERN)

Average annual usage of this family at their previous residence for the four years prior to January '94 was about 120 kL, but in the following twelve months total usage dropped significantly. This can be attributed to the fact that the garden area at this site is smaller and that every appliance installed in the house is water efficient.

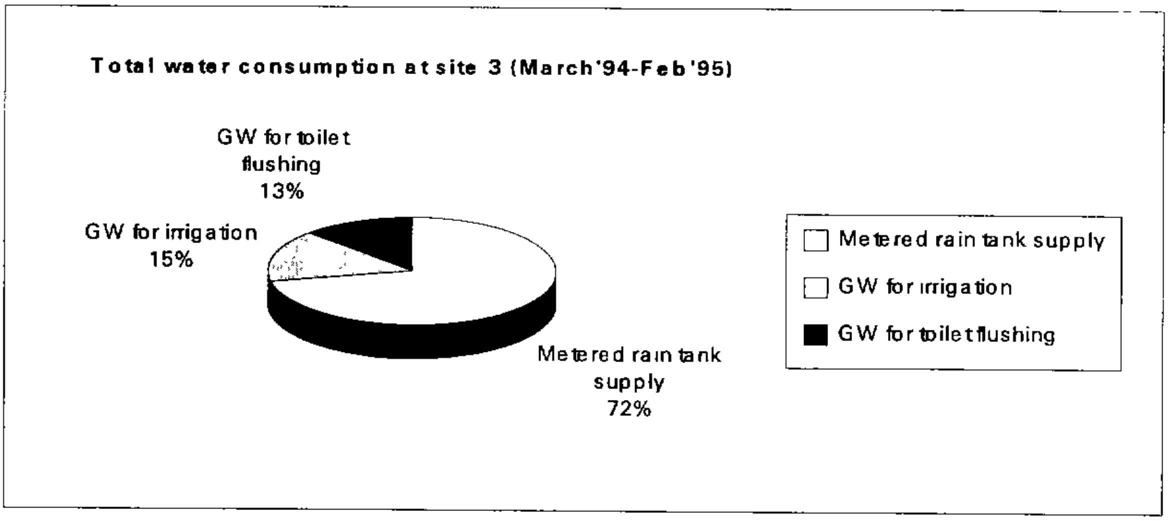


Figure 6.5: **Total water consumption at site 3 (Malvern)**

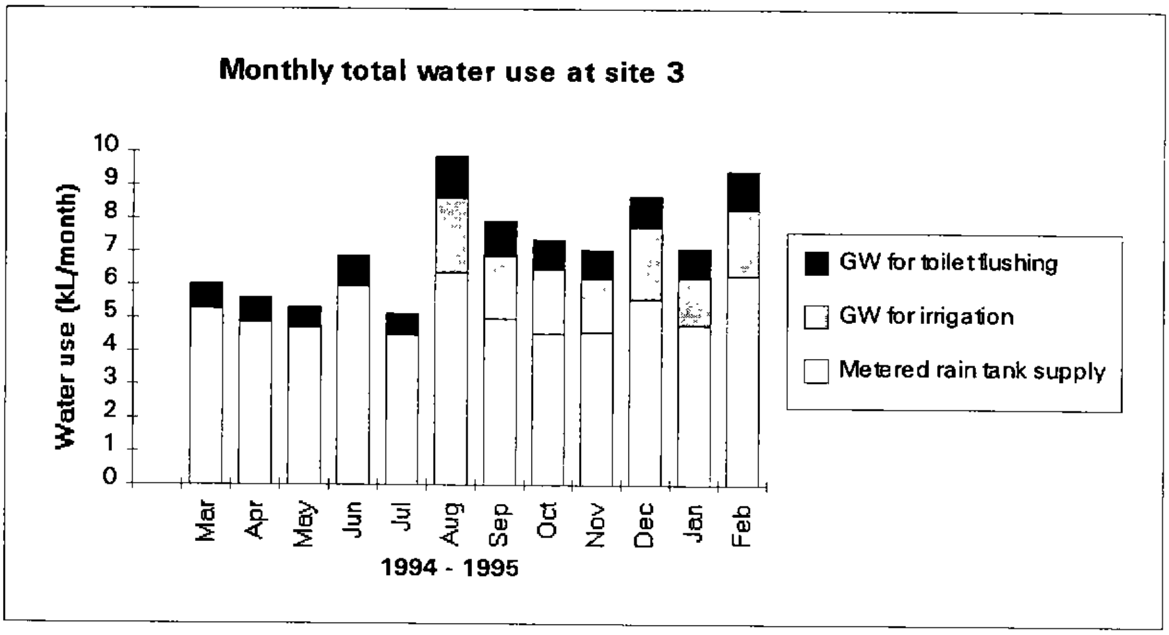


Figure 6.6: **Monthly total water use at site 3 (Malvern)**

The total amount of water used for the period of March'94 to Feb.'95 was 86.5 kL. Of this amount approximately 11 kL (13%) and 13.3 kL (15%) were greywater used for irrigation and toilet flushing respectively, so total savings comprise approximately 24.3 kL (28%).

Figure 6.5 shows the total water consumption at site 3, and Figure 6.6 shows the monthly water use of potable water, greywater for irrigation and greywater for toilet flushing.

The analysis for the period Aug'94-Feb'95, when the water reuse is most efficient, showed that the total water use was 57.5kL, of which 13.3 kL (23%) and 7.2 kL (13%) were greywater from the bathroom and the laundry respectively. This indicates that at site 3 both bathroom and laundry greywater were efficiently utilised. The actual water savings achieved (28%) are very close to the theoretical maximum (29%) for an average household.

6.2.4 SITE 4 (STRATHMORE)

The annual usage for the year prior to July'94 was about 224 kL, but in the following twelve months total usage was expected to increase as a baby was born in the family. The total amount of water used for the period of January'95 to March'95 was 73.6 kL. Of this amount approximately 20.9 kL (28%) were estimated as greywater used for irrigation. Based on extrapolation of the amounts measured and estimated in the three months period, an estimate has been made that the water savings for a whole year would be 41.8 kL (17%) of the total water consumption calculated as 252.6 kL. Figure 6.7 shows the expected total water consumption at site 4, and Figure 6.8 shows the estimated monthly water use of potable water and greywater for irrigation.

The total water use for the period Jan.'95-March'95 was 73.6kL, of which 8.3 kL (11%) and 12.6 kL (17%) were greywater from the bathroom and the laundry respectively. This indicates that both bathroom and laundry greywater were efficiently utilised. As greywater is used only for irrigation for half of the year the theoretical maximum savings are 20%(see Section 2.3.1.5). The comparatively low percent for bathroom water can be attributed to the very high water consumption of a number of house appliances, ie. dishwasher (73 L/wash), toilet flushing (11 L/flush) and intensive use of the kitchen sink.

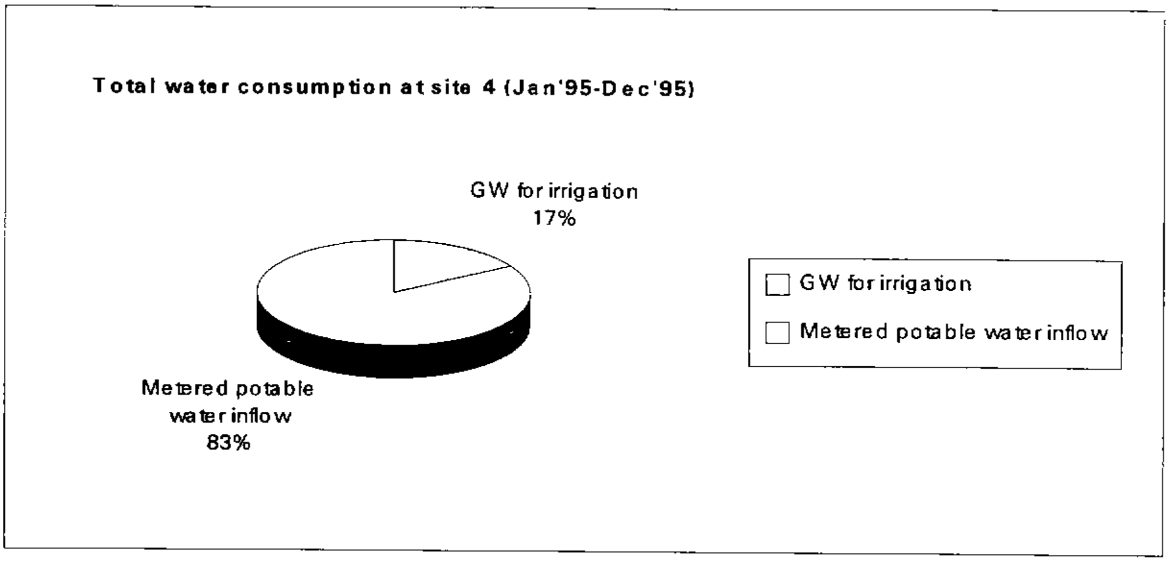


Figure 6.7: **Total water consumption at site 4 (Strathmore)**

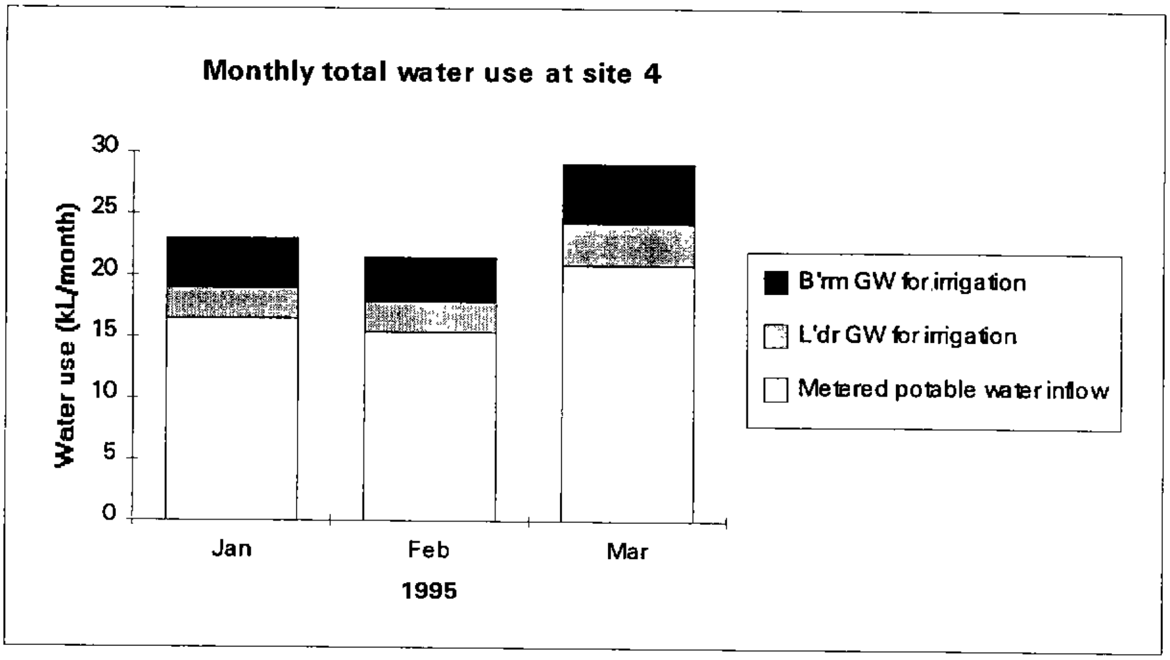


Figure 6.8: Monthly total water use at site 4 (Strathmore)

6.2.5 SUMMARY OF FINDINGS

Conclusions drawn regarding the savings achieved by the greywater systems installed at sites 1, 2, 3 and 4 are:

(1) Water savings depend significantly on individual habits, household water appliances and features of the site (eg. irrigation area, number of bathrooms, number of toilets).

(2) Water savings in the range of 12% to 28% were achieved when reusing greywater for irrigation and toilet flushing. The water savings achieved at the four experimental sites and

the total water used are presented on Figure 6.9. At site 1 and 2 the water savings could have been higher if all the greywater sources could have been used for both toilet flushing and garden watering. This could not be achieved because of practical inaccessibility, which would be one of the constraints in many retrofit situations. The high savings at site 3 are due to the water efficient appliances used and the opportunity this newly-built house offered to capture all the greywater sources for reuse.

(3) If at site 1 the usage of the appliances could be optimised (eg. by introducing a more regular clothes washing pattern) the water saving would be increased.

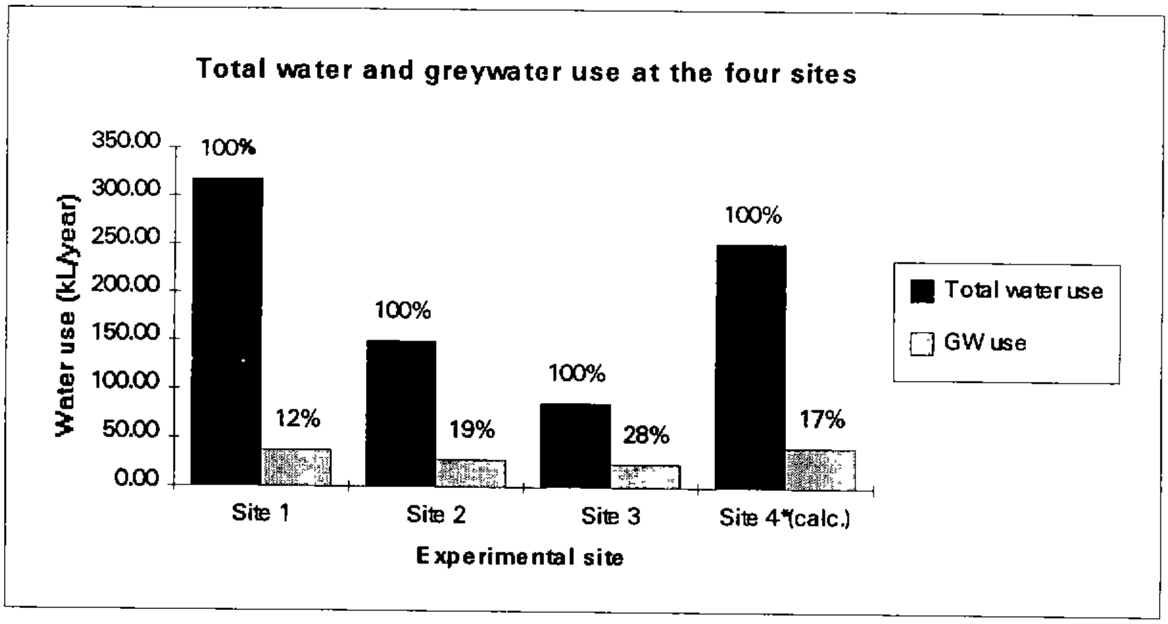


Figure 6.9: Comparison of the total water and greywater use at the four sites

The goal for the future is to seek a balance between greywater supply and greywater demand. However, it is very unlikely that the majority of houses could achieve the theoretical maximum of 20% to 29% water savings, as these figures are calculated on the assumption that all the bathroom and laundry greywater is diverted for reuse and that all the toilet flushing and irrigation demands can be efficiently met with greywater. Homes occupied by few individuals and containing large landscapes would not be able to reach the maximum potential savings, because the greywater they produce would not be sufficient and some potable water would be needed for irrigation. Also, homes with many occupants and a small area of landscaping could not achieve these maximum levels of savings as all greywater generated could not be utilised.

6.3 GREYWATER QUALITY

The purpose of the quality tests was to identify the contaminants in greywater, their concentration and the possible adverse effects associated with greywater reuse. The aim was to determine appropriate reuse practices to provide the most beneficial reuse of greywater without posing any significant risk to public health and the environment. Determinant values from the six rounds of sampling and testing were grouped together for the bathroom and laundry samples from the four sites. Parameters such as TDS, SAR and SO_4 were calculated for assessment of the quality of greywater (see Tables D.1 and D.2, Appendix D). Analyses of the potable water supply for the four sites were obtained for comparison with these parameters (see Tables D4-D7). The greywater quality parameters were assessed according to the recommended limits in the existing wastewater guidelines. A summary of the major greywater quality parameters showing ranges of typical values is presented in Table 6.2. There were some extreme values which are not included in this table, but are presented in the more comprehensive tables of detailed sample results in Appendix D.

In general, the results showed high variability of the greywater quality due to factors such as source of water, type of appliances (clothes washing machines) and fixtures (shower heads), individual habits, products used (soaps, shampoos, detergents), and other site-specific characteristics. The values for a number of parameters were similar for all samples, having a small range of variation, and none exceeded the recommended limits of water quality for reuse. These were: arsenic, boron, cadmium, chromium, manganese, nickel and selenium (see Table D.2, Appendix D). Other parameters showed a very wide range of variation, with values significantly exceeding the recommended levels. An analysis of these results, identification of the possible sources and comparison with the existing wastewater standards are presented in the following sections.

Table 6.2 - Typical Values of Greywater Quality Parameters: Physical, Chemical and Microbiological and Corresponding Recommended Limits for Comparison

Parameters	Project Values		Literature Values (see Table 2.11)	Tap water (see App.D)	Recom. limits NSW Guidelines (see Sec 2.5.4)	Recom. limits EPA-Guidelines (see Sec 2.5.4)
	Bathroom water	Laundry water				
pH, units	6.4 - 8.1	6.3 - 9.5	5 - 9.9	7.2 - 8.2	6.5 - 8.0	6.5 - 8.4
EC 25C, microS/cm	82 -250	83 - 880	330 - 580	50 - 87		0-270(-780)
Total solids	-	-	-	39 - 65		
T.D.S.	52.5 - 160	53 - 563	140 - 5960	-		0-175(-500)
Suspended Solids	34 - 380	26 - 400	20 - 1500	-	30 (implied)	< 50(median)
Colour, Pt/Co units	15 - 70	15 - 160	-	5 - 14	< 15	
Turbidity, NTU	15 -270	22 - 350	20 - 140	1 - 2.3	< 5 (95%smp)	
Total Alkalinity	19 - 60	19 - 220	125 - 382	7.9 - 18.9		
Chloride	9.0 - 33	9.0 - 91	3.1 - 136	6.8 - 19		< 100 (350)
Fluoride	0.49 - 1.05	0.57 - 1.6	-	0.68 -0.97		1.0
Nitrate & Nitrite	<0.02 -0.20	0.023 - 0.44	0 - 4.9	0.02 - 0.38		
Ammonia N	<0.1 -7.8	< 0.1 - 11	0.1 - 8.1	-		
T K Nitrogen	2.4 - 23	1.0 - 40	0.6 - 50	0.05 - 0.13		
Phosphorus (total)	0.1 - 0.88	0.062 - 42	0.3 - 35	0.005-0.02		10-50 kg/ha/yr
Sulphate	<0.3 - 12.9	4.2 - 168	4 - 40	1.4 - 4		
Potassium	1.3 - 5.2	1.1 - 23	4.5 - 13	0.4 - 0.72		
BOD, 5 day	45 - 330	10 - 520	33 - 620	-	20 (implied)	< 50(median)
AAA Substances	0.8 - 13	14 - 150	-	-		
Oil and Grease	10 - 180	8.0 - 170	-	-		

Results are in mg/L unless specified otherwise.

Table 6.2 continued on next page.

Table 6.2 - Typical Values of Greywater Quality Parameters (continued)

Parameters	Project Values		Literature Values (see Table 2.11)	Tap water (see App.D)	Recom. limits NSW Guidelines (see Sec 2.5.4)	Recom. limits EPA-Guidelines (see Sec 2.5.4)
	Bathroom water	Laundry water				
Calcium	2.7 - 8.6	2.3 -12	4 - 824	0.05 - 3.3		) Related to
Magnesium	1.2 - 2.3	0.7 - 5.3	1 - 15	0.1 - 1.6		) SAR values
Sodium	7.4 - 29	12 - 480	32 - 1090	4.2 - 18		) (Sect. 2.5.3.2)
SAR*	0.79 - 3.18	1.33 - 13.03	-	-	-	range of values
Aluminium	< 1.0 - 1.4	< 1.0 - 44	0.02 - 0.67	0.04 - 0.82		5.0
Arsenic	<0.001 - 0.013	0.0001 - 0.007	-	< 0.001		0.10
Boron	< 0.1	< 0.1 - 0.6	N.D.	-		0.75
Cadmium	< 0.01 - 0.05	< 0.01 - 0.05	< 0.01	<0.0005		0.01
Copper	<0.05 - 0.32	< 0.05 - 0.49	0.15	<0.02-0.05		0.2
Iron	<0.05 - 8.0	<0.05 - 4.2	0.79 - 28	<0.05-0.19		5.0
Lead	< 0.05	<0.05 - 0.48	< 0.05	< 0.001		5.0
Selenium	< 0.001	< 0.001	-	-		0.02
Zinc	0.13 - 13	0.1 - 11	0.38	0.01-<0.05		2.0
Total Coliforms cfu/ 100mL	10^4 - 10^7	10^5 - 10^8	45 - 2.8x10^7	0 - 7 org/100mL	< 10 (95%samples)	< 10 (95%samples)
Faecal Coliforms cfu/ 100mL	10^3 - 10^5	10^4 - 10^6	<10 - 2x10^8	0 - < 1 org/100mL	< 1	< 2x10^3 (95%samples)
Faecal Streptococci cfu/ 100mL	10 - 10^3	< 2 - 5x10^3	19 - 1.51x10^3	-	-	-
Parasite / 50L					< 1	
Virus / 50 L					< 2	

Results are in mg/L unless specified otherwise.

* SAR values were calculated using equation 2.2.

The first two bathroom samples at Malvern and the last two laundry samples at Clifton Hill have to be given special consideration. At Malvern because of the site-specific plumbing arrangements the influence of laundry water could not be completely separated. At Clifton Hill the last two samples were of disinfected laundry greywater, taken from the galvanised steel toilet flushing tank.

6.3.1 PRESENTATION AND DISCUSSION OF RESULTS

6.3.1.1 Physical parameters (refer Table D.1)

In general, the physical parameters measured in this study were similar to data from previous studies. The physical qualities of tap water deteriorate, which is manifested in increases in turbidity, solids and colour levels in the greywater. These results are consistent with previously reported data (Rose et al., 1991; Siegrist and Boyle, 1987).

TDS/Conductivity

TDS (Total Dissolved Solids) was calculated from conductivity measurements. Results showed that 94% of the bathroom samples were in the range of 52.4 to 160 mg/L. There was one value outside this range (the first bathroom sample at Malvern) - 268.8 mg/L.
Of the laundry samples 40% were in the range of 53.12 to 140.8 mg/L, another 40% were in the range of 204.8 to 307.2 mg/L. The remaining 20% were between 556.8 and 896 mg/L.

TDS values for wastewater can be divided into 5 salinity classes (see Section 2.5.4). According to this classification the greywater samples fall into the first three classes (refer Table 6.3). Bathroom greywater samples were mainly of low salinity and therefore suitable for most plants and soils. Laundry greywater samples showed higher variation in TDS values, depending mainly on the type of laundry detergent used. Detailed analysis of the influence of laundry detergents on greywater quality is presented in Section 6.5.

Table 6.3 - TDS Classes of Greywater Samples.

Class	Description	Range (mg/L)	Proportion of samples		Comment
			B'rm GW	L'dry GW	
1	Low salinity	0 - 175	95%	40%	(a)
2	Medium salinity	175 - 500	5%	40%	(b)
3	High salinity	500 - 1500	0%	20%	(c)

(a) Suitable for most plants and soils. Laundry product used was the potassium-based detergent.

(b) Can be applied to most plants but requires a moderate amount of leaching. Laundry product used was "Bio-Z".

(c) Harmful effects will occur unless the soil is permeable with good drainage and salt tolerant plants are used. Laundry products used included "Cold power" and "Softy concentrate" liquid detergent. The sodium content of detergents is a major contributor to the high salinity.

Suspended Solids

With one exception, all the bathroom samples (comprising 94%) were in the range of 34 to 380 mg/L, the exception was the first bathroom sample at Malvern being 500 mg/L. Similarly, 95% of the laundry samples were in the range of 26 to 400 mg/L, with one exception of 640 mg/L at Malvern. The very high values from the Malvern site, being the first in a series could be due to previously accumulated sediment on the bottom of the tank and the pit.

Strainers, screening and filtering devices were used to control the level of suspended solids in diverted greywater. The ample use of strainers, screens, and filters can produce greywater of suitable quality for toilet flushing and irrigation provided they are regularly inspected and cleaned. Even so, occasional blockages occurred resulting in reduced or no flow to irrigation lines and toilet cisterns and increasing the volume of wasted overflows to sewer. The long term effects on irrigation pipes and emitters could not be assessed in this program. For further details see Section 6.6

Colour

Of the bathroom samples 94% were in the range of 15 to 70 Pt/Co units, and one sample was 100 Pt/Co units at Clifton Hill. Of the laundry samples 90% were in the range of 15 to 70 Pt/Co units, with two exceptions of 160 and 400 Pt/Co units at Malvern.

The colour of greywater would not have any effect on irrigation, but could impair the aesthetic view of the greywater for toilet flushing which was identified as a problem at one of the experimental sites.

Turbidity

Of the bathroom samples 94% were in the range of 15 to 270 mg/L, with one exception of 460 mg/L at Malvern (first bathroom sample). Of the laundry samples 95% were in the range of 22 to 350 mg/L, with one exception of 1200 mg/L. In general, laundry samples showed higher turbidity levels than bathroom samples of greywater. The high turbidity would reduce the efficiency of disinfecting greywater for toilet flushing, but would not have any implications for subsurface irrigation.

In general, the measured levels of suspended solids, colour and turbidity of greywater (especially laundry samples) were much higher than the NSW recommended guidelines for reclaimed water. However, it should be noted that the laundry samples showed 2 to 3 times less suspended solids and turbidity levels if liquid (ie. non-powdered) detergents were used.

6.3.1.2 Chemical parameters (refer Table D.2)

pH

The pH values of 81% of the bathroom samples were in the range from 6.5 to 8.1, only three values were below 6.5.

Of the laundry samples 20% were below 6.5, 45% were in the range of 6.5 to 8.1, and the remaining 35% were in the range of 8.3 to 10.

The typical values of bathroom greywater observed were in the allowable range for irrigation water. The laundry samples were more alkaline (35% of the samples were in the range of 8.3 to 10). These high values depend on the type of detergents used (see Section 6.5.1). If such greywater is used for irrigation, the pH of the soil would in time be adversely affected and when soil pH exceeds 8 to 8.5 some micronutrient deficiencies would occur. When greywater is used for toilet flushing the only likely adverse effect is reduced efficiency of disinfection although this was not experienced at site 2 (see Section 6.5.2).

BOD

The BOD values of 94% of the bathroom samples were in the range from 45 to 330 mg/L. Of the unchlorinated laundry samples 78% were in a similar range from 48 to 290 mg/L, but the upper 22% were from 420 to 740 mg/L. BOD of disinfected greywater was < 10 mg/L.

The BOD load from the bathroom was larger than from the laundry. However, there were a few exceptionally high values in Malvern laundry greywater of 420 - 740 mg/L. In general, all values were substantially above the recommended limit of 20 mg/L for reclaimed water quality. No implications are expected when greywater is used for subsurface irrigation as the biological activity of the soil would provide the necessary treatment. When used for toilet flushing, it was found that BOD levels for disinfected greywater fell within the recommended limits.

Total Kjeldahl Nitrogen (TKN)

TKN levels ranged from 2.4 to 23 mg/L from the bathroom samples and from 1 to 40 mg/L for the laundry samples. Levels for 94% of the bathroom samples and 65% of the laundry samples were below 20 mg/L.

Results demonstrated that the laundry is a larger contributor of TKN than the bathroom. The measured values are consistent with levels reported in previous studies. For the nitrogen levels observed no implications are expected for subsurface irrigation of lawns and gardens with greywater as it can only contribute to enrich the level of nutrients in the subsoil layers.

Phosphorus

The bathroom samples were in a narrow range of values from 0.1 to 1.8 mg/L. Of the laundry samples 65% were in the low and narrow range from 0.06 to 3 mg/L, but the upper 35% were distributed from 4.4 to 42 mg/L.

The main source of phosphorus is the laundry. Depending on the type of detergent (low or high in phosphorus) the values were in the low range of 0.1 to 0.22 mg/L, the medium range of 0.56 to 1.2 mg/L, or the high range of 3 to 42 mg/L.

Phosphorus from detergents would not usually pose a problem when disposed to land since it is normally a plant requirement, but clay soils may become phosphate saturated. There would then be a potential for leaching to groundwater or seepage to a watercourse. Excess phosphorus leaching to groundwater in sandy soils might be a significant problem.

Potassium

The bathroom samples were in a range from 1.3 to 5.2 mg/L.

The range of values from the laundry was wider from 1.1 to 23 mg/L, with 75% of the samples below 7 mg/L.

No implications are expected of subsurface irrigation with greywater, as it can only contribute to enrichment of nutrients in the subsoil layers.

Sulphate

Of the bathroom samples 94% were in the range from < 0.3 to 12.9 mg/L.

Of the laundry samples 95% were in a wider range from 4.2 to 168 mg/L, with one exception of 261 mg/L at Malvern.

No implications are expected of subsurface irrigation with greywater with these levels of sulphate.

Chloride

Of the bathroom water values 94% were in the range from 9 to 33 mg/L, with one exception of 67 mg/L at Malvern.

The lower 70% of the laundry samples were in a small range from 9 to 34 mg/L, and the upper 30% were distributed in a range from 42 to 91 mg/L.

In general, the chloride levels in laundry greywater were higher than in bathroom greywater. All of the values were below the recommended limit of 100 mg/L. No implications are expected.

Fluoride

Of the bathroom samples 25 % were between 0.05 and 0.07 mg/L. These samples came from the household with rainwater supply. Of the bathroom samples 70% were in the range of 0.65 to 0.99 mg/L. There was one exception of 1.05 mg/L.

The laundry samples from the house with rainwater supply were in the range of 0.07 to 0.15mg/L, constituting 20% of the samples. Of the laundry samples 65% were in the range of 0.57 to 0.96 mg/L. There were three samples, comprising 15 %, that were in a higher range of 1.2 to1.6 mg/L.

There were 15 % of the laundry samples above the recommended limit of 1 mg/L, but as most of these higher values were attributable to the potable water supply no adverse effects would be expected.

Calcium

Of the bathroom samples 94% were in the range of 2.7 to 8.6 mg/L, with one exception (the first sample at Malvern) of 30 mg/L.

Of the laundry samples 75% were in the range of 2.3 to 9 mg/L, the remaining 25% ranged from 11 to 27 mg/L. Although the laundry samples showed obviously higher levels, there was no consistency in the distribution by sites or by products to explain this fact.

Magnesium

Of the values 88% were in the range of 1.2 to 2.3 mg/L, with two higher values (which were the first two samples at Malvern) of 3 and 3.3 mg/L.

Of the laundry samples 90% ranged from 0.7 to 3.2 mg/L, and two samples from Malvern were higher at 4.6 and 5.3 mg/L.

Sodium

Of the bathroom samples 94% were in the range of 7.4 to 27 mg/L, and one value (the first bathroom sample from Malvern) was 66 mg/L.

Of the laundry samples 70% were from 12 to 100 mg/L, 25% were from 140 to 200 mg/L and one value was exceptionally high at 480 mg/L at Clifton Hill.

The sodium levels in laundry greywater were strongly dependent on the type of detergent used and were several times higher that those in bathroom greywater. It can be concluded that if the laundry detergent is appropriately selected the sodium might not present a problem (see Section 6.5.1).

SAR

SAR values were calculated using formula (2) from Section 2.5.3.

All the bathroom samples were in the range of 0.79 to 3.18.

Of the laundry samples 70% ranged from 1.33 to 7.79, 20% were in the range from 9.27 to 13.03, and 10% were as high as 17.46 and 37.30 (both samples from Clifton Hill).

All bathroom samples were below 8, which according to the guidelines is water suitable for irrigation and would present no problems. Of the laundry samples 70% were in the same category, 20% were in the range of 12 to 15, which represents marginal water quality for irrigation, and the remaining 10% had very high values of 17.46 and 37.30 and would indicate serious problems if the water was to be used for irrigation.

The concentrations of Ca, Mg and Na are not expected to have any implications for toilet flushing with greywater. For irrigation of lawns and gardens their concentration is very important and is assessed by using SAR. A high SAR can be detrimental in the long term to the hydraulic conductivity and physical properties of clay soils and associated plant systems.

Aluminium

With three exceptions, all the bathroom samples were less than 1.0 mg/L, the exceptions being one sample of 1.4 mg/L at Clifton Hill and two samples of 18 mg/L at Malvern (the first two bathroom samples collected).

There was a very wide range of values for the laundry samples. Of the laundry samples 40% of the values were below 1.0 mg/L. All of remaining samples were in the range of 7.6 to 44 mg/L, apart from one sample of 96 mg/L at Malvern.

The bathroom samples and about 45% of the laundry samples were below the recommended limit of 5 mg/L and no implications would be expected. The remaining 55% of the laundry samples exceeded this limit, with the extreme value reaching 96 mg/L. There was no evidence for any substantial contribution of aluminium from the water supply, as these levels were all below 0.15mg/L, apart from one reading of 0.82 mg/L. Laundry detergents were identified as the main contributor of aluminium, and more specifically, zeolite which is used as a substitute for phosphorus in detergents. The ICP test did not distinguish between soluble and insoluble forms of aluminium. Further research is needed to identify the proportion of the two forms, as they have different uptake by plants. Like phosphates, zeolites are non-toxic, but their impact on the environment is not completely understood.

Copper

The bathroom samples have a small range of values with 81% in the range of 0.05 to 0.20 mg/L. Only three samples, approximately 19% of the total, had higher levels of 0.21 mg/L at Balwyn, and 0.32 mg/L and 1 mg/L at Malvern (the first two samples).

Of the laundry samples 70% were in the range of 0.05 to 0.20 mg/L and 25% were in the range of 0.21 to 0.32 mg/L. There was one exception of 0.49 mg/L at Malvern.

All of the bathroom samples and 62% of the laundry samples were below the recommended limits and no implications would be expected. The remaining 38% of the laundry samples displayed levels up to 2.5 times the recommended limit. The laundry samples were taken from the toilet flushing tanks at Clifton Hill and Malvern, where the source may have been leaching from the supply plumbing pipework. The source of fresh water at Malvern was rainwater, which was generally more acidic than the conventional water supply from Melbourne Water, and this may have contributed to the extraction of metals.

Iron

Of the bathroom samples 56% were in the range of 0.05 to 0.97 mg/L and 25% were in the higher range of 1.1 to 1.4 mg/L. There were two higher values of 2 and 6.2 mg/L at Malvern (first bathroom samples) and 8 mg/L at Clifton Hill.

Of the laundry samples 80% were in the range of 0.05 to 1 mg/L. The remaining 20 % were in the range of 1.2 to 4.2 mg/L (all at Malvern).

The iron levels observed in the bathroom samples were higher than levels in the laundry samples. Generally the levels were below the recommended limit of 1 mg/L. Two bathroom values exceeded the limit and the source of iron cannot be adequately explained. In a study by Lock (1994) the average net load of iron recorded was up to 169 mg/capita/day in bathroom greywater, and the probable source of iron was some cosmetic products.

Lead

Of bathroom samples 75% had values less than 0.05 mg/L. The remaining 25% of values were in the range of 0.28 to 0.56 mg/L, all from the Malvern site.

Of laundry samples 70% had values less than 0.05 mg/L. Two values or approximately 10% of the laundry samples were 0.06 and 0.08 mg/L. The remaining 20% (all from Malvern) were in the range of 0.18 to 1.3 mg/L.

In three of the four households, for the minimum detection level of 0.05 mg/L, no difference in contribution from bathroom or laundry water was identified. At Malvern the levels of lead in laundry greywater were two to three times higher than those in the bathroom greywater. According to Lock (1994) the average net load of lead recorded was as high as 11 mg/capita/day, which cannot explain the high levels of lead at the Malvern site. The source of lead can be attributed to the removal of old lead-based wall paint, particles of which collected in clothes which were subsequently washed in the clothes washing machine.

Zinc

Of the bathroom samples 62% were in the range of 0.13 to 1.5 mg/L. The remaining 38% were in the range of 4.2 to 13 mg/L, and all were from the Balwyn and Malvern sites where greywater flows though the toilet flushing tanks.

Of the laundry samples, 70% were in the range of 0.09 to 0.34 mg/L, 20% were in the range of 5.1 to 11 mg/L, and the remaining 10% were two extremely high values of 19 and 31 mg/L at Clifton Hill (the two samples of disinfected greywater from the toilet flushing tank).

All the greywater samples which contained high levels of zinc (above the recommended limit of 2.0 mg/L) had been exposed to contact with toilet flushing tanks. These high levels can be attributed to the leaching of zinc from the tank walls, if the water is acidic. At Malvern the acidity can be due to the rainwater supply, at Balwyn the bathroom greywater was of pH below 7, while at Clifton Hill the acidity can be due to chemical reactions related to the presence of chlorine tablets for disinfection. If such greywater is used for continuous irrigation the accumulation of zinc in soils may cause damage to turf. Soil zinc levels should not exceed 12 ppm to avoid this problem. Implications regarding toilet flushing with such greywater are not expected.

Arsenic, Cadmium, Chromium, Manganese, Nickel, Selenium

From both bathroom and laundry the samples were in the range of 0.001 to 0.007 mg/L for arsenic, less than 0.05mg/L for cadmium, chromium, and nickel, less than 0.2 mg/L for manganese, and less than 0.001 mg/L for selenium.

The levels of these parameters were below the recommended limits (see Sect.2.5.4) and no adverse effects are expected.

Boron

In all the bathroom samples boron was less than 0.1 mg/L. In 40% of the laundry samples boron was below this level, the remaining samples with two exceptions were in the range of 0.1 to 0.6 mg/L. The two exceptions being 3.2 mg/L and 4.4 mg/L at Clifton Hill (the two samples of disinfected greywater).

The contribution of boron was mainly from the laundry, but in general the levels were below 0.7 mg/L. These low levels were consistent with results reported by the City of Los Angeles study(1992).

There were only two extremely high values of 3.2 and 4.4 mg/L in the toilet flushing tank at Clifton Hill where the water was disinfected with chlorine. This is unlikely to be the explanation for these high levels.

In general, most of the high levels of metals (Al, Cu, Fe, Pb, and Zn) were observed in the laundry greywater from one household (at Malvern). The source of water is rainwater collected from the roof. It is interesting to note that this household has a selection of the most water efficient appliances, which can be part of the explanation of the high levels. For example, the clothes washing machine uses 2 to 3 times less water compared to the conventional ones, but the same amount of detergent. It can be expected that the concentration of pollutants would be two to three times higher. This tendency might be typical for most of the water conscious and conservation orientated households. There can be other sources such as leaching from galvanised steel tanks and the metal components of other equipment.

Oil & Grease

Of the bathroom samples 88% were in the range of 10 to 94 mg/L, but there were two values outside this range of 170 mg/L (the first bath sample at Malvern) and 180 mg/L at Clifton Hill.

Of the laundry samples 90% were in the range of 8 to 95 mg/L, with two higher values of 130 and 170 mg/L at Malvern.

In general the bathroom contribution of oil and grease appears higher than that from the laundry. This can be attributed to the higher content of body oil and fat discharged in the bathroom greywater. It would be expected that if oil and grease levels are high some soil clogging might occur with the long term application to land, while for toilet flushing the main implication would be the buildup of scum and slimy films on the tank walls and components of the toilet cistern and bowl, requiring extra cleaning. Assessing such long term effects was beyond the scope of this program.

Azure-A Active Substances (Surfactants)

Of the bathroom samples 88% ranged from 0.1 to 10 mg/L, the remaining two values were 13 and 35 mg/L at Malvern.

Of the laundry values 85% were in the range from 8 to 94 mg/L and 15% were in the range from 130 to 150 mg/L.

The main contributor of surfactants is the laundry. No distiguishable difference in the contribution of the different laundry products was identified. The main concern regarding surfactants is their biodegradability. However, it should be expected that if the products used in the household meet the requirements of AS - 1792/76, no problems would occur.

6.3.1.3 Microbiological parameters (refer Table D.3)

Total coliforms

In bathroom greywater the number of total coliforms varied from 5×10^2 to $>2.4 \times 10^7$ colony forming units (cfu) per 100 mL.

In laundry greywater the total coliform numbers were in the range of 2.3×10^3 to $>2.4 \times 10^8$ cfu/100 mL.

In the third round of samples both bathroom and laundry greywater samples were $>2.4 \times 10^7$cfu/100 mL.

Faecal coliforms

The numbers of faecal coliforms for bathroom samples were in the range of 1.7×10^2 to 3.4×10^6 cfu/100mL.

For laundry samples the faecal coliform levels ranged from 1.1×10^2 to 9.2×10^7.

Faecal Streptococci

In bathroom greywater the numbers of faecal streptococci were in the range of 14 to $>2.4 \times 10^3$.

For the laundry greywater the range was from < 2 to 1.3×10^4.

An interesting result was obtained in the third sampling round when all the laundry samples displayed counts of less than 2 cfu/100mL.

Disinfected greywater

In the two samples of disinfected greywater (from Clifton Hill) none of the above microorganisms were found.

Sludge samples

Samples of the sludges deposited at the bottom of toilet flushing tanks at sites 1, 2 and 3 were collected and tested. The total coliforms enumerated were 1×10^6 orgs/mL at Balwyn, 1.1×10^8

orgs/mL at Clifton Hill, and 1.4×10^8 orgs/mL at Malvern. The source of water at Balwyn was the bathroom, while at the other two sites it was the laundry.

Pathogens

Four disease-causing organisms were monitored in all the samples of greywater - Salmonella, Campylobacter, Giardia and Cryptosporidium. With one exception of one sample, none were found. The exception was the Malvern laundry greywater on 09.02.95 when campylobacter was isolated. The opinion of specialists from the testing laboratory is that this was most likely an environmental species. It was not isolated in the follow-up samples from the same source.

Pseudomonas Aeruginosa

In five of the 36 samples heavy growth of Pseudomonas Aeruginosa was observed. This is a very common microorganism in laundry tubs, sinks, and warm water environments so it might be expected to be found in most samples.

Comments on Microbiological parameters

The results of the microbiological testing showed very high variability and a lack of consistency. Factors that contributed to this variability appeared to be family characteristics (number and age of children), source of water, and condition of the surge tank and pipes. Climatic conditions can also have some influence on the microbiological quality. Financial restrictions limited the number of samples analysed because of the high cost of testing. Testing for Giardia and Cryptosporidium in greywater was difficult because of the high turbidity and concentration of soaps. Techniques were developed to reduce these difficulties, but there were still some limitations on the accuracy of the early results.

It was very difficult to establish a trend in the results from the different sources of greywater due to the high variety of the microbiological profiles, limited number of samples and lack of consistency. In general, the numbers of total and faecal coliforms and faecal streptococci were high from all the samples and significantly higher than the levels recommended in the NSWRWCC (1993) guidelines (total coliforms < 10/100mL, and faecal coliforms <

1/100mL). A possible reason for these high numbers might be the growth of microorganisms in the slime on tanks and pipes. It can be expected that the physical and chemical quality of greywater contributed to this growth. The elevated temperature and increase in turbidity, phosphorus and nitrogen in greywater would provide favourable conditions and nutrients for growth of microorganisms.

Microbial quality of shower and laundry greywater was compared. In several cases laundry greywater displayed higher numbers of total and faecal coliforms than bathroom greywater which might be partly attributed to the availability of nutrients in the form of phosphorus and nitrogen, and possibly higher temperatures, which support the growth of microorganisms. No significant difference between the two sources in the number of faecal streptococci was found. Data for microbiological quality of laundry greywater from individual families showed that total and faecal coliforms and faecal streptococci concentrations were generally higher for the family with a baby.

No pathogens were found in the greywater samples. This can be attributed to the fact that none of the residents was shedding these organisms during the period the research was carried out. This does not imply the absence of pathogens in greywater in other households or even in these households at another time.

No microorganisms were isolated from the disinfected samples, which might be an indication that chlorination was an adequate treatment of greywater for toilet flushing.

6.3.2 CONCLUSIONS

- Greywater quality was analysed and assessed to determine any potential public health and environmental risk associated with its reuse. A limited number of samples, 20 of bathroom greywater and 16 of laundry greywater, were tested to determine a number of physical, chemical and microbiological characteristics. The samples were small in number and cannot be considered statistically significant, but still they provide a general indication of typical greywater characteristics, the influence of family characteristics, local detergent products and other site specific conditions.

- In general, greywater quality showed high variability, due to factors such as source of water, type of products used, type of family (age of members), individual lifestyle, and specific house characteristics including water appliances used and configuration of the system piping.
- Greywater quality is very site specific and difficult to predetermine or control except for the use of some products that can be recommended (see Section 6.5).
- The comparison of tap water quality with greywater quality showed that tap water deteriorates significantly after the first use. An increase in the concentration of a number of parameters such as phosphorus, nitrogen, conductivity, turbidity, some heavy metals and microbiological pollutants was observed.
- The results from this research were consistent with data previously reported. Typical ranges of values from this and previous studies are summarised in Table 6.2.
- The results of this study regarding greywater quality are summarised as follows:

Physical and Chemical Quality

Many of the physical and chemical aspects of greywater quality depend on the types of detergents used. A detailed analysis of suitability of products is presented in Section 6.5.

- The pH of the bathroom greywater samples were all in the allowable range for irrigation water, but some of the laundry samples showed very high alkaline values, due to the use of certain detergents.
- Salinity of greywater was assessed. Bathroom water is not likely to present any problems as its quality corresponds to class 1 salinity water, which is suitable for all soils and plants. Laundry greywater displayed three different degrees of salinity: class 1, 2 and 3, depending on the type of laundry products used.
- Sodium and SAR were determined for assessment of the possible adverse effects on soil structure. Bathroom greywater is not likely to present problems as SAR values from these samples were below 3.2, which is well below the acceptable limit of 8. Most laundry greywater samples showed marginal to very high values (17.46 and 37.30) of SAR. Selecting an appropriate detergent with low sodium content can help reduce this problem.

- High levels of boron, although a common component of some detergents, were not detected. It is not expected to present a problem if appropriate detergents are used.
- There were high levels of the following metals: aluminium, copper, iron, lead and zinc. Aluminium can be attributed to the laundry products, copper to plumbing and some cosmetic products, iron to some cosmetic products, iron piping, and galvanised tank walls. The source of zinc is mainly due to leaching from the galvanised steel walls, and only a small part can be attributed to the products used.
- In general, the levels of aluminium can be minimised by choosing a suitable detergent. Zinc and iron levels can be minimised by not using metal and galvanised steel as the material for the tanks and drums. It is not possible to reduce copper levels if their source is the plumbing.
- Most of the high metal levels (Al, Cu, Fe, Pb, and Zn) were observed in the laundry greywater samples from one of the four households. The analysis of the possible reasons included factors such as source of water, products used, lifestyle, and house characteristics. It can be concluded that the highly water efficient appliances contribute to higher concentrations of contaminants (although not necessarily to higher total loads).
- Based on the comparatively lower levels of contaminants, it can be concluded that bathroom greywater is generally less harmful and more suitable for irrigation than laundry greywater.
- It can be concluded that the quality of laundry greywater is more contaminated than bathroom greywater, due to the components in the laundry products. Careful selection of detergents can avoid a number of these problems (high pH, salinity, sodium, aluminium). However, it is most unlikely that all of these parameters can be reduced simultaneously. In general, laundry greywater may be more suitable for toilet flushing than for irrigation.
- Bathroom products seem not to present problems, but based on these limited number of samples, it cannot be guaranteed that all bathroom products would be safe for the environment.

Microbiological Quality

- With regard to microbiological quality, no statistically significant difference between bathroom and laundry greywater quality could be calculated because of the small number of samples tested. However, from general observation of the results, there did appear to be some difference in the quality of the two sources. Typical ranges for total coliforms were 10^4 - 10^7 and 10^5 - 10^8 cfu/100mL for bathroom and laundry sources respectively, while the corresponding ranges for faecal coliforms were 10^3 - 10^5 and 10^4 - 10^6 cfu/100mL, and for faecal streptococci were 10 - 10^3 and <2 - 5x10^3 cfu/100mL. Counts both lower and higher than these ranges were observed for both sources of greywater. These results indicate high microbiological contamination, and potential presence of pathogens. The levels of microorganisms in greywater are significantly higher than levels recommended in guidelines. As may be expected, the higher levels of total and faecal coliforms were generally observed in laundry water from the family with a small baby.
- None of the disease-causing pathogens Salmonella, Campylobacter, Giardia and Cryptosporidium was found in the greywater samples. This can be attributed to the fact that none of the residents shed these organisms during the time of the sampling. This does not imply the absence of pathogens in greywater from other households or even from the same households at another time.

General Conclusions:

- The results of this study lead to the final conclusion that, although the possible health risk associated with exposure to greywater is undefined, it is important to take a cautious approach and avoid any human contact with greywater. It can be recommended that for the purposes of irrigation the safest method of reusing greywater is by subsurface application immediately after being produced. Selecting appropriate products, especially in the laundry, is essential in order to minimise the possible adverse effects on the environment. For toilet flushing purposes additional treatment (eg. filtration, disinfection, etc.) has to be provided to obtain an adequate quality for reuse. The risk of contact with aerosols due to flushing would be minimised by first closing the toilet seat cover before flushing.

6.4 RECEIVING SOILS ANALYSIS

A number of parameters were tested to assess the risk of soil structure decline: Total Cation Concentration (TCC), Electrical Conductivity (ECs), Exchangeable Sodium Percentage (ESP), Exchangeable Cations, and Ratio of Calcium to Magnesium, etc. Soil samples from each site were collected from the top soil (at an approximate depth of 0 - 250 mm) and from the subsoil (at an approximate depth of 250 - 400 mm). For the sites where two sources of greywater were used, soil samples for each irrigation distribution zone were analysed. Tests were carried before the start of irrigation with greywater to establish baseline soil conditions and after the end of each irrigation season to check for any changes. A full set of the soil testing results is included in Appendix E. Detailed discussion is presented in the following sections.

An assessment by a soil specialist indicated that in general, the surface soils were high in organic matter and have a low to moderate level of fertility typical of a home lawn, while the subsoil was low in all nutrients and cations. This is a typical condition of the soil layers as the nutrients and cations are usually retained in the upper section of the soil profile due to the higher cation exchange capacity (CEC) of the organic matter, whereas the subsoil has a lower CEC and is more readily leached of nutrients.

Microbiological analyses of early soil samples from sites 1 and 2 were carried out to determine the presence of Salmonella, Campylobacter, Giardia and Cryptosporidium. None of these organisms were found in the soil samples (see Table E.5). These tests were not conducted for later soil samples as the greywater results showed that none of these pathogens was present in the greywater applied to the soil. Microbiological tests were not carried out on the soil samples from sites 3 and 4 as they were stored for an excessive period of time.

6.4.1 BASELINE SOIL CONDITIONS

Baseline conditions were established after the first round of soil samples had been analysed by a soil specialist. For ease of reference the topsoil samples will be refered to as (top) and the subsoil samples as (400mm). The following baseline conditions were found:

pH

The pH was in the normal range for all sites except for Balwyn (400mm) sample, which was moderately acid and lime was recommended at 10kg/100 m^2.

Electrical conductivity, Chloride, Exchangeable Aluminium, Boron

For parameters such as electrical conductivity, chloride, exchangeable aluminium, and boron the levels in all samples were low to moderate and would not have any adverse effects on grasses and plants.

Phosphorus

The Olsen P levels are an indicator of the amount of phosphorus available to the plants. The total P represents all the phosphorus in the soil, including available and unavailable forms. Balwyn and Clifton Hill samples had low and Strathmore samples had very low phosphorus levels and an application of superphosphate at 2.5 kg/100m^2 was recommended. The phosphorus level at Malvern was adequate.

Potassium

The potassium levels for all samples except Balwyn (400mm) were moderate and adequate for grass growth. The Balwyn (400mm) value was extremely low, but low potassium levels in the subsoil are of no concern according to the soil specialist.

Nitrogen

The nitrogen levels for all samples except Balwyn (400mm) were within the normal range while the Balwyn (400mm) value was very low. The soil results indicate adequate nitrogen fertility in the topsoil probably associated with the high organic matter content.

Iron

For Malvern and Strathmore samples iron levels were within the normal range for turf growth. Iron levels were very low for Balwyn and Clifton Hill samples.

Organic matter

The organic matter content was high for Balwyn (top) and Clifton Hill (top) samples, moderate for Clifton Hill (400mm), Malvern and Strathmore samples, and very low for Balwyn (400mm). The organic matter content in the subsoils was usually very low.

Exchangeable Manganese

The exchangeable manganese for Balwyn and Clifton Hill samples was very low and fertiliser was recommended. The exchangeable manganese was in the normal range for Malvern and Strathmore samples.

Extractable Cations

The calcium levels were in the acceptable range for all the samples. The magnesium levels were slightly higher than normal for Strathmore samples, adequate for Clifton Hill and Malvern samples, and low for Balwyn (top). The sodium levels were low for all the samples and there would be no adverse effects on soil structure. The potassium levels were adequate for Clifton Hill (top), marginal for Balwyn (top), while the subsoil levels at these sites were low.

Calcium : Magnesium Ratio

The balance between calcium and magnesium was satisfactory for Malvern and Strathmore samples.

Copper

The copper levels for Balwyn and Clifton Hill (400mm) were in the normal to low range. For the Strathmore samples the levels were moderate. The levels for Clifton Hill (top) and Malvern samples were high and could be due to a recent application of fertiliser.

Zinc

The zinc levels were moderate to high for Balwyn (top), Clifton Hill and Strathmore samples and very high for Malvern samples. These levels were unusually high and it was difficult to explain the source of zinc. The Balwyn (400mm) value was low.

6.4.2 FINDINGS

After application of greywater the results of the soil analyses for each site and each subzone were analysed and compared with the baseline conditions. The parameters that changed were pH of the soil, exchangeable aluminium, sodium and calcium. These are discussed in detail below.

SITE 1 - BALWYN

The type of soil at site 1 was silty sandy top soil and silty fine to medium sand as subsoil. Initially the pH of the subsoil was acidic. After the first season of irrigation both top soil and subsoil exhibited moderate to very strong acid pH. The levels were acidic in both bathroom and laundry greywater irrigated zones. The change of pH can be partially related to the bathroom greywater (which had pH in the range of 6.4 to 6.7), but not to the laundry greywater (for which pH was 8.6 to 9.4). The major source of acidity can be attributed to naturally occurring processes in the soil such as leaching of cations, plant uptake of nutrients or large deficiency of organic matter. The high acidity can be corrected by applying agricultural lime (see Table 6.4).

Exchangeable aluminium at this site was initially low and of no concern. After the first irrigation season the level of exchangeable aluminium had increased in the Balwyn laundry zone subsoil. Generally, availability of aluminium is strongly dependent on soil pH and increases as the acidity increases. The increase in soil acidity cannot be connected with the greywater application as the pH of the laundry greywater during the first irrigation year was in the range of 8.6 to 9.4. It is probably due to natural processes in the soil. However, the level of total aluminium in the laundry greywater was higher than 5.0mg/L (the recommended limit), and together with the acid soil conditions, may have contributed to the high levels of exchangeable aluminium.

After the second season of greywater irrigation the exchangeable aluminium levels also became relatively high in the subsoil of the area irrigated with bathroom greywater. This was related to the acid pH of the soil, which leads to an increase in the availability of aluminium. The application of bathroom greywater (pH of 6.2 to 6.8) may have partially contributed to the acidity of the soil, but not to the increase of aluminium content as all bathroom greywater samples showed low aluminium levels (of < 1 mg/L). It is more likely that the natural processes occurring in the soil have a major influence on the levels of aluminium. This can be corrected through addition of agricultural lime ($CaCO_3$).

After the first season of greywater application, the calcium levels in the subsoil irrigated with laundry greywater began to fall, while the sodium levels began to rise. After the second season of application, the pattern of low calcium levels and high sodium levels in the subsoil irrigated with laundry greywater became more apparent and it was also manifested in the top soil of the same area. This can be attributed partially to the application of laundry greywater which had sodium levels of 14 to 93 mg/L. It should be noted that the sodium level increased in the second season even though a low sodium detergent was used. It is expected that high sodium levels would cause breakdown in the soil structure at sites with clayey soils. This can be corrected by adding a source of calcium (eg. $CaSO_4$ (gypsum) or $CaCO_3$).

SITE 2 - CLIFTON HILL

The soil at site 2 was black clayey silty top soil and black/grey silty clay as subsoil. The copper and zinc levels were high at this site before applying greywater and remained in the high range after two seasons of irrigation. The greywater quality results showed that copper and zinc in the greywater were below the recommended limits for irrigation water and no adverse effects were expected. The rest of the tested parameters were within acceptable limits.

SITE 3 - MALVERN

The type of soil at site 3 was grey/brown silty sand as top soil and subsoil. The initial levels of copper and zinc were high to very high and remained in the same range after one season of application of greywater. In 50% of the samples copper and zinc levels in the greywater were higher than the recommended limits for irrigation water quality. But the levels in the soil did not indicate a change following irrigation with greywater. It can be expected that one season of irrigation is insufficient time for the adverse effects to be manifested, and a long term application of greywater is needed to observe any changes. Heavy metals such as Cu and Zn are very strongly adsorbed onto clay and organic matter particles. These metals are not easily leached even with sandy soils.

SITE 4 - STRATHMORE

The type of soil at site 4 was grey silty top soil and grey/brown clayey silt as subsoil. The initial conditions of the soil for all tested parameters were at acceptable levels except phosphorus which was very low and magnesium which was slightly high. Lawn starter fertiliser was applied with an NPK of about 8:10:10 at 4 kg/100 m^2 to facilitate the establishment of the new lawn at this site and to correct the phosphorus levels. No adverse effects were observed in the condition of the soil after one season of application of greywater, although a longer period of observation may be necessary. The pH values of the bathroom greywater soil samples were within acceptable limits (5.4 - 5.9), although they exhibited stronger acidity than the laundry greywater soil samples (6.1 - 6.6). The quality of laundry greywater was satisfactory with pH levels in the range of 6.4 to 7.0. Bathroom greywater could not be tested due to technical limitations.

For the parameters that demonstrated unacceptable levels and needed correction, a number of remedies were recommended after the end of the project by the soil specialist. Actions were not taken during the two years of the experimental program to avoid interfering with the aims of the project. A summary of these recommendations is presented in Table 6.4.

Table 6.4 - Remedies for Correction of Unacceptable Levels of Soil Parameters

Parameter	**Levels that need correction**	**Recommended remedy**
pH	4.5 - 4.9 very strongly acid 5.0 - 5.5 strongly acid 5.5 - 6.0 moderate acid	Application of agricultural lime at 150 gram/m^2 on clay soils and at 100 gram/m^2 on sand*
Phosphorus (extr. low)	2.9 - 3.5 ug/g	Application of superphosphate at 2.5 kg/100m^2
Potassium (low levels)	18 - 38 ug/g	Application of muriate of potash at 2.5 kg/100m^2
Exch. Aluminium (high) - (related to acid pH)	54 - 59 ug/g	Would be corrected with the application of lime to correct soil pH
Calcium (extr.low)	31 %**	Application of gypsum at 10kg/100m^2- two repeat applic.
Sodium (high levels)	13 - 18 %**	Application of gypsum to displace the sodium

* These doses will increase the pH by 0.5 units. If pH is 4.5 and the aim is for pH 6 - 6.5, there is a need for 3 times the dose (eg. 3 x 100 g/m^2) about 2-4 weeks b/n applications.

** Desirable ranges for Ca, Mg, Na, K, as % of Cations are presented in Table 6.5.

Table 6.5 - Desirable Ranges for Ca, Mg, Na, K, as % of Cations present in Soils.

Parameter	Desirable range
Ca:Mg ratio	2 - 5
Ca	65 - 70 %
Mg	15 - 20 %
Na	< 6%
K	5 - 10 %

6.4.3 SUMMARY OF FINDINGS

In general, at sites 2, 3 and 4 (Clifton Hill, Malvern and Strathmore) the levels of the tested parameters did not exhibit significant changes after the application of greywater to the soil. However, a two year period is too short to make a conclusive judgement and a longer term of investigation is needed to assess the effects on soil. Only at site 1 (Balwyn) were some changes observed in soil parameters such as pH, aluminium, sodium, and calcium levels, but these changes could be only partially attributed to the greywater application, as the influence of the natural processes in the soil appeared to be more significant.

6.5 SUITABILITY OF PRODUCTS FOR GREYWATER REUSE

6.5.1 DETERGENTS

As was indicated in Section 6.3.1.2 the laundry greywater quality strongly depends on the products used during its production. Three detergents were used in this experimental program. The first two were both commercially available powder products: "Cold Power" - which is not a low phosphorus detergent, and "Bio-Z" - which is phosphate free, contains both enzymes and zeolites, and is claimed by the manufacturer to be fully biodegradable. It should be noted that the zeolites in detergents are synthetic compounds (sodium alumino silicates). The third detergent was a liquid one - "Pure Laundry Detergent", based on 0.5% Potassium Citrate and supplied as a specially designed product to be tested for suitability for greywater reuse - in this text it is referred to as Potassium Based Detergent (PBD). The three detergents were tested in different sequences at the four sites. Details about the sampling order are presented in Table 6.6. The results of the testing for some of the more important parameters are summarised in Table 6.7. The detailed results of these tests are presented in Appendix D.

Table 6.6 - Sequence of Tests of Detergents at the Four Sites.

DATE	ROUND	SITE / DETERGENT			
		Balwyn	**Clifton Hill**	**Malvern**	**Strathmore**
27.01.94	I	Bio - Z	Cold Power	-*	-*
17.03.94	II	Bio - Z	Cold Power	-*	-*
9/10.11.94	III	Bio - Z	Cold Power	Bio - Z	Bio - Z
7/8.12.94	IV	PBD	Cold Power	Bio - Z	PBD
8/9.02.95	V	PBD	Cold Power	Softy concentr.	PBD
22/23.02.95	VI	PBD	Cold Power	PBD	PBD

* - sites not included in the experimental program at that time.

Table 6.7 - Detergents and their Influence on Greywater Quality

Detergents	Cold Power	Bio-Z	PBD
Parameters	range	range	range
pH, units	7.4 - 10	7.2 - 9.4	6.3 - 7
EC 25C, microS/cm	320 - 1400	190 - 480	83 - 380
TDS, mg/L	204.8 - 896	121.6 - 307.2	53.12 - 243.2
Sodium, mg/L	65 - 480	49 - 150	12 - 61
SAR	7.22 - 37.3	4.4 - 9.27	1.33 - 5.07
Phosphorus, mg/L	3 - 42	0.062 - 4.4	0.1 - 0.63
Boron, mg/L	<0.1 - 4.4	<0.1 - 0.1	<0.1 - 0.3
Aluminium, mg/L	< 1.0 - 1.2	14 - 96	<0.1 - 9.4

6.5.1.1 Cold Power

The results of the sampling indicated that greywater produced with "Cold Power" was alkaline to strongly alkaline, highly sodic and saline, and comparatively rich in phosphorus. Boron was in the acceptable range of < 0.1 to 0.6 for untreated greywater, but rose to 3.2 and 4.4 mg/L when greywater was disinfected with chlorine. Aluminium was very low and not of concern. However, because of the highly sodic, alkaline and saline character, greywater produced with "Cold Power" is not recommended for irrigation.

6.5.1.2 Bio - Z

The greywater produced with "Bio-Z" detergent was alkaline to strongly alkaline, two to three times less sodic and saline than Cold Power, with a very low content of phosphorus and boron, but due to the zeolite content of the detergent the aluminium levels were very high. The sampling method used did not provide information on the form of aluminium and its availability to plants. It can be expected that alkalinity and aluminium would create problems with long term application and especially in clayey soils.

6.5.1.3 Potassium Based Detergent (PBD)

In comparison with the other two household detergents the potassium based detergent exhibited a number of advantages with respect to greywater quality. The results showed significant reductions in the levels of some parameters, especially the ones of major significance such as sodium, pH, electrical conductivity, and phosphorus. In contrast with the other two detergents the pH of greywater using the potassium based detergent was acidic to neutral. This range is preferable for irrigation water, as long as the greywater does not become too acidic (below 6.5). The salinity levels were two to three times less compared to samples of greywater produced with the other detergents. However, two high values of 340 and 380 microS/cm could have been influenced by residual particles in clothes previously washed using other detergents. Sodium levels were two to five times less. SAR values were in the range 1.33 to 5.07 with a geometric mean of 2.2. Phosphorus levels were very low and about 10 to 40 times less than with "Cold Power" and up to two times less compared with the low phosphorus detergent "Bio-Z". Aluminium levels ranged from <0.1 to 9.4. In personal discussion, the producer of this product stated that there were no aluminium compounds present in the detergent. The presence of aluminium might be attributed to particles in clothes previously washed using other detergents or sediments in the surge tanks. Suspended solids and turbidity levels were two to three times less than for other detergents. Potassium levels were up to two times higher compared with the other detergents, but this is beneficial for plant growth. Sulphate levels were two to eight times less than with other detergents.

6.5.1.4 Summary of Findings

In general, the levels of all metals, with the exception of aluminium, were below the recommended limits and posed no concern. Further research is needed to identify the reason for the high levels of aluminium and the proportions that are soluble and insoluble. As the potassium based detergent was used to wash clothes previously washed with "Bio-Z", it can be expected that some particles have remained in the clothes or in the surge tanks.

It can be concluded that the liquid potassium based detergent is a more suitable detergent for greywater reused for irrigation. A further factor to be considered is the price of the detergent, which at present costs \$6 - \$7 /L compared with \$ 1.50 - \$ 4.80 for other liquid detergents available on the market. Two other products recommended (C.T.C. Productions, 1994) are OMO microconcentrate and ARK, which produced the least pH, salinity, and alkalinity problems. In general, further research is needed to identify more products suitable for use with greywater reuse systems.

When reused for toilet flushing one greywater parameter of interest is the pH of the solution. If chlorine tablets are used as a disinfectant the optimum range is 7.2 to 7.6, however, even out of this range chlorination can prove to be effective. The detergent involved in the tests was Cold Power.

6.5.2 DISINFECTANTS

The heterogenic nature of greywater poses a major difficulty in identifying an optimum disinfectant because of the variability in microbiological quality (due to possible presence of different pathogens in different households) and in physical and chemical quality (because of the great variety of washing and cosmetic products). Some combinations of surfactants can neutralise a disinfectant. High turbidity and the presence of certain ions and organic matter reduce the effectiveness of disinfecting agents. The difference in the volumes produced and volumes needed and the patterns of production and usage make the chemical dosing of the greywater a complicated task.

The properties of the optimum disinfectant can be described as:

- reacting in any laundry/bathroom waste solution (regardless of composition);
- low product cost;
- low ancilliary equipment cost;
- ease of application of disinfectant (prepacked in sachets or blocks);
- coloured (to provide an indicator of presence).

The trials carried out in this study with (1) chlorine tablets and (2) a disinfectant "Process 946N"(a quaternary ammonium product) identified the chlorine tablets as the more suitable product for the purposes of greywater disinfection. The experiments were done using laundry greywater for toilet flushing at site 2 (Clifton Hill). The residents at sites 1 and 3 chose not to chlorinate their toilet flushing water.

6.5.2.1 Chlorine Tablets

To identify the best method of application and dosing the chlorine tablets were placed in several locations in the toilet flushing tank. The best results were achieved when the tablet was in a floating dispenser and fully submerged in greywater. The levels of residual free Cl were equal to or more than 3 mg/L. The microbiological tests for total and faecal coliforms using Oxoid Dip Slides indicated absence of these microorganisms. These results were confirmed by testing disinfected greywater samples in the Fairfield Hospital laboratory (see Table D.3, App.D).

The average volume of greywater used per month for toilet flushing at site 2 was 0.8 kL, and a single chlorine tablet typically lasted for a month. Tablet life would vary depending on both the quantity of greywater being reused and its quality. Quality factors such as high pH, turbidity and presence of organic matter and ferrous ions would also reduce the effectiveness of the disinfection process. It would be beneficial if colouring of the tablets could be introduced as an indicator of disinfectant concentration in the greywater. Disinfecting with chlorine tablets is an easy and simple procedure and is already practiced by householders in domestic applications such as swimming pools. Based on a period of 30 days and a tablet price of $ 2.00 the daily cost of chlorine is equal to $ 0.07. The annual expense for chlorination of greywater for toilet flushing would be approximately $ 24.00 .

The pH of raw and disinfected laundry greywater was measured. The pH values of the raw greywater were in the range of 7.2 - 8.2, after disinfection this range was from 5.5 to 6.6. The more acid conditions led to leaching of zinc from the tank walls of the galvanised steel toilet flushing tank. As a result the greywater samples taken from the toilet flushing tank had very high levels of zinc (up to 7 mg/100 mL). A greywater sample taken before it entered the toilet flushing tank showed a zinc level of 0.1 mg/L indicating that the major source of zinc was the galvanised steel.

Any chlorinated greywater that overflows the toilet flushing tank would not be recommended for irrigation as the low pH levels and the high concentration of chlorine would be harmful to plants, soil and soil biota. Arrangements should be made in the design of toilet flushing tanks to prevent surplus raw greywater from entering the tank thus diverting it for irrigation.

6.5.2.2 "Process 946N"

The second chemical disinfectant tested was "Process 946N", which is routinely used for disinfecting the water in aircraft toilets. Several steps were implemented in order to determine the proper dose and reacting time for applying Process 946N. Microbiological testing of the greywater was done before and after disinfecting for estimating the disinfecting effect. The count of faecal coliform colonies before disinfection was in the range of 0.5×10^6 to 1.5×10^6 . The corresponding count after disinfection was in the range of 1×10^5 to 4.2×10^5. There was a reduction in the number of colonies but the values were still well above the required safety levels. A two or four hour contact time (see Section 5.5.2) did not produce any difference in the sampling results. The sachets dissolve almost instantaneously and last about a week and act as a bacteriostatic agent and less as a disinfectant.

Despite the number of beneficial properties that "Process 946N' has (eg. easy to dose, coloured, safe on metal surfaces, and a solution pH of 9), the results of the microbiological tests clearly indicated that "Process 946N" cannot be efficiently used for disinfecting greywater for toilet flushing. The expected cost of this disinfectant is a prohibitive $0.29 per day or approximately $ 100 per year.

6.5.2.3 Summary of Findings

- The tests on greywater showed that it can be heavily contaminated and should not be used for toilet flushing without being adequately disinfected. If no effective and suitable disinfectant is used the option of using greywater for toilet flushing should not be practised.
- The heterogenic nature of greywater poses a major difficulty in identifying an optimum disinfectant because of the variability in microbiological quality (due to different pathogens in different households) and physical and chemical parameters (because of the great variety of washing and cosmetic products).
- The difference in the volumes produced and volumes needed and the patterns of production and usage make the dosing of the disinfectant a complicated task.
- The chlorine tablets proved to be a feasible way of disinfecting greywater. No microorganisms were isolated from the disinfected greywater. With regard to the material of the tanks, it should be non corrosive (eg. plastic, fibreglass, etc.) or at least should be coated to prevent corrosion.

- "Process 946N" showed that this product can stop growth but is unlikely to kill the microorganisms in the solution.
- Greywater that overflows a toilet flushing tank after being disinfected is not recommended for irrigation use as harmful effects on the environment (plants, soil, soil biota, etc.) could result.
- Arrangements should be made in the design of the toilet flushing tanks to prevent surplus raw greywater from entering the tank thus diverting it for irrigation.

6.5.3 DISPOSABLE FILTERS (ONE USE ONLY)

The results of microbiological tests indicated (see Section 6.3.3) that contact with greywater should be avoided and the safest way to reuse it is for irrigation using subsurface distribution systems.

The reusable filters at the experimental sites required regular servicing at least once a week regardless of the source of greywater (bathroom or laundry) and each service required a minimum of 15 - 20 minutes. Sometimes, depending on the activities in the household, the filter system needed servicing twice a week. An important factor to be considered is the disposal of the filter residue which should be directed to the sewer or the garbage bin. Gully traps are not always suitable for cleaning filters. Some filter elements need to be washed under a pressurised water flow and unless a householder took special care the residue could end up on the surface of the lawn which poses a health risk.

These findings highlight the need for disposable-type filters which would be quick and easy to change and would not pose an unacceptable health risk. In general, filters should:

- have an efficient filtering capacity;
- be of a low cost;
- have a large surface area (requiring less frequent changing);
- be incorporated in an in-line filter housing.

Tests were conducted with three different filter materials ("Cleaning cloth" filterbag, "Geotextile" filtersock, and "Nylon stocking" filter) in order to assess their efficiency and suitability for use as disposable filters in greywater systems. Filter characteristics are presented in Table 4.2 The disposable filters were weighed before being used and again after being used and sundried.

6.5.3.1 "Cleaning cloth" filterbag

The "Cleaning cloth" filterbag ruptured after the third or fourth filtering cycle to an opening 7 cm long, and after this the gathered material got washed off the inside of the filter indicating that this type of material is not suitable for a disposable filter.

6.5.3.2 "Nylon stocking" filter

The "Nylon stocking" filter demonstrated very satisfactory results. Thanks to its elasticity this type of filter provided an expanding surface area as more residue was collected and could effectively filter greywater for up to 3 weeks. The price per filter was $ 0.32 and it is readily available on the market.

6.5.3.3 "Geotextile" filtersock

The "Geotextile" filtersock also exhibited very good filtering capability. This material comes in a number of different diameters, and the one used in the experiment was 100 mm. Because of its smaller openings (0.18-0.43 mm), the "Geotextile" filtersock collected more material per event and could be used for up to 2 weeks. According to the product description this material has the advantage of not promoting as much biological growth as nylon material. The price of this filter was $ 0.50 but would possibly decrease if the filter was produced in commercial quantities.

6.5.3.4 Summary of Findings

It can be concluded that both "Nylon stocking" and "Geotextile" filtersock types of filters can be successfully used with greywater reuse systems. In general, the main advantage of the disposable filters is in the area of health and environmental safety. From a health point of view this is the best way to minimise contact with greywater and reduce the risk of infection.

6.6 SYSTEM PERFORMANCE RESULTS

The following section summarises the results of the weekly monitoring and servicing of the experimental greywater systems and continuing evaluation of the performance of their components. Some of the difficulties encountered during the design and installation of the systems are also reviewed in this section.

6.6.1 DIVERSION ARRANGEMENTS

All the diversion arrangements functioned well. Attention should be paid to the position of the tee on a vertical pipe (see Section 2.2.3). The newly designed diversion arrangement (see Section 4.3.1.1) performed satisfactorily. The low ground clearance available with some houses presented installation difficulties. The connection of gravity scours of surge tanks back to the existing sewer presents difficulties because of elevations and in some cases is impossible. Emptying of the tanks may need to be done by pumping. Venting of the systems and connecting overflow pipes to sewer in retrofit situations can require substantial extra plumbing work and materials, particularly if there is little choice of tank location. Some of these difficulties may be eliminated and substantial savings in labour and material costs achieved where greywater systems are installed integrally with the plumbing system in new houses.

6.6.2 REUSABLE FILTERS

As already discussed in Section 6.5.3 the screening and filtering devices required a regular time commitment for servicing. It was observed that filter clogging was very site specific and depended on factors such as type of clothes washed (regarding their lint producing ability), type of detergent (liquid or powder), type of household appliance (clothes washing machines with gentle performance), and individual habits of the residents.

To assess performance and the effect of the greywater source, flywire filters were analysed for the amount of material gathered after one week's use. Filters were dried in the oven at 85°C for 18 hours before and after use and the residue weighed. It was observed that typically the laundry greywater produces 2 to 4 times more residue material than the bathroom greywater. Laundry powder detergents typically contribute more residue material per wash than liquid detergents, particularly when used in excess and some of the particles fail to dissolve during the washing process.

The regular servicing requirements for reusable filters are influenced by mesh size and are summarised in Table 6.8. Performance of disposable filters is discussed in Section 6.5.3.

Table 6.8 - Servicing Requirements of Reusable Filters

Stage of process	Type of Filter	Mesh size	Frequency of cleaning
STAGE 1 (Preliminary)	Metal strainer	2.3 mm	After every second use.
	"Hair share"	0.9 mm	After every second use.
STAGE 2 (Intermediate)	Fly wire mesh screen	1.45 - 1.88 mm	One to two weeks
	"HI-FLO" filter	1.0 mm	One to two weeks
	"Leaf canister" filter	0.9 mm	One to two weeks
	Stainless steel screen	1.3 mm	Twice per year
STAGE 3 (Final)	"Amiad" mesh filter	0.2 mm	Once a week.
	"Arkal" disc filter	0.17 mm	Once a week.
	Irrig. tube filter-19 mm	0.3 - 0.5 mm	Once or twice a week.

In favourable circumstances (eg. very gentle clothes washing machine) the "Flywire mesh screen" can operate for six to eight weeks without cleaning.

In general, almost all the permanent filters and screens functioned adequately. The only exception was the irrigation tube filter (DN=19mm) which proved to have insufficient surface area and filtering capacity. The initially installed 100 micron mesh and 110 micron disk elements of the in-line irrigation filters ("Amiad" and "Arkal") suffered almost instantaneous clogging and had to be replaced at a very early stage of the research program with the next larger size of 200 micron mesh and 170 micron disk elements. The "HI-FLO" filter and the "Leaf canister" filter demonstrated very high performance. They provided sufficient surface area and the opportunity to eliminate tanks in gravity fed systems. It is recommended that the "Leaf canister" filter casing should be made of non-transparent plastic, to prevent the growth of green algae.

Some health risk exists for the person who cleans filters and simple protective measures need to be taken (eg. wearing gloves and possibly face protection). This risk could be avoided by using automatic backwashing filters of appropriate size (with the backwash water disposed to sewer). Indications are that such a filter would have a high initial cost but the operating costs would be no greater than for disposable filters.

6.6.3 TANKS

The collection/surge tanks provide a housing for the pump and the filtering devices, but in general present a number of difficulties. Physically, tanks require space which is either limited or unavailable (in retrofit situations), especially for the typical one storey houses of Melbourne. It is not uncommon for their optimum siting to conflict with existing services or, if located beneath a dwelling, lack of clearance often presents installation difficulties. Above ground tanks located exterior to the dwelling may have undesirable visual impact, whilst those that are buried must be anchored. All tanks must be easily accessible for cleaning.

Typically a tank would have five to six openings (inlet, outlet, overflow, vent, scour, and in some cases fresh water supply) to comply with the requirements of AS 3500. During the design and installation of the greywater systems it became apparent that site-specific characteristics dictated unique tapping and venting arrangements for each site. If tanks are used attention needs to be paid to tank material selection. Extra long-lasting chlorine tablets were used in this study to disinfect greywater for toilet flushing and this led to the problem of zinc being leached from the tank walls. The material of the tank or any coating used would need to be resistant to disinfectants and corrosion.

Where pumps were used to empty partially buried tanks there was always a 50 to 80 mm residual of greywater left on the bottom of the tank. The same problem occurs if the scour or an outlet pipe protrudes above the bottom of the tank. In time, as more particles settle, the bottom layer becomes a sludge with high numbers of microorganisms which may not have ideal conditions for growth but can survive for a long time. To avoid this problem tanks should have a hopper type floor sloped to the scour with a sump provided for any pump.

These difficulties together with the requirements that a collection/surge tank needs to be vented, have a sealed access opening, have warning signs, and comply with local health and plumbing by-laws, makes the design and installation of tanks a specialised, time, cost and labour consuming task.

It can be seen that collection/surge tanks have the advantage of providing a temporary storage and housing for the pumps and filters, but have attendant difficulties. For systems that do not require pumping, collection/surge tanks should be avoided. This will simplify the system design and reduce substantially the cost for materials, labour and time for installation.

6.6.4 IRRIGATION SYSTEMS

The assessment of the design and performance of irrigation systems was based on a number of parameters monitored throughout the research program such as condition of the grass, moisture content of the soil, and operational and control requirements for the different systems. All these factors were strongly related to site-specific conditions such as soil type, vegetation irrigated and type of irrigation system installed. A summary of the vegetation irrigated and the predominant grass cover is presented in Table 6.9. Details about greywater distribution systems are presented in Table 4.3.

Table 6.9 - Type of Vegetation and Grass cover Irrigated with Greywater

Site	**Source of greywater/ Type of irrigation**	**Vegetation and Grass cover Irrigated**
Site 1 (Balwyn)	Laundry greywater/ Gravity irrigation Bathroom greywater/ Pressure irrigation	Tall Fescue (Festuca arundinacea) Ryegrass (Lolium perenne)
Site 2 (Clifton Hill)	Bathroom greywater/ Pressure irrigation	Buffalograss (Stenotaphrum secundatum) Kikuyu (Pennistum clandistinum) Couchgrass (Cynodon dactylon) Lemon tree
Site 3 (Malvern)	Bathroom and laundry greywater (combined)/ Pressure irrigation	Native plants and Shrubs
Site 4 (Strathmore)	Laundry greywater/ Gravity irrigation Bathroom greywater/ Gravity irrigation	Tall Fescue (Festuca arundinacea) Perennial Ryegrass (Lolium perenne) Lemon tree Native shrubs

SITE 1 (BALWYN)

The type of soil at this site was silty sandy top soil and silty fine to medium sand as subsoil. The best results were achieved in zones B and C which have pressure irrigation. Through the whole irrigation season the condition of the grass was very good, the moisture content and the efficiency of greywater distribution were adequate. In zone A (again pressure irrigation) only one third of the area achieved good results; the remaining part was dry , primarily due to the presence of a large Golden Elm tree which would be expected to be drawing moisture from the soil and the root zone of the turf. In the gravity zone F the results were satisfactory, but zone E remained dry which can be attributed to a number of trees around the zone as well as the spacing of the irrigation lines.

SITE 2 (CLIFTON HILL)

At site 2 the soil was black clayey silty top soil and black/grey silty clay as subsoil. The results achieved in zones P and Q (having pressure irrigation) were good except for the areas close to the large Eucalypt trees. The condition of the grass was good and the moisture content and efficiency of greywater distribution were satisfactory. For zones M and N (with gravity irrigation) the condition of the grass was good but there were some dry areas around the trees and along the buffer zone. The spacing between the lines and uneven gravity flow distribution could have also contributed to this. The lemon tree in the front lawn was irrigated with greywater (from the bathroom) and no adverse effects were apparent after two irrigation seasons.

SITE 3 (MALVERN)

The type of soil at site 3 was grey/brown silty sand as top soil and subsoil, on top of which was a 50 mm layer of mulch. The greywater system was a pressure one. The condition of the native garden after one irrigation season was good, the moisture content and distribution efficiency were very good. A longer period of time is required for complete assessment of the effects of greywater on native plants.

SITE 4 (STRATHMORE)

At site 4 the type of soil was grey silty top soil and grey/brown clayey silt as subsoil. The greywater distribution at this site was solely by gravity. The best results regarding grass condition, moisture content and efficient distribution were achieved in zone A. This can be attributed to the spacing between the lines, the short lengths of the branches and the method of manual control for each line with a gate valve. The gate valve control proved to be the most efficient method of gravity irrigation control. For zones B and C there were some slightly dry areas especially at the ends of the lines. The results in zone D were very satisfactory. The shrubs surrounding the mini-leach field have grown significantly and no adverse effects were manifested after this one irrigation season. The greywater applied on them was from the laundry. In contrast, the lemon tree (planted a year ago), irrigated with laundry greywater, did not show much growth. The Kourik type of system trialled in zone C, which used a mobile supply hose for feeding each line in turn, proved to be time consuming and required a special commitment to change the supply hose location before each washing cycle. In addition, there is a potential for gradual clogging of the lines as some soil particles and leaves occasionally fall into the irrigation pipes where the supply hose enters. The buffer zone of one meter on the high side of the irrigation area remained extremely dry and some of the grass in this zone died.

In general, no ponding or surface run off was observed at any of the experimental sites during these two irrigation seasons. The monitoring of the moisture content of the soil was carried out with tensiometers at 300mm, 600mm and 900mm depth in the buffer zones at Balwyn and Malvern. The results indicated no subsurface lateral seepage of greywater towards the buffer zones. Based on these observations it can be concluded that the buffer zone would not have enough moisture for a uniform growth of a lawn. It is suggested that the buffer zones which are likely to remain dry in lawn areas, should be re-planted with shrubs or other plants and irrigated independently with tap water if necessary.

6.6.5 CONTROL EQUIPMENT

The correlation between the rainfall measurements and the quantities of greywater reused at sites 1 and 2 indicated that the "Rain bird" type rain sensors provided an adequate and effective method for pump control of the irrigation systems. At the other two sites (3 and 4) only a rain gauge was available to aid in the control of the irrigation system by the resident and no run off or ponding was observed. In order to reduce the complexity of the greywater system the latter method provides sufficient control assistance for irrigation needs. However, for some homeowners with gardening experience the use of such devices would not be necessary.

A comparison was made between the pressure irrigation systems and gravity fed systems. Pressure irrigation has the advantages of independent automatic pump switch control, uniformity of distribution of flow and minimum restrictions on the layout and length of the irrigation lines. The deficiencies are the higher complexity and consequent cost of the system, the need for surge tanks, the use of electricity and the requirement for more frequent maintenance checks on the pump system.

In contrast, the gravity fed systems rely on manual control which requires time and commitment for regular operating of the valves, have some deficiency in uniformity of the distribution of flow, and restrictions on the length of the irrigation lines. The advantages of manual control are that it reduces the complexity and the cost of the system, eliminates the need for surge tanks and there are no pump-related expenses and maintenance.

6.6.6 PROBLEMS AND OPERATIONAL DIFFICULTIES

A serious problem encountered at the three sites using greywater for toilet flushing was the occurrence of offensive smells during the very hot summer days in November and December 1994. When the temperatures were above 30°C, regardless of the source of greywater (bathroom or laundry) the odour could be smelt both in the toilet flushing tank and inside the toilet room. The smell can occur even if the greywater has been disinfected.

Highly coloured laundry greywater can produce an unpleasant visual effect. In some cases laundry greywater was coloured green or red, or whatever colour the washed clothes were. This presents an aesthetic and social problem, especially where there are visitors to the house. At times there can be scum layers and detergent foam in the toilet bowl.

At site 1 and 2, where DN 20 copper pipe was used outside the dwellings and connected to DN 15 copper pipe inside the dwellings to supply the toilet cisterns, the filling time was excessive (see Table 6.10). This arrangement was adopted due to the retrofit circumstances and the ease of connecting to the existing toilet cistern plumbing. At site 3, where solely DN 20 copper pipe was used to supply the cistern, the filling time was more satisfactory. A maximum filling time of about 2 minutes is considered adequate.

Table 6.10 - Time for Filling of the Cisterns at the Experimental Sites

Site	Time to fill in the cistern		Volume of cistern
	Full flush	Half flush	
Site 1 (Balwyn)	6 min 40 sec	4 min 35 sec	11/6 L
Site 2 (Clifton Hill)	5 min 16 sec	3 min 37 sec	9/4.5 L
Site 3 (Malvern)	2 min 37 sec	1 min 56 sec	6/3 L

No significant build up of scum was observed in the toilet cisterns, but a thin scum line did appear in all three cisterns. However, at site 1 and 2 there were a few occasions when the toilet cistern supply line became blocked and required flushing. At site 3 the inside of the cistern was lined with a thin slimy film of brownish colour.

6.7 SUMMARY OF FINDINGS

Based on the experience gained from this project the following difficulties and problems can be identified. Careful consideration should be given to these in the design of greywater systems in the future.

6.7.1 POSSIBLE DIFFICULTIES WITH DESIGN AND INSTALLATION

A number of difficulties were encountered when a greywater system was designed and installed. These can be summarised as:

- Insufficient hydraulic head for a gravity irrigation system and the consequent need to use a pump,
- Floor level outlets near to ground level - resulting in collection tanks being installed below ground level and the need for ground anchoring,
- Specific requirements for tank materials, especially for toilet flushing tanks,
- Provision of adequate screening and filtering of greywater,
- Provision of adequate disinfection of greywater for toilet flushing,
- Provision of an appropriate level of irrigation system control,
- Design of gravity irrigation systems which provide reasonably uniform flow distribution,
- Subsurface irrigation systems are labour intensive and expensive.
- A general requirement should be that all systems are fail-safe and provide for greywater to be automatically directed to sewer whenever a blockage or system malfunction occurs.

In addition to these, in retrofit situations some of the following difficulties might occur:

- Limited or unavailable floor clearance precluding utilisation of all greywater sources,
- Site specific tank inlet and outlet requirements leading to difficulties in achieving a one-design all-purpose tank,
- Long collection, distribution and overflow pipe lines,
- Difficulty in connecting the scour back to sewer,
- Selection of tank location to avoid interference with existing services eg. gas, sewer, water, stormwater.

Many of these difficulties can be successfully avoided if the greywater reuse system is included in the initial design of a house prior to its construction.

6.7.2 POSSIBLE PROBLEMS WITH OPERATION AND MAINTENANCE

Operational and maintenance problems that may be encountered include:

- Filter maintenance is time consuming and requires a constant commitment,
- Disposal of filter residue in an appropriate manner,
- Health risk involved for persons cleaning and changing filters and need of adequate protection measures,
- Difficulty of access to filter units in under-floor tanks,
- Need of strong resident interest and motivation for proper operation and maintenance of the systems.

In addition there are some specific difficulties related to the different systems:

(a) For toilet flushing greywater systems:

- Long filling time of the cisterns, unless adequate supply pipe size or hydraulic head is provided,
- Occasional smell, foam, greywater colouring and scum layers in the WC bowl,
- Complications introduced by the variability of greywater quality,
- Ability to provide adequate dosing of disinfectants and maintenance of appropriate concentrations.

(b) For irrigation greywater systems:

- Selection of detergents and soaps to minimise any likely environmental problems,
- Need of strong resident commitment for regular control of gravity irrigation systems with manual valve control.

CHAPTER 7 ECONOMIC EVALUATION OF GREYWATER REUSE

7.1 GENERAL

Cost - benefit analysis is an important component in water industry planning. It facilitates the careful planning, conduct and documentation of water conservation programs for the benefit of both water utilities and the public. This part of the research project provides an analysis of the costs and water savings associated with greywater reuse systems, and the implications for Melbourne domestic water consumers under the current water tariff strategy.

7.2 COST OF GREYWATER SYSTEMS

In general, the costs for a greywater system can be classified as follows: (1) design costs and permit fee, (2) installation costs, (3) operation and maintenance costs. The design costs depend greatly on the suitability of the site and the complexity of the system. If greywater reuse becomes a legal practice, it would be expected that a permit would be necessary to construct an appropriate system and that there would be a fee. The installation costs would include materials and labour. These would be site and system specific. In some cases the owner might prefer to do part of the work, but for some specific components of the system a licensed specialist (plumber and/or electrician) would be required. The operating costs include electricity, disposable filters, and disinfectants. For systems with pumps and other ancilliary equipment it may be necessary to meet the cost of repair or replacement parts.

The installation costs for the four experimental systems established in this project are shown in detail in Table 7.1. It should be noted that at each of the sites additional costs were incurred for instrumentation comprising the measuring and monitoring equipment previously described. Because of the experimental nature of the installed systems (especially for sites 1 - 3) and the need for maximum flexibility and control, the installation costs for these systems were higher than would be expected for a typical domestic greywater reuse system. On the other hand, a substantial amount of site-specific design work has not been costed and included, and if these systems were to be designed on a commercial basis, design costs would

Table 7.1 - Itemized Costs of Greywater Experimental Systems

	Site 1			Site 2			Site 3			Site 4			Self installed (range)	Professional job (range)
	Materials	Labour	Total	Materials	Labour	Total	Materials	Labour	Total	Materials	Labour	Total		
Diversion, plumbing, tanks, etc.	1438	1030	2468	1821	975	2796	426	1395	1821	519	560	1079	426 - 1821	1079 - 2796
Irrigation systems	1250	2000	3250	1150	2000	3150	470	985	1455	692	1100	1792	470 - 1250	1455 - 3250
Research metering and instrumentation	1508			1373			490			426				
TOTAL COST of exper greywater systems	**4196**	**3030**		**4344**	**2975**		**1386**	**2380**		**1637**	**1660**			
			7226			**7319**			**3766**			**3297**		
Cost without meters and instrumentation	2688	3030	5718	2971	2975	5946	896	2380	3276	1211	1660	2871	896 - 2971	2871 - 5946
Self installed systems (incl only materials)	2688			2971			896			1211			896 - 2971	
Professional inst systems (incl materials & labour)			5718			5946			3276			2871		2871 - 5946

need to be added. Site 4, although designed to trial several types of subsurface irrigation arrangements, can be regarded as more closely representative of the "typical" household installation. It should be noted that site 4 has one of the simplest possible greywater systems, which involves neither collection tanks nor pumping, and that the greywater is reused only for irrigation. Based on the experience of this research, indicative ranges of diversion costs were developed as shown in Table 7.2. It would be expected that these costs would be 30% to 70% lower if the homeowner installed the system, but under current regulations this work would have to be done by a licensed plumber.

Table 7.2 - Typical Greywater System Diversion Arrangements and Range of Costs

Code	DESCRIPTION OF THE ELEMENTS INCLUDED	Total cost $
	FOR IRRIGATION PURPOSES**	
D 1	Gravity greywater system diversion arrangement from either bathroom or laundry including pipework, in-line filter, and labour.	**300- 450**
D 2	Gravity greywater system diversion arrangement from both bathroom and laundry including pipework, in-line filter, and labour.	**450 - 650**
D 3	Pressurised greywater system diversion arrangement from either bathroom or laundry including pipework, pump, tank(s) and filters, power point installation and labour.	**750 - 1000**
D 4	Pressurised greywater system diversion arrangement from both bathroom and laundry including pipework, pump, tank(s) and filters, power point installation and labour.	**1050 - 1300**
	FOR TOILET FLUSHING PURPOSES	
D 5	Gravity greywater system diversion arrangement from either upper floor bathroom or laundry including pipework, tank, filter and labour.	**500 - 650**
D 6	Pressurised greywater system diversion arrangement from either bathroom or laundry including pipework, pump, tanks and filters, power point installation and labour.	**1100 - 1350**

** - irrigation distribution system pipework not included (for this component see Fig. 7.1)
Note: Where irrigation and toilet flushing reuse systems are both installed, it may be expected that the total cost would be somewhat less than the sum of two values taken from the table above, because of savings resulting from combined pipework and other components.

The plumbing and diversion costs are likely to vary widely with the suitability of the site and the system complexity. Typically the lowest range of costs refer to systems with a minimum level of automation. Such systems would definitely impose substantial demands on householders' commitment, attitudes, motivation, memory and time available for system operation, manual control and proper maintenance.

The costs of the irrigation system will depend on the available area for irrigation, but in general the subsurface irrigation arrangements including accessories may cost:

$ 5 - $ 8 / m^2	- if installed by a householder
$ 15 - $ 20 / m^2	- if installed by a contractor.

In future, as contractors become more familiar with these installations it would be expected that the cost would drop. Some examples of the sizing and costing of typical greywater systems are shown in Appendix F. Graphs providing information about greywater production, greywater demand, costs of irrigation systems and water savings have been developed in this project for the preliminary sizing and costing of greywater systems and are shown in Fig.7.1.

A comparison of a gravity system using corrugated slotted pipes and a pressure system using "Dripmaster 17" for an irrigation area of 100 sq.m. indicated that they are similar in price. The advantage of the pressure system is that it could operate automatically and require minimal time for control. The disadvantages are the need for a surge tank for housing the pump, the need for power and (possibly) a more complicated control system, and the additional maintenance requirements for the pump. The advantage of the gravity system is that it would not need a pump with its associated complications, but it has the disadvantage that it would probably require more time input for the control of the greywater distribution, as it would rely more on manually operated valves.

The factors that influence the cost of greywater systems can be summarised as follows:

- suitability of the site,
- complexity and level of automation of the system,
- number of greywater sources that can be tapped,
- area available for irrigation
- whether installation is carried out by a householder or a professional tradesperson.

The cost of these systems would be substantially less for installations in new dwellings. The cost of diversion arrangements, pipes and labour would be less as these elements would be incorporated in the initial design and construction and would not add much to the cost of a

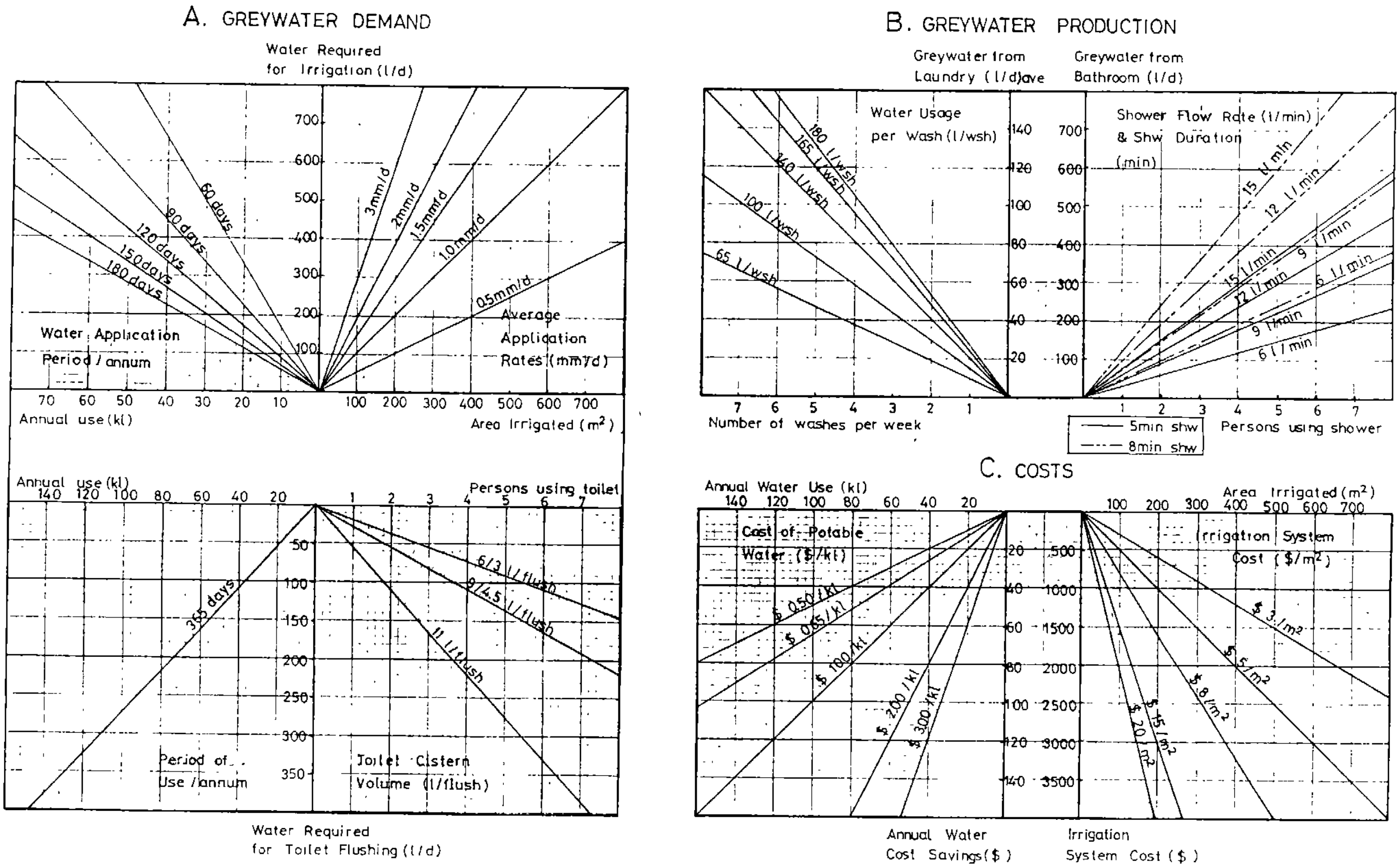


Figure 7.1: Greywater system design & costing graphs

conventional plumbing system. However, the usual expenses would still be incurred for other components including filters, tanks, pumps and irrigation systems.

The costs in Australian dollars of systems described in overseas studies (see Section 2.3.3) are summarised in Table 7.3. It should be noted that the "do it yourself" system included only a clothes washing machine as a source and a small irrigation area based around two 3 m long mini-leach fields. Systems which include all sources are more complicated and are installed by professional personnel. It should be noted that these systems are currently available on the market in the USA.

Table 7.3 - Typical Ranges of Greywater System Costs (reported overseas-see Table 2.7)

	Do it yourself	**Professional job**
Low tech system for CWM* greywater	$ 300 - $ 750	$ 1100
Low tech system usually for all sources	-	$ 1370 - $ 2050
Fully automatic system for all sources	-	$ 3425 - $ 6850

* CWM - stands for clothes washing machine.

A comparison with the costs of systems used in this research program shows that in the lower end of the range the prices are similar. For the more complicated (but still not fully automatic) systems utilising a number of greywater sources, the costs of the experimental systems were higher than those reported in the literature. One of the reasons might be due to different irrigation areas being included in the price. No precise comparison can be made as areas for the overseas systems were not specified in the literature. Fully automatic systems for irrigation with greywater were not evaluated in this project, as simple designs were sought. With regards to the costs of toilet flushing systems using greywater, no comparison can be made with systems used in this project as the costs reported in the literature are only for fully automatic systems.

7.3 GREYWATER SAVINGS

As presented in Section 6.2 the water savings achieved at the experimental sites were in the range of 21 kL to 38 kL per year. Calculated with the current price of water in Melbourne of 65c/kL, the maximum saving would be $25 per year. Because of a number of technical and other constraints involved in the project (see Section 6.2), the experimental sites did not demonstrate the highest possible water savings. But even when calculated on the basis of theoretical possible savings of 77 kL/a for an average household (see Section 2.3.1.5) the maximum annual saving is only about $50 (see Table 7.4).

Table 7.4 - Theoretical Possible Savings in Dollars

	Max GW reuse (kL/a)	Saving in dollars ($)
1. Garden use only	52 kL/a	$ 34
2. Toilet flushing only	49 kL/a	$ 32
3. Garden and Toilet flushing	77 kL/a	$ 49

Operating costs

The operating costs involved in greywater reuse depend on the type of system but typically include components such as disposable filters, disinfectant or electricity for a pump. These costs are presented in Table 7.5.

Table 7.5 - Operating Costs

	Cost/item	Typical life	Annual cost
Disposable filter	$ 0.32	3 wk	$ 5.55
Disinfectant (chlorine tablets)	$ 2.00	1 month	$ 24.00
Electricity for a pump (irrig. only)	-	-	$ 6.00

Operating costs alone in some cases are likely to exceed potential water cost savings. It can be expected that detergents suitable for greywater reuse might initially have a higher price (eg. 1 litre of potassium based detergent might cost $ 6 - $ 7 compared to $ 1.50 - $ 4.80 for the commonly used liquid detergents), which would add to the operating costs.

7.4 COST-BENEFIT STUDIES

Three case studies were developed for typical greywater systems (see App. F) and the findings are summarised in Table 7.6. These examples confirmed reports in the literature that domestic scale greywater reuse systems are not economical under current water tariff charges.

Table 7.6 - Summary of Findings for three Case Studies *

Case Study	Number 1		Number 2		Number 3	
Total capital cost of GW system	$ 1700		$ 1550		$ 2300	
Annual water savings in kL	32 kL		27 kL		57 kL	
Annual water cost savings in $	$ 21		$ 18		$ 37	
Effective interest rate in %	4 %	8%	4%	8%	4%	8%
Total annual cost of system	$ 130	$ 190	$ 110	$ 160	$ 150	$ 220
Benefit/cost ratio	0.16	0.11	0.16	0.11	0.25	0.17
Required water cost in $	$ 4	$ 6	$ 4	$ 6	$ 3	$ 4

* - See Appendix F for details.

The aim of the studies was to determine costs and benefits for typical greywater systems and compare these with the required cost for water in order for a householder to break even. However, a break even point might not be a sufficient incentive for a homeowner to install a greywater system.

The total capital costs for the sample greywater systems were in the range of $ 1550 to $ 2300. Based on effective interest rates of 4% and 8% per annum and a reasonable system lifespan (of 15 years for pumps, tanks and irrigation system components, and 50 years for diversion plumbing works, valves, power points and stands) the total annual cost of the three greywater systems was in the range of $ 110 to $ 220 (if the annual operating costs are included). Based on the water savings estimated in the range of 27 to 57 kL, and costed at $ 0.65/kL (the current water charge in Melbourne) the annual cost savings for water would be from $ 18 to $ 37. The cost of water therefore would need to be in the range of $ 3 to $ 6/kL for a householder to break even.

On this basis it is concluded that greywater systems of the type considered in this report are not economically viable in Melbourne at the present time or in the foreseeable future.

7.5 POTENTIAL COMMUNITY COSTS AND BENEFITS

Although the foregoing analysis indicates that greywater reuse is not likely to be an attractive economic proposition to an individual householder, a much broader analysis of the costs and benefits to the whole community of widespread greywater reuse as a water conservation option might lead to a different conclusion. Benefits of greywater reuse in this context are likely to be highly dependent on the level of market penetration that could be achieved. In general, reduced water consumption in domestic premises, achieved by reusing greywater, has the potential to:

- reduce the volume of potable water to be stored and distributed,
- defer the cost of water supply augmentation,
- reduce the volume of wastewater to be treated,
- lower wastewater treatment costs, and
- reduce pollution levels in receiving waters.

Although not within the scope of this study, it is recommended that a broader economic investigation, as indicated above, should be undertaken to establish the benefit/cost ratio for widespread adoption of greywater reuse systems for the community as a whole.

In view of the low benefit/cost ratio for individual property owners and depending on the results of such a study, water authorities might consider offering incentives to consumers to encourage them to install reuse systems, eg. reductions in sewerage rates for houses with greywater reuse systems, waiving of permit and inspection fees, etc. The routine introduction of reuse systems in new dwellings could also be promoted.

Another option which might be considered (but which was not investigated in this research) is the implementation of larger greywater reuse systems in multi-dwelling residential buildings such as units, cluster housing, motels and hotels, where economies of scale and combined maintenance may have advantages over the use of small systems in individual houses.

7.6 CONCLUSIONS

- The cost of installing greywater systems varies greatly with their complexity and capabilities, as well as with site-specific conditions.
- Minimal-risk greywater reuse systems of the type studied in this project have the potential of saving water, but at present are not economically viable in individual domestic dwellings because the total costs for installation and operation are very high in relation to the likely annual water cost savings at the current prices of water.
- At present (with the current water tariff of $ 0.65/kL) there is no economic incentive for householders to install greywater reuse systems. If, in future, fresh water resources become very scarce and the price of water increases considerably, such systems may become economically viable.
- It is recommended that a broader economic study should be undertaken to establish the benefit/cost ratio for widespread adoption of greywater reuse systems for the community as a whole.
- If greywater reuse should prove to be a viable option for the community, then water authorities may need to consider providing incentives for homeowners to install appropriate systems.
- The installation of larger systems in multi-dwelling residential buildings or cluster developments might be more economic than for single family dwelling systems. Further research is needed to assess whether such systems offer any financial benefit.

CHAPTER 8: SOCIAL SURVEYS ON GREYWATER REUSE

8.1 GENERAL

One of the objectives of the greywater reuse research project is to assess social attitudes towards reusing greywater in and around the house.

The greywater reuse option for conserving water can be implemented only if the broad public accepts the concept and starts practising it. Acceptance of greywater reuse by homeowners is a key issue for the success of this water conservation concept and it is essential to have precise and more up-to-date information about public opinion.

8.1.1 OBJECTIVES

In general the aims of the social survey were to generate information about the level of understanding of greywater (GW), the attitudes and concerns people have about its reuse, and their information needs in this area.

Specifically, the objectives of the study were to assess :

- the general public's perception of greywater use and acceptable costs for toilet flushing and garden watering;
- the level of education required for the general public to become familiar with, or become proficient in, the use of greywater recycling systems;
- the potential extent, concerns and difficulties of establishing greywater recycling systems;
- the sympathetic customer segment that can be effectively reached in a greywater marketing campaign (eg. retired people, people living in a detached dwelling, inner suburbs, interested in gardening, etc.).

8.2 RESEARCH METHODOLOGY

8.2.1 METHODS

There are two main methods for collecting quantifiable data:

- interviews (of one type or another) and
- self-administered questionnaires (Gardner, 1976).

The essential difference between these two is the presence or absence of an interviewer when the questions are being answered. Both methods have their advantages and disadvantages. The final choice of method depends on the purpose of the survey as well as on factors such as costs, time and personnel involved.

In order to meet the objectives it was decided that the greywater reuse survey would be designed and conducted as two separate forms of social survey : one by telephone and one by mail. Thus by adopting both methods it was possible to obtain a substantial quantity of good quality information, whilst compensating for some of the disadvantages of each of the methods.

8.2.2 ADVANTAGES AND DISADVANTAGES OF INTERVIEWS

The advantages and disadvantages of the two methods were studied with the purpose of finding the best approach for conducing the social survey and analysing its results.

Advantages of interviews

The survey conducted by telephone was an interview type of survey. Some of the main advantages of interviews are:

* **More personal** - The interviewer can answer questions about the purpose and content of the survey.

* **Greater motivation and ease of response** - The presence of an interviewer allows for more explanation. In addition - people find it easier to talk than to write, and therefore give more information. Interviews are preferable for less educated respondents and those for which English is a second language.

***Interviews yield more complete data** - An interviewer can facilitate the understanding of all the questions and ensure that all questions are answered. Trained interviewers can obtain a very high response rate, almost 100 % of the sample (Gardner, 1976). Thanks to this high response rate, interviews are the only way of ensuring a truly random sample.

***Standard procedure and control** - Interviewers can control the sequence of questions and can provide extra information at a precise time before or after a given question. The respondent cannot look ahead and anticipate the trend of the inquiries.

***Interviews can be more valid** - The respondent has to answer immediately and has no time to consult others, and therefore the responses reflect the respondent's own views.

Disadvantages of interviews

There are a number of disadvantages that have to be considered when using interviews.

***Reliability** - Even with very formal interviews reliability can be lower than for questionnaires because the presence of an interviewer can produce response error and bias (Gardner, 1976).

***Validity** - Validity is affected by reliability and cannot be high if reliability is low (Gardner, 1976). Interviews are not usually anonymous, and therefore the respondent may not be completely convinced about the confidential nature of the survey.

***Cost** - Interviews are relatively expensive, time consuming and require trained interviewers. The cost factor may limit the survey to a smaller sample.

8.2.3 ADVANTAGES AND DISADVANTAGES OF QUESTIONNAIRES

Advantages of questionnaires

The advantages of mail questionnaires to some extent compensate for the disadvantages of the interviews.

***Standard procedure and control** - Better standardisation can be obtained by using the printed instead of spoken word. Printing the available response categories makes it easier for more precision in replies. The respondent fills in their own answers and so cannot be misheard.

***Absence of bias** - There are no interviewer errors or bias effects as no interviewer is present.

***Cost** - Questionnaires are less expensive and provide larger samples for lower total cost.

***More convenient to respondent** - The respondent can complete the questionnaire in their own preferred time.

Disadvantages of the questionnaires

There are a number of disadvantages to be aware of when using questionnaires.

***Incomplete sample** - One of the serious disadvantages is the low response rate from questionnaires; it ranges from 15-50 percent as against 70-98 percent for interviews (Dillon et al., 1990). The poor return can be improved by having collection call back, more than once if necessary. Another approach is to have a collector to help if this difficulty should arise.

***Incomplete and inaccurate data** - Items are often omitted. Few people have the motivation to write as fully as they would speak.

***Lack of control, some loss of standardisation** - The respondent may depart from the printed sequence. No control can be exercised for completing the whole questionnaire.

8.2.4. CHOOSING A RANDOM SAMPLE

A sample to be representative should be completely **random** - this means the selection of units for the sample must be without bias; no person must have a greater chance of being selected than any other person.

There are two main principles to be followed in order to draw a random sample:

- Each unit or element in the population must have an equal chance of being included in the sample.
- The selection must be determined entirely by chance - units must be chosen at random.

8.2.5 SIZE OF THE SAMPLE AND STANDARD ERROR

The size of the sample depends largely on the precision required or, in other words, on the margin of error which is acceptable.

The accuracy of the results depends on the size of the sample.

If the sample size n is small, computing a confidence interval for a proportion p must be based on the formula for binomial distributions (Moore and McCabe, 1993). To calculate the 95% confidence interval for a proportion p the following expression can be used:

$$\hat{p} \pm 2\sqrt{\frac{\hat{p}(1-\hat{p})}{n}} \qquad (8.1)$$

where $\hat{p}$ = is the sample proportion, and n = is the size of the sample.

The margin of error in the 95% confidence interval includes random sampling errors only. There are other sources of error that are not accounted for (Moore and McCabe, 1993).

8.2.6 ANALYSING AND INTERPRETING DATA

There are two statistics used in the analysis: **descriptive**, which have to come first, followed by **inferential.** They are both used for interpretation of the results (Gardner, 1976).

Descriptive statistics are used to describe, in quantitative terms, the results of a survey. The totals are called **frequencies** and are presented in tables either as actual counts or given in equivalent percentages. At the descriptive level data can be examined for any **relationships** by cross-tabulating the data. Descriptive statistics may be used even if the sample is not random.

Inferential statistics can be applied only for random samples and preferably a probability sample (that is when the size of the population is known and the probability can be specified). Inferential statistics are used to relate the sample data to the population from which the sample is drawn. This is a process of **estimation** and involves the measurement of **standard error** and **confidence levels** (Gardner, 1976). Another purpose of inferential statistics is to test any apparent differences and relationships to make reasonably sure that they did not show up by chance. This **hypothesis testing** mainly involves significance tests such as "t" and contingency tests.

8.3 GREYWATER REUSE SURVEYS

In order to achieve the objectives of this part of the program, it was initially decided to carry out a survey amongst a reasonable number of Melbourne residents on their attitudes to various aspects of greywater reuse. Subsequently, through co-operation with officers from the Shire of Melton, it became possible to conduct a second survey, in this case of residents in the town of Melton, which is situated in a low rainfall area some 39 kilometres to the west of Melbourne and comprises a little over 10100 households.

The questionnaires for the two greywater reuse surveys were developed in conjunction with the Urban and Social Policy Department of Victoria University of Technology. A pilot questionnaire was tested and the final versions generated consisted of 25 questions. A copy of the final form of the questionnaire for the Melbourne survey together with sample characteristics of the respondents, full definition of the term greywater as given by the respondents, and a map of Melbourne regions appear in Appendix G. The corresponding information for the Melton survey is in Appendix H.

8.3.1 GREYWATER REUSE SURVEY FOR MELBOURNE

The greywater survey amongst residents of Melbourne was conducted by telephone. The size of sample used was 300. Based on the confidence intervals shown below, a sample of this size is considered representative for the 1034000 households of Melbourne (provided that the sample is random).

Telephone numbers were randomly generated from the Telephone Directory by choosing the first private number on every second page. The sample was intended to be random and will be treated as such, although it might not be completely random owing to non-response and other losses from the sample.

The 95% confidence interval was calculated using the formula (8.1) for binomial distributions. In the worst case 50% 'yes' and 50% 'no' answer for 300 responses, the 95% confidence interval is [0.44-0.56], ie. $n = 300$ and $\hat{p} = 0.50$.

When the expected majority opinion is likely to be 66% in favour or an overwhelming 90%, the 95% confidence interval (CI) for these two proportions will be respectively:

Proportion	Standard error	95% CI
0.66	5.47	[0.61-0.71]
0.90	3.46	[0.87-0.93]

Summary of findings

From the responses of the survey participants, it is possible to make the following summary:

- The general public preference for greywater reuse was more in favour of garden watering than toilet flushing. A summary of the answers is presented in Table 8.1 and illustrated in Figure 8.1.

Table 8.1 - Interest in Greywater Reuse (Melbourne survey)

	For watering garden			For toilet flushing		
	L'dry GW	B'rm GW	Kitch. GW	L'dry GW	B'rm GW	Kitch. GW
Yes	**40.3%**	**43.0%**	**42.0%**	**11.7%**	**11.3%**	**6.0%**
No	**29.0%**	**26.7%**	**26.7%**	**47.0%**	**47.0%**	**55.3%**
Don't know	**30.3%**	**30.0%**	**31.0%**	**40.7%**	**41.0%**	**38.0%**
Not stated	**0.3%**	**0.3%**	**0.3%**	**0.7%**	**0.7%**	**0.7%**

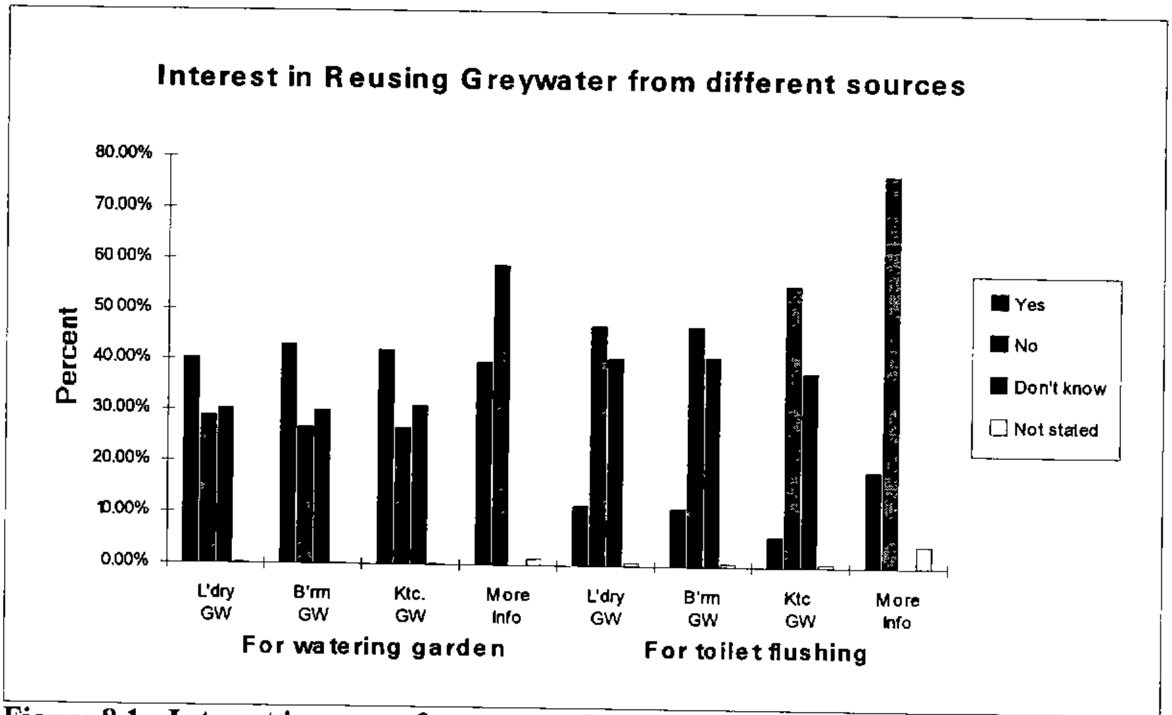


Figure 8.1 - Interest in reuse of greywater from different sources (Melbourne survey)

Regarding different sources of greywater there was similar preference for laundry, bathroom or kitchen greywater to be used for garden watering. The interest in using greywater for toilet flushing was significantly lower, with kitchen greywater being the least preferred source.

- The public awareness of the term "Greywater" is very low (7%), with correct understanding of greywater being 4%. Definitions of the term as given by the respondents are presented in Appendix G.

- The demand for more information was higher for the garden watering option (39.7%) compared to toilet flushing (18.7%). This is graphically presented in Figure 8.1.

- There were a number of reasons for the interest in greywater reuse. These can be summarised in four groups in order of preference:
    - Conserving water
    - Saving money
    - Saving water & money
    - Other

- The aspects of most concern to respondents were:
    - Detergents and effects on the environment
    - Grease & fats in kitchen greywater

- A sympathetic customer segment that can be effectively reached in a greywater marketing campaign is difficult to determine at this stage. The following preliminary results can be presented.

    (1) Interest in greywater reuse for garden watering was higher amongst males compared with females, those aged 40-49, para-professionals and managers/administrators, those retired, and those owning their house.

(2) Interest in greywater reuse for toilet flushing was higher amongst females compared with males, those aged 40-49, managers/administrators and professionals, those who listed their occupation as home duties, and those owning their house.

- The payback period acceptable to respondents was in the range of 2-3 years. A considerable number of respondents (21.7%) answered "Don't know" and outlined the need for more information before answering this question. The results are illustrated on Figure 8.2.

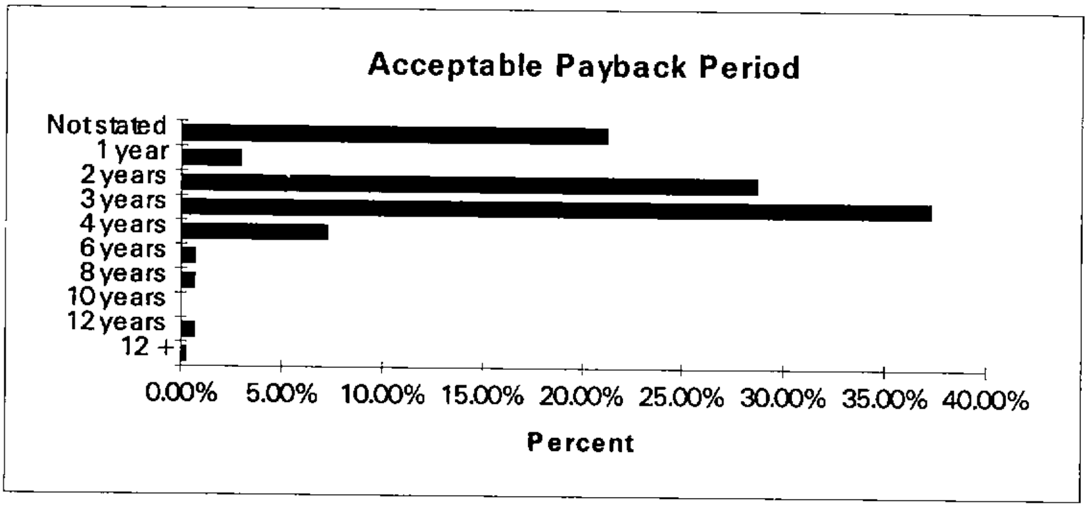


Figure 8.2-Acceptable payback period for greywater systems (Melbourne survey)

8.3.2. GREYWATER REUSE SURVEY FOR MELTON

The survey amongst residents of Melton was conducted by mail. Nine hundred and ninety questionnaires were sent together with postage paid envelopes to facilitate the return of the completed questionnaires.

Addresses were randomly generated by selecting every eighth address from the data base of rate numbers of Melton households.

Number of questionnaires sent	990
Number of the responses	146
Percentage of return	14.75%

Using again formula (8.1) the 95% confidence interval was calculated. In the worst case 50% 'yes' and 50% 'no' answer for 146 responses, the 95% confidence interval is [0.42-0.58], ie. $n = 146$ and $\hat{p} = 0.50$.

When the expected majority opinion is likely to be 66% in favour or an overwhelming 90%, the 95% confidence interval (CI) for these proportions will be respectively:

Proportion	Standard error	95% CI
0.66	7.84	[0.58-0.74]
0.90	4.97	[0.85-0.95]

For a mail survey sent to a list of randomly selected respondents, without any pre- or post-mailing follow-up, typically no more than 10% of the questionnaires are likely to be returned (Dillon et al., 1990).

The response rate of the survey conducted by mail in Melton is 14.75%. As a result of this low response rate the actual sample becomes a sample of self-selected volunteers and as such bears little resemblance to the target random sample. This makes the results statistically not representative for the population from which the sample was drawn. The reasons for the low response may be low motivation, lack of time, no interest in the topic, not confident in answering surveys, etc.

No strong conclusions can be made and findings should be regarded as tentative as the sample was not completely random. However, the 146 returned surveys showed that 14.75% of the 990 households contacted were interested in conserving water. The analysis of the results presents their perceptions and concerns, and indicates the preferred segment for a future marketing campaign.

Summary findings

From the responses of the survey participants, who were a sample of self-selected volunteers, it is possible to make the following summary:

- The general public preference for greywater reuse was more in favour of garden watering than toilet flushing. A summary of the answers is presented in Table 8.2 and illustrated in Figure 8.3.

Table 8.2 - Interest in Greywater Reuse (Melton survey)

	For watering garden			For toilet flushing		
	L'dry GW	B'rm GW	Kitch. GW	L'dry GW	B'rm GW	Kitch. GW
Yes	**85%**	**88%**	**62%**	**64%**	**70%**	**38%**
No	**4%**	**5%**	**26%**	**15%**	**11%**	**40%**
Don't know	**11%**	**7%**	**11%**	**21%**	**18%**	**20%**
Not stated	**0%**	**0%**	**0%**	**1%**	**1%**	**1%**

Kitchen greywater was the least preferred source for both garden watering and toilet flushing. Laundry and bathroom greywater were similar in preference.

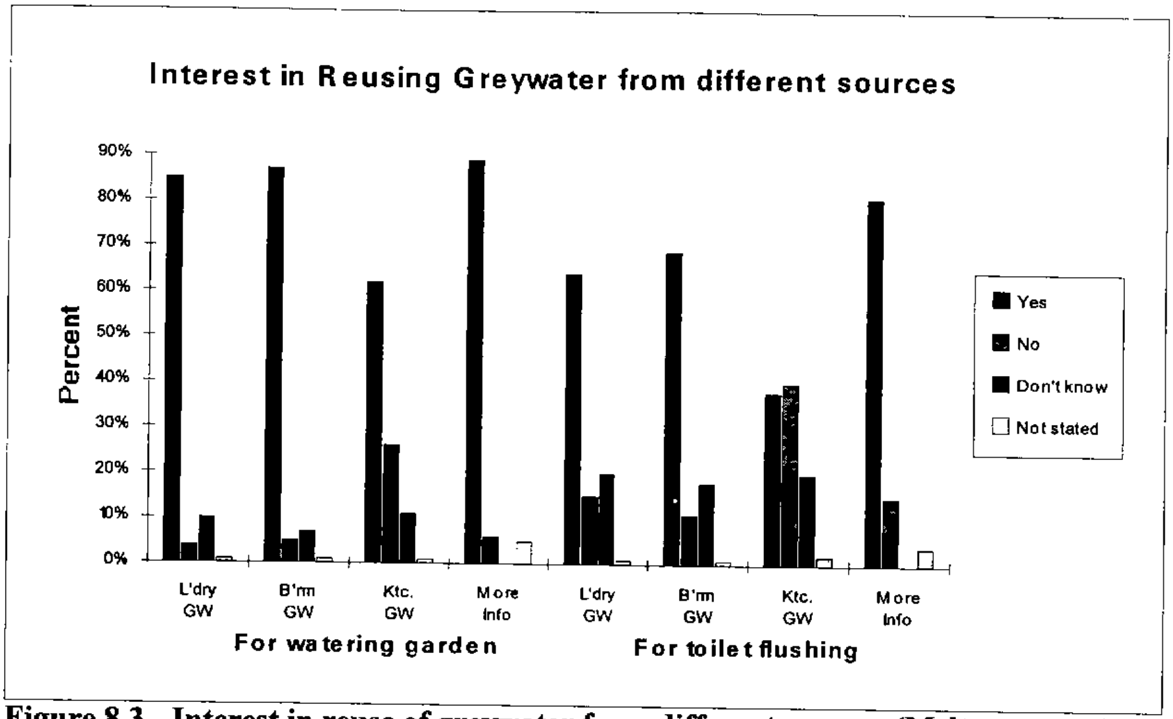


Figure 8.3 - Interest in reuse of greywater from different sources (Melton survey)

- The public awareness of the term "Greywater" was (42%), with correct understanding of GW being 23%. Definitions of the term as given by the respondents are presented in Appendix H. It should be noted that a definition was given in the beginning of the questionnaire - thus there is a possibility of bias.

- The demand for more information was higher for the garden watering option (90%), compared to toilet flushing (81%). This is graphically presented in Figure 8.3.

- There were a number of reasons for the interest in greywater reuse. They can be summarised in four groups in order of preference:
  - * Conserving water
  - * Saving money
  - * Saving water & money
  - * Other

- The aspects of most concern to respondents were:
    - * Detergents and effects on the environment
    - * Unhygienic effects and smells

- A sympathetic customer segment that can be effectively reached in a greywater marketing campaign is difficult to determine at this stage. Interest in conserving water was higher amongst: those aged 40-49 and 70-79; professionals, para-professionals, managers/administrators and "other" (this category includes people with home duties, retired and pensioners and other).

- The payback period most acceptable to respondents was 2 years and the second most favourable 4 years. A considerable number of respondents (15%) answered "Don't know" and outlined the need for more information before answering this question. The results are illustrated on Figure 8.4.

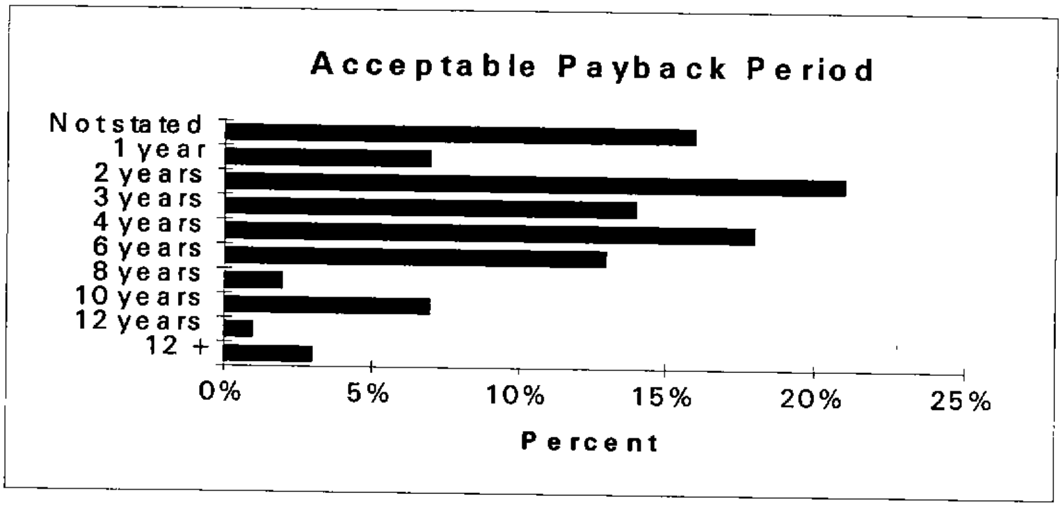


Figure 8.4 - Acceptable payback period for greywater systems (Melton survey)

8.4. COMPARISON OF THE RESULTS

8.4.1 MELBOURNE AND MELTON SURVEYS

As already stated the Melbourne survey can be regarded as unbiased whilst the Melton survey respondents were self-selected volunteers and most probably people that were already familiar with or interested in greywater reuse.

Melton residents showed very high interest in receiving more information and a clearer understanding of the differences between the greywater sources (with kitchen water being the least preferred one). This fact may be an indication of better knowledge of the issues involved in greywater reuse.

Another distinct difference was in the payback period acceptance. Melbourne respondents preferred a 2-3 years payback period, whilst for Melton there was a wider spread with a preference for 2 to 6 years.

The public awareness of the term "Greywater" in Melbourne was very low (7%) with correct understanding being only 4%. In contrast, the respondents of Melton showed higher awareness of the term (42%) and higher understanding (23%). There is a possibility of bias as the definition was given in the beginning of the questionnaire.

A summary of the current watering methods used by the respondents in Melbourne and Melton is presented on Figure 8.5 and 8.6. Predominant methods were hand-held hose, followed by movable sprinklers and fixed sprinklers.

Regarding currently practised conservation methods, respondents who were already using greywater for watering the garden in Melbourne were 1% and in Melton were 23% (see Figure 8.7 and 8.8).

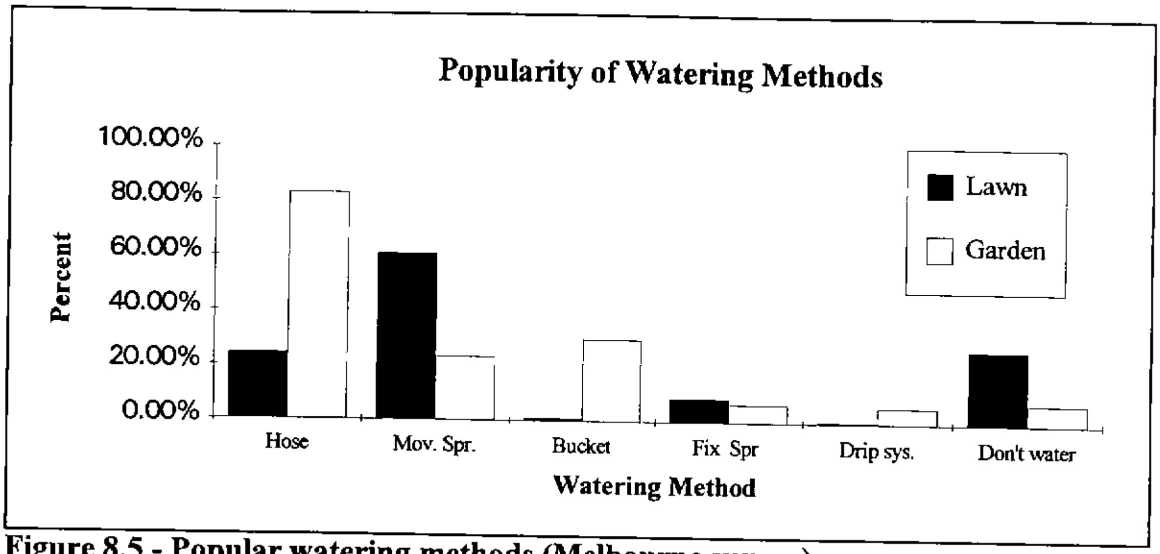


Figure 8.5 - Popular watering methods (Melbourne survey)

For Melbourne the most popular method for irrigation of lawn is movable sprinklers (61%), followed by hose (24.3%) and fixed sprinklers(8.7%). More than a quarter of the respondents (27%) "don't water" their lawn. For garden irrigation the most popular method is hose (83%), followed by bucket (30%) and movable sprinklers (23.3%).

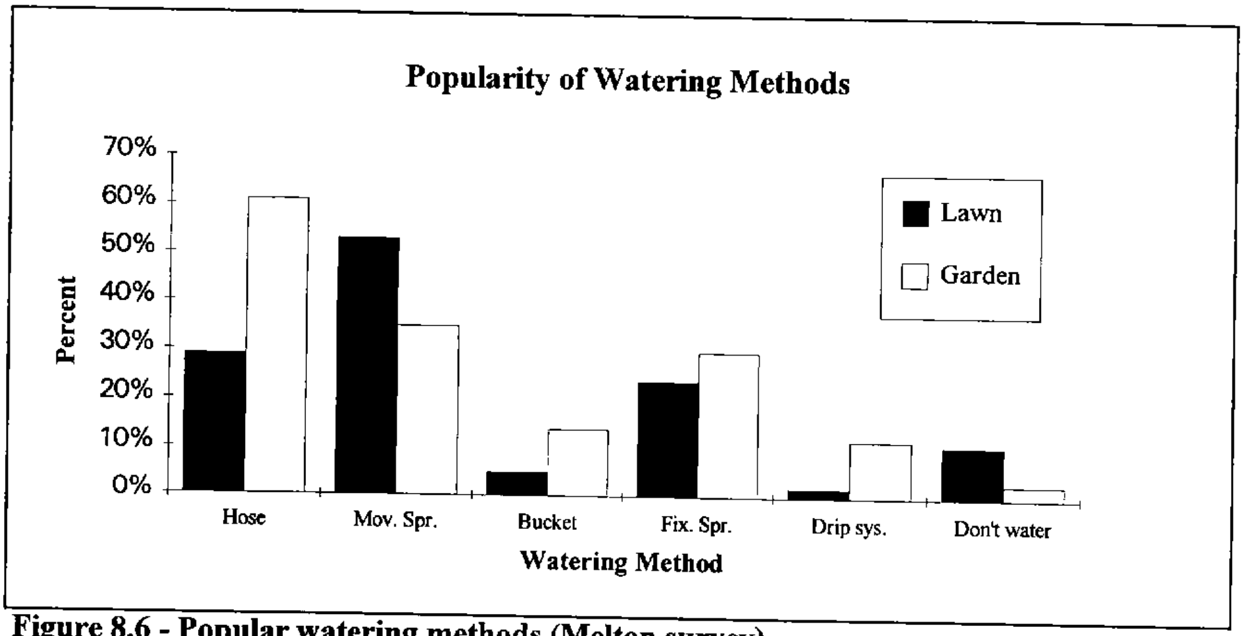


Figure 8.6 - Popular watering methods (Melton survey)

For Melton the most popular method for irrigation of lawn is movable sprinklers (53%), followed by hose (29%) and fixed sprinklers (25%). For garden irrigation the most popular method is hose (61%), followed by movable sprinklers (35%) and fixed sprinklers (31%).

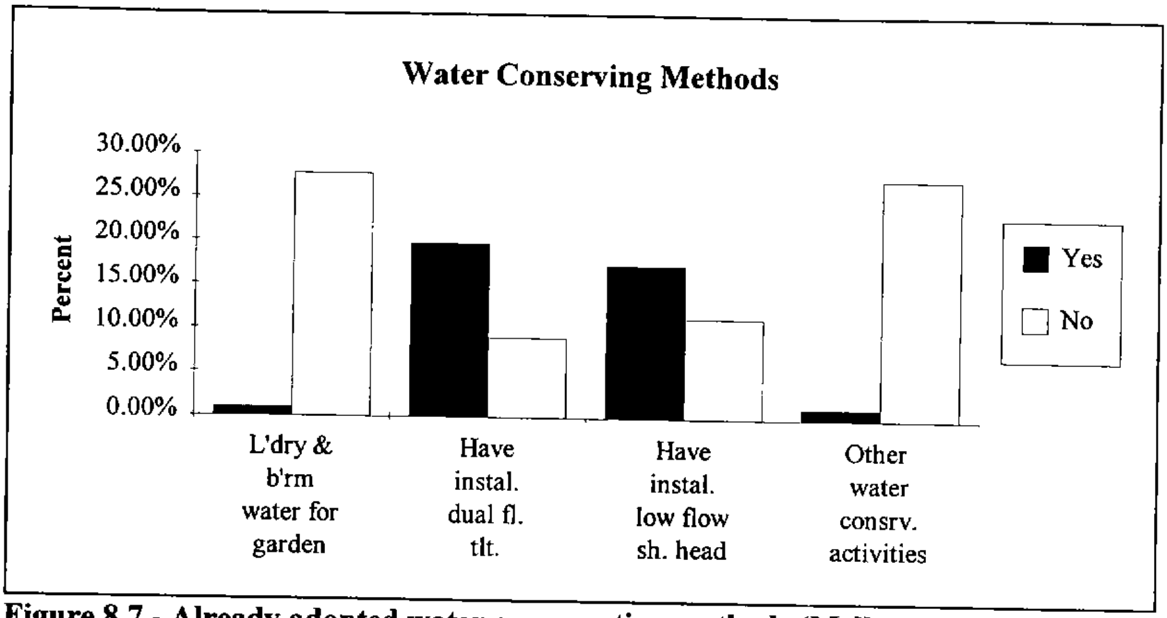


Figure 8.7 - Already adopted water conservation methods (Melbourne survey)

In Melbourne about a fifth of the respondents (19.7%) have installed dual flushing toilet cisterns. The next most popular method is installation of low flow shower heads (17.3%). Use of l'dry & b'rm water for watering gardens is practised by (1%) of the respondents.

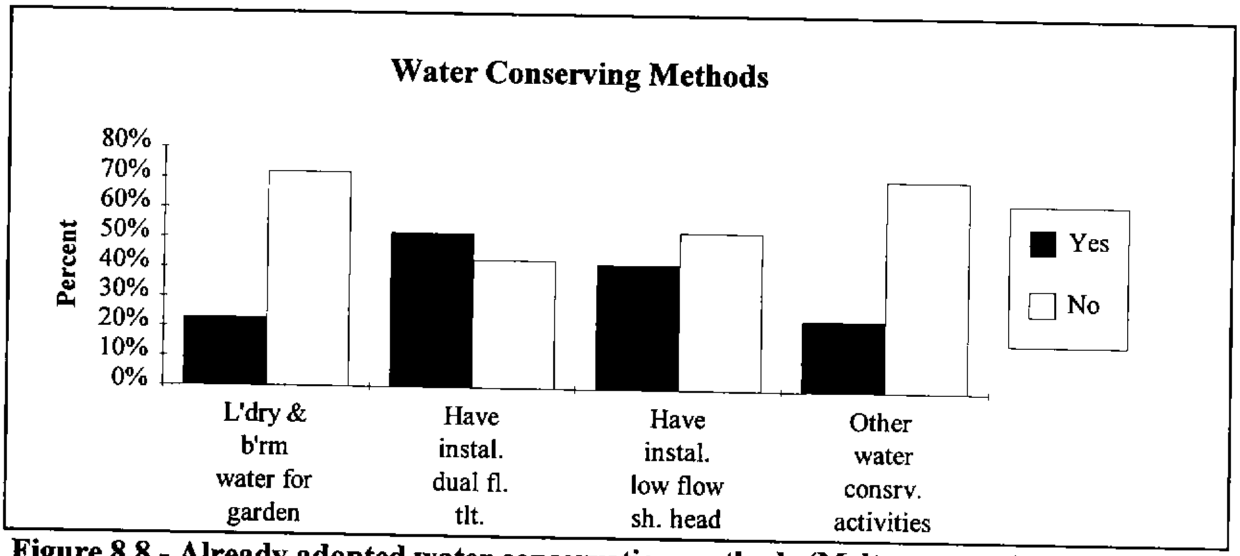


Figure 8.8 - Already adopted water conservation methods (Melton survey)

In Melton about half of the respondents (53%) have installed dual flushing toilet cisterns. The next most popular method is installation of low flow shower heads (42%). Use of l'dry & b'rm water for watering gardens is practised by (23%) of the respondents.

8.4.2 COMPARISON WITH PREVIOUS SURVEYS

A comparison of Melbourne greywater survey results with the results of a previous survey investigating the interest in reuse of treated effluent for irrigation (refer Table 2.8), indicated that greywater reuse had less support than the treated effluent reuse. This may be an indication that the community prefers water conservation options that are introduced and controlled by water authorities and where the equipment is installed and maintained by authorised personnel.

The public survey into Garden Watering Systems (refer Table 2.9) found that 5% of owners were currently practising recycling as a means of watering their gardens compared to 1% shown in this study. The difference could be the result of recent discussions on radio and television that greywater reuse is not legally permitted and should not be practised without consulting the local authority.

8.5 INTERVIEW SURVEYS OF THE PROJECT SITE RESIDENTS

The residents of the four experimental sites were surveyed with regards to their understanding of greywater recycling concepts, their attitudes towards having a greywater system and their experience in servicing the system. Household members over the age of sixteen years were interviewed. The total number of people surveyed was eight. To observe the development in the residents' attitudes towards greywater reuse, the survey was divided into three groups of questions referring to the period: (1) before installing the greywater systems at the sites, (2) after installing the greywater systems, but when serviced by research personnel, and (3) of two months in which the residents were responsible for the servicing of the greywater systems. The findings of the survey can be summarised as follows:

8.5.1 GROUP 1 - Initial opinions, attitudes and concerns of the residents and some characteristics.

- Six of the residents were strongly in favour of recycling and had previous experience in food, paper and cardboard, glass,and plastic materials recycling.
- Five of the residents have had an interest in conserving water in and around the house and have made use of dual flush toilet cisterns, low flow shower heads, and one household had installed a rainwater tank.
- Hand held hose, fixed ground sprinklers and movable sprinklers were the most used methods of irrigation prior to installation of greywater systems.
- Six residents had not heard the term "greywater", but had made use of greywater from laundry for watering the garden during drought. The two residents that had heard the term greywater were a teacher and a civil engineer.
- Residents were neutral or in favour of greywater reuse for toilet flushing and interested to find out more about the system and costs involved. The main incentive for greywater reuse for toilet flushing was water conservation. Main concerns were smell and hygiene.
- All the residents were in favour of greywater reuse for garden watering. The only concerns were the soapy water and any possible damage to plants, any accumulation of chemicals in the soil, and any effects on pets (eg. rabbits). Main incentives were water

conservation, optimising the use of natural resources and reducing the need for the construction of new reservoirs.

- Of the residents 50% considered that the payback period was not an important issue and that the saving of water was more important. They considered that an acceptable payback period was in the range of 25-30 years. The remaining 50% of residents specified 4 to 5 years as an acceptable payback period. One resident expected the price of a greywater system to be about $ 1000.
- The age groups of the residents were 16-20, 30-39 and 50-59, the gender was 62% males and 38% females and all were Australia born and of Australian origin.
- All but one of the residents were responsible for the water bill, which made them aware of the price of potable water. All residents were employed and all were white collar workers. With regard to young children in the households, there was only one child under the age of 3 years.

8.5.2 GROUP 2 - Residents attitudes, opinions and concerns after a greywater system was operating for one or two years on their property.

The experience of having a greywater reuse system confirmed and increased the residents' interest in greywater reuse and most of them thought that the practice should be widely adopted. Their interest and understanding of greywater reuse systems increased. However, the residents' preconceived ideas of greywater recycling systems were more simplistic. The actual greywater reuse systems were more complicated and more difficult to install than they originally thought, (eg including pumps, subsurface irrigation, maintenance, etc.) There was one resident who was disappointed and disillusioned with the operation and maintenance activities involved.

Greywater Reuse for Toilet Flushing

- All residents except one were interested to continue reusing greywater for toilet flushing. This one resident stated that they could not see the need for reusing greywater as a means of conserving water and this may be due to the lack of sufficient awareness of the need to conserve water.

- Conserving water and contributing to more sustainable water systems were the main benefits that the residents perceived with this practice.
- The main concerns expressed by residents were:

  - Build up of scum over time when the systems were not used,

  - Developing odour and froth in the toilet bowl,

  - Effort of cleaning strainers,

  - Inability to discharge oils and other nasties in the laundry trough, which was seen as an inconvenience.
- Problems with toilet flushing that were outlined:

  - Slime in the bowl and need for more cleaning,

  - Does not look clean and produces occasional smells,

  - Unaesthetic appearance of the toilet tank on the outside wall of the house,

  - Dye (colouration) of the greywater after washing clothes - a minor problem but a social issue if guests use the toilet.

Greywater Reuse for Garden Watering

- All the residents were prepared to continue using greywater for garden irrigation. Some think that it is a worthwhile practice.
- The benefits that residents found included saving of water, keeping their garden green, and reducing time spent on watering with a hand-held hose. Two residents perceived a substantial saving of water and thought that greywater reuse was the best way to keep their garden green.
- The concerns of residents related to the chemicals in laundry and bathroom products. i.e. would they accumulate in soil; would there be any adverse effects on plant growth; whether in time there would be any problems with clogging of irrigation system emitters.
- Problems identified with the systems were:

  - once the subsurface system is in place you cannot plant a tree in the lawn without disturbing the layout pattern.

  - extra lawn mowing, which is not considered a serious problem,

  - zebra stripe effect in one of the lawns, due to some poor plant growth and dry grass conditions in one of the irrigation zones.

8.5.3 GROUP 3 - Residents attitudes, opinions and concerns after they were responsible for maintaining the greywater system for two months.

All the residents agreed that having to maintain the greywater system affected their views of recycling greywater. Comments included:

- It is another household duty;
- It is quite demanding;
- Time consuming;
- Have to remember to do it;
- The system works well and maintenance is not a problem but have to find time to do it. The cleaning and changing of filters add to the tasks to be carried out each week around the house.
- Cleaning of the filters requires a place to do it (eg. gully trap) and a set method to follow. The strainers in the shower have to be cleaned every day.
- There is a need for a convenient and quick way to divert laundry trough waste to sewer when bleaches were used.
- The laundry trough should not be diverted so that nasties can be discharged to sewer.
- Having a greywater system makes one feel good about saving water.
- Makes one more aware of how much water is used, the mode of using it, and the laundry and bathroom products one uses.
- Makes one think of how to organise the variety of water using activities to optimise savings (eg. not all the washing at the end of the week).
- In hot weather there were smells in the toilet and residents tended to avoid using it, which made the smells worse. In cold weather there was no smell problem.
- The Kourik type of system may fill with leaves and become clogged. In addition, the owner has to remember to move the hose before each laundry wash cycle.
- For the gravity fed systems it is important to have short lengths of distribution trenches so that flow from one shower is sufficient to fill each one. Manually controlled valves at the head of each trench distribute flow better than overflow arrangements between trenches.

8.5.4 <u>CONCLUSIONS AND RECOMMENDATIONS</u> (from the residents' survey)

- The term "greywater" needs to be introduced and explained to the broad public.
- The residents were happy to continue using the greywater systems and expressed strong interest in conjunctive use of greywater and rain water.
- The actual greywater systems were more complex than the residents expected, including more equipment and requiring specific maintenance.
- The laundry trough should not be included in the diversion arrangement for the washing machine if possible.
- There is a need for a manual with instructions for the operation of the system.
- There is a need to improve the aesthetics of the toilet flushing tank and associated pipework.
- The greywater system servicing should not be too time demanding on the householder.
- A valve close to the CWM should be provided to allow the diversion of laundry greywater for reuse or to the sewer.
- There is a need for a simpler system with less equipment. One of the residents was in favour of a hose on the surface for watering the trees.
- The payback period which was considered acceptable after using the system was 6 to 12 years. There were homeowners for whom this was immaterial.
- Disposal of the residue from the filters is a problem and may create a health risk if it is washed onto the surface of the ground, especially in families with young children. The use of disposable filters is preferred.

CHAPTER 9 ASSESSMENT OF THE POTENTIAL RISKS ASSOCIATED WITH GREYWATER REUSE

9.1 INTRODUCTION

The risk to health and the environment will be a major criterion in establishing the feasibility of greywater reuse and setting appropriate guidelines for its reuse.

Health and environmental risk assessment are defined by ANZECC/NHMRC (1992) as follows:

Health risk assessment is the process of estimating the potential impact of a chemical or physical agent on a specific human population under a specific set of conditions.

Environmental risk assessment is the process of establishing the potential impact of a chemical or physical agent on a specific ecological system under a specific set of conditions.

Definitions of health risk assessment vary slightly but a well accepted one is that of the United States National Academy of Science (1983), which says:

> "Risk assessment.....mean(s) the characterisation of the potential adverse health effects of human exposure to environmental hazards. Risk assessments include several elements: description of the potential adverse health effects based on an evaluation of results of epidemiological, clinical, toxicological, and environmental research; extrapolation from those results to predict the type and estimate the extent of health effects in humans under given conditions of exposure; judgements on the number and characteristics of persons exposed at various intensities and durations; and summary judgements on the existence and overall magnitude of the public-health problem. Risk assessment also includes characterisation of the uncertainties inherent in the process of inferring risk."

The health risk and environmental consequences of a particular economic activity have to be weighed against the economic and social benefits. Quantification of health risks assists the control of environmental health hazards by providing valuable information on the identity and characterisation of the risk. Based on this information appropriate control guidelines and strategies can be developed.

9.1.1 GENERAL BACKGROUND

The purpose of the study is:

(a) to review the methodology of risk assessment studies of similar reuse systems,

(b) to analyse the factors that have to be considered in a risk assessment of greywater reuse,

(c) to present the results of other relevant studies on risk assessment,

(d) to assess the existing data,

(e) to develop the pathways exposure models for each specific reuse (eg. irrigation, toilet flushing)

(f) to summarise the conclusions and recommendations,

(g) and to outline areas for further research.

The two applications of greywater garden watering and/or toilet flushing are of a different nature and the risk assessment analysis has to be done separately. The reuse of greywater for watering the garden and/or lawn might have adverse effects both on humans and on the environment (eg. soil, plants, animals, soil biota). Therefore there are two aspects to be addressed in assessing the risk associated with this application - public health risk and environmental risk. The reuse of greywater for toilet flushing may pose a significant risk to the people using it, but adverse effects on any ecological system are unlikely to occur. Therefore this application requires only public health risk assessment. A schematic view of the above analysis in presented in Figure 9.1.

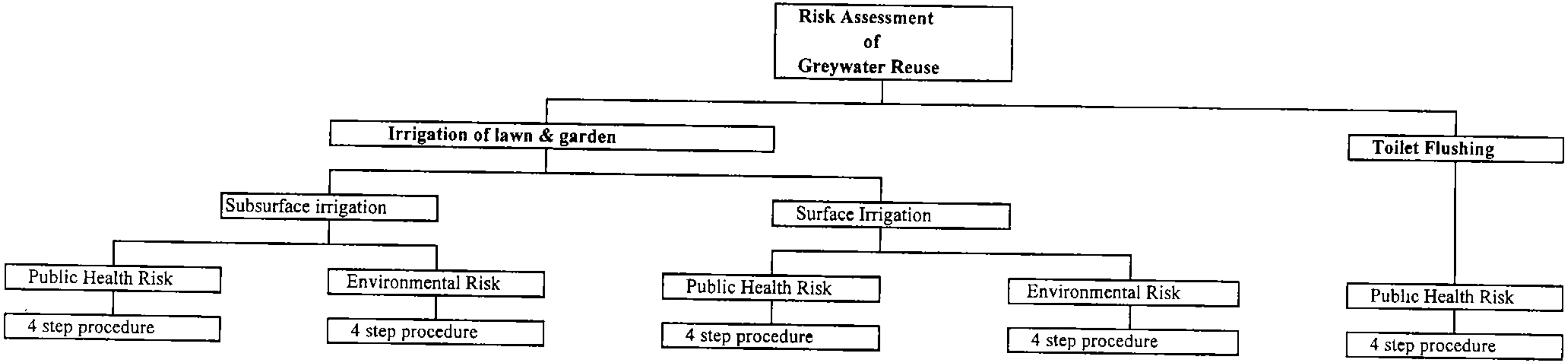
There are four main steps to be followed in a risk assessment process:

(a) Hazard identification,

(b) Dose response determination,

(c) Exposure assessment,

(d) Risk characterisation.



Generalized four step procedure

1. Hazard identification	GW quality - hazards
2. Dose response determination	Dose response models
3. Exposure assessment	Exposure pathways
4. Risk characterization	Risk quantification

Figure 9.1 - Overview of Risk Assessment Process

9.1.2 DESCRIPTION OF THE FOUR MAIN STEPS FOR PUBLIC HEALTH RISK ASSESSMENT

9.1.2.1 Hazard identification

Hazard identification is accomplished by observing and defining:

- the agents of concern
- the type of adverse health effects they have in humans.

Important components of hazard identification are:

- morbidity or illness rates
- severity and duration of illness
- mortality rates

and the epidemiological evidence showing the links of various diseases with specific pathogens.

The following key factors should be considered when assessing the potential health risks of wastewater reuse:

(1) A disease causing agent must be present and in sufficient concentration to produce disease (the dose);

(2) A susceptible host must come into contact with the agent in a manner that results in infection and disease.

Subsidiary factors which should be studied include length of the infection cycle, persistence outside the host, paths of transmission, and median infective dose rates. The disease causing agents of major concern are indicated below.

(a) Microbial Agents

A variety of pathogenic enteric bacterial, viral and parasitic agents may be found in wastewater. Their number and type depends on the enteric disease morbidity in the people generating the wastewater. The majority of these pathogens can be transmitted via food, through water, or from person to person. It can be expected that the general sanitation practised by the community can have a significant impact on disease morbidity and respectively on the concentration of pathogenic agents in wastewater.

(b) Chemical Agents

Chemicals in wastewater may be classified as inorganic and organic. The degree of impact that chemicals in reused wastewater will have on the exposed users is normally greater when there is a greater industrial input to the wastewater stream (Maynard, 1992). In the case of greywater, there is no industrial input and with sensible use, any harmful chemicals can be excluded at the source by informed users. Therefore there should be no significant adverse effects on humans due to chemical agents.

9.1.2.2 Dose-response assessment

Dose-response assessment describes the relationship between the magnitude of exposure (or the dose of an agent administered) and the incidence of an adverse health effect in an exposed population. The risk of infection can be defined as a mathematical probability of infectivity from a given unit dose or exposure (Rose, 1992). There are two components of this probability of infection model which help to characterise the risk: (1) the level of exposure and (2) the interaction of the particular pathogen and the host (defining the dose response curve). It has to be noted that the host population tested would influence the model outcome because of differing susceptibilities to the pathogens which depend on general and specific immunity, genetic factors, age, sex, and other underlying diseases or conditions.

Dose-response experiments have been conducted where human volunteers were exposed to known average concentrations of several microorganisms of concern including bacteria, protozoa and viruses (Regli et al., 1991). Beta-Poisson and exponential models as shown in equations 9.1 and 9.2 below have been developed for determining low dose risks.

Beta - Poisson model
$$P = 1 - (1 + \frac{\mu V}{\beta})^{-\alpha} \qquad (9.1)$$

Exponential model
$$P = 1 - \exp(-r\mu V) \qquad (9.2)$$

In each case P represents the probability of infection. In equation (9.1) the parameters α and β characterise the dose-response curve, μ represents the mean concentration of organisms in a water, and V represents the water volume sampled. In equation (9.2), r is the fraction of the ingested microorganisms that survive to initiate infections (Regli et al., 1991). These models provide the tools necessary for evaluating data for assessment of the potential public health risks associated with exposure to pathogens in wastewater.

The best point estimates for a number of studies were summarised by Rose (1992) (see Table 9.1).

Table 9.1 - Probability of Infection Models and Best Fit Dose-Response Parameters

Organism Parameters	Best Model	Model Parameters
Echovirus 12	beta - poisson	$\alpha = 0.374$; $\beta = 186.69$
Rotavirus	beta - poisson	$\alpha = 0.26$; $\beta = 0.42$
Poliovirus I	exponential	$r = 0.009102$
Poliovirus I	beta - poisson	$\alpha = 0.1097$; $\beta = 1524$
Poliovirus III	beta - poisson	$\alpha = 0.409$; $\beta = 0.788$
Giardia	exponential	$r = 0.02$
Entamoeba	beta - poisson	$\alpha = 0.128$; $\beta = 0.581$

Source: Rose, 1992

9.1.2.3 Exposure assessment

Exposure can be defined as contact with a chemical, physical or biological agent. Exposure assessment is the estimation (qualitative or quantitative) of the magnitude, frequency, duration, route and extent of exposure to a contaminant.

Infectious disease can be transmitted through direct or indirect contact (eg. infected individual or infected media, respectively). The major route of infection for most enteric pathogens is direct person to person contact. However, in the case of greywater reuse, the most probable routes might include:

- ingestion of contaminated water; or
- inhalation of infectious water droplets or aerosols; or
- bodily contact with previously contaminated media (filters, family pets, soil).

The typical routes of exposure to contaminated soil are:

- intake/ingestion of soil (by mouth);
- inhalation of dust;
- skin absorption.

For the purpose of exposure assessment ANZECC/NHMRC (1992) adopted figures of soil intake for different age groups (see Table 9.2). They are conservative estimates which overestimate typical exposures. According to Langley (1993), inhalation and skin routes of exposure are considered relatively insignificant (in most circumstances). For greywater reuse they are unlikely to be significant.

Table 9.2 - Soil Intake Estimates

Age (years)	Soil Intake (mg/day)
0 - 1	negligible
1 - 5	100
5 - 15	50
Adult	25

Source: ANZECC/NHMRC, 1992.

The following points are important in the process of exposure assessment for contaminated sites (Langley, 1993) and are also of relevance to this study.

(i) Children usually receive a higher exposure to soil contamination per unit body weight than adults.

(ii) Soil ingestion by small children is usually by far the most important exposure route.

(iii) One exposure route will possibly predominate.

(iv) All exposure pathways must be considered in assessing the level of health risk as each will contribute to the overall risk.

9.1.2.4 Risk characterisation

Risk characterisation uses the information from the dose - response and exposure assessment steps to establish the expected frequency of the adverse effects. It involves quantification of risk and determination of acceptability.

For evaluating the risk associated with exposure to microbial contaminants the Quantitative Risk Assessment (QRA) approach can be used. This is a relatively new approach that has been used in risk assessment of the quality of drinking water (Rose and Gerba, 1991, Regli et al., 1991) and of reused waters (Rose, 1992). QRA uses the levels of pathogens detected in wastewater and the risk assessment models (discussed in dose-response) to establish the risk of infection through exposure to reused waters. In order to use the QRA approach, pathogen types and numbers in the water must be determined.

People during their daily lives are engaged in different activities which involve some level of risk of incurring serious injury or death. Even if not engaged in any particular activity, there is still constant exposure to the risk of death from heart attack, cancer, vehicle or air travel accident, or even an accident while walking along the street. Levels of risk vary from country to country and according to how careful people are in performing their daily activities. The approximate levels of risk of death associated with a number of activities are presented in Table 9.3. The figures are typical averages based on information reported in the literature for Australia and countries similar to Australia.

Table 9.3 - Levels of Risk Associated with Selected Daily Activities.

Accident Type Causing Death	**Risk Level Per Year**
All causes (1)	1 in 130
Heart disease (1)	1 in 450
Cancer (2)	1 in 550
Occupant of motor vehicle (4)	1 in 5,000
Pedestrian struck by automobile (4)	1 in 20,000
Fire or burns (4)	1 in 40,000
Drowning (2)	1 in 50,000
Poisoning (4)	1 in 60,000
Air travel (all forms)(4)	1 in 100,000
Electrocution (3)	1 in 200,000
Civil aviation (4)	1 in 1,000,000
Lightning strike (4)	1 in 2,000,000

Source: (1) Australian Bureau of Statistics, Death, Victoria, 1990.
(2) Australian Bureau of Statistics, Death, Australia, 1990.
(3) Australian Bureau of Statistics, Causes of Death in Australia, 1990.
(4) Prospects and Problems in Risk Communication, William Leiss (ed), Univ. of Waterloo, Univ. of Waterloo Press, 1989.

There appears to be a significant risk of death associated with typical every day life activities (eg. occupant of motor vehicle) and the majority of people are exposed to this risk.

Acceptability of risk differs from individual to individual, and also depends on whether the risk is voluntary or involuntary. A voluntary risk of 1 in 5000 and an involuntary risk of 1 in 1000000 are typically considered as acceptable levels of risk. Regarding acceptability of risk the US Environmental Protection Agency has stated that an infection rate in the community of 1 in 10,000 population is a socially acceptable risk (Brisbane City Council, 1994).

9.1.3 METHODOLOGY FOR HEALTH RISK ASSESSMENT

A number of studies have involved a risk assessment on reuse of wastewater, greywater or sewage sludge. These include studies by Rose and Gerba (1991), Enferadi et al. (1986), Gibbs and Ho (1993), and the USEPA (1992 b). It may be concluded from these studies that a complete risk assessment is a complex process requiring:

- a wide range of specialists,
- time consuming, expensive and complicated computer modelling of a range of different factors, and
- a substantial number of samples and test results.

For example the risk assessment procedure used by Enferadi et. al (1986) for the health risk assessment of biological toilet systems and greywater treatment was the probability matrix technique (PMT), which required two groups of health experts. Members of the first group included bacteriologists, virologists, parasitologists, entomologists, sanitary engineers, and similar professionals who were instructed to make judgements on the probability of problem occurrence. Members of the second group were all physicians who were directed to make judgements concerning the severity of the problems named by the first group. The technique used by the health experts in this study is called the objective decision-making technique. It is especially useful for evaluating new technologies where there is an absence of definitive test information.

In the methodology for exposure assessment and risk management used by the USEPA (1992 b) in determining the pollutant limits for sewage sludge, existing models were adapted and new ones developed to determine the concentration of pollutants. "The models simulated the movement of pollutants into and through the environment with a series of mathematical equations or algorithms", which link "the pollutant disposal or release rates to the concentration of pollutant that moves into the air, water, or land and, subsequently, reaches a target organism (ie. plant, animal and human). Each algorithm in a model represents one exposure pathway through which sewage sludge-borne pollutants enter and pass through or affect an environmental medium"(USEPA, 1992 b). The next steps in the process were to select numerical values for the parameters in the algorithms of each model, to translate the models into computer programs, and where appropriate, to use the models to calculate the numerical limits.

The above example demonstrates the complexity of the risk assessment process, which would require substantial time and expense to be properly carried out. Another requirement is sufficient information on pathogen type and numbers in the media under investigation.

The number of samples and tests performed for the purpose of risk assessment in the various studies was different but always substantial. Rose et al. (1991) analysed nine to ten greywater samples from each of the six families participating in the program. The study carried out by Enferadi et al. (1986) monitored the performance of and analysed samples from nine different greywater systems over a period of 12 months.

In general a complete risk assessment of the potential public health and environmental risks associated with greywater reuse will require similar approaches and a separate major research effort. Because of limitations of time, finance, staff and other resources, it was not possible to undertake such an effort within the current research program. The following material therefore represents an introduction to some of the major aspects of the problem.

9.1.4 VARIABILITY OF GREYWATER

Risk assessment for greywater reuse is an extremely difficult and complex process due to the heterogeneous nature of greywater and the wide range of factors influencing its quality.

There are two main groups of factors responsible for the microbial and chemical composition of greywater:

- Group 1 - factors involved in its production that determine the quality of freshly produced greywater.
- Group 2 - factors involved in its treatment and/or storage that determine its final quality before reuse.

Group 1 factors

This first group includes the factors described in the Brisbane City Council (1994) report as:

- source of greywater(such as kitchen, bath, laundry),
- socioeconomic factors,
- personal hygiene habits and activities (such as gardening or use of cloth nappies),
- types of cleaners and detergents used,
- family composition,
- climate.

There is at least one other factor which should be included -

- health condition of members of the family producing the greywater, and the occurrence of infectious diseases.

Group 2 factors

The second group of factors influencing the greywater quality before its reuse depends on the greywater reuse system (as chosen by the home owner, or as applicable to the specific conditions of the site), as well as the maintenance of the system. Some of these factors are:

- type of treatment involved (eg. filtration, disinfection)
- type of equipment (strainers, filters, collection tanks, vents)
- presence or absence of surge tank (or storage tank)
- distribution system and its components
- maintenance and control of the whole system.

All these factors will vary and be site specific for every greywater reuse case, even though all greywater systems will have to be installed in accordance with appropriate standards and approved by an Authority. Practice has shown that reliance on home owners for maintenance of the systems has not been successful in the majority of cases. Studies reported by the City of Los Angeles (1992) and Enferadi et al. (1986) indicated respectively that (i) up to 80% of the systems were poorly maintained and (ii) most of the greywater treatment systems failed to perform their functions successfully.

The heterogeneous and specific nature of greywater makes a realistic risk assessment extremely difficult and complex. When compared with domestic wastewater that is collected, treated at a sewage treatment plant and then reused, there are important factors which make greywater considerably different in quality. In the case of reused community effluent:

- the mixing of flows from many households averages the chemical and microbial parameters,
- the treatment and the final quality of the wastewater for reuse are controlled by professionally trained people and local Authorities.

Neither of these situations apply in the case of on-site reuse of domestic greywater.

9.2 PUBLIC HEALTH RISK ASSOCIATED WITH GREYWATER REUSE

9.2.1 HAZARD IDENTIFICATION

To identify the potential microbiological agents of concern the quality of greywater has to be addressed. A number of studies that have analysed greywater quality have been reviewed (see Sections 2.5.1.2 and 2.5.2), and have indicated significant levels of total and faecal coliforms and faecal streptococci. Similar results were obtained in this study. Based on this evidence it can be concluded that greywater might contain significant levels of pathogenic microorganisms, similar to the pathogens found in wastewater and wastewater sludge.

Sources of pathogenic contamination in greywater

There are many different potential sources of pathogens in greywater. Some of them are:

- skin cells or human body secretions emitted during bathing/showering,
- clothes washed in a trough or CWM after gardening or active sport activity,
- soiled nappies washed in a trough or CWM,
- clothing or linen washed in a trough or CWM and containing vomit or excretions from an infected person,
- muddy or faecally contaminated childrens' shoes washed in the trough,
- family pets washed in the bath or laundry trough.

It is of interest to note the possible extent of contamination or how many organisms can be introduced in greywater by a gram of faeces. A study by Gibbs and Ho (1993) summarised the typical number of organisms which might be excreted per gram of faeces from an infected individual (see Table 9.4).

Table 9.4 - Estimated Excreted Load of Some Enteric Pathogens

Group	Pathogen	Excreted Load*
Viruses	Rotavirus	10^6
	Adenovirus	NS
	Enteroviruses	10^7
	Hepatitis A	10^6
Bacteria	Campylobacter species	10^7
	Salmonella species	10^8
	Shigella species	10^7
Protozoa	Giardia intestinalis	10^5
	Cryptosporidium species	NS

* - Typical number of organisms per gram of faeces from an infected person. NS - not stated.
Source: Gibbs and Ho (1993)

Bearing in mind the large number of microorganisms that can be introduced in greywater and the low dose of some types of microorganisms (eg., Cryptosporidium) necessary to cause infection, it would appear that greywater can pose a serious risk to human health and it should be carefully assessed.

Microbiological Agents of Concern

Typically in studies assessing the health risk associated with wastewater, greywater or sludge reuse the major microbial agents of concern are viruses, protozoa, and bacteria. Assessing the potential health risk of reclaimed water in Arizona and Florida, Rose and Gerba (1991) analysed the presence and levels of enteric viruses, Giardia and Cryptosporidium. The qualitative risk assessment performed by Gibbs and Ho (1993) suggested that enteric viruses in wastewater sludge pose the most risk, followed by Salmonella and Giardia. The same study on the basis of infection rates in Perth and Melbourne identified Campylobacter, Giardia and Salmonella as the dominant enteric pathogens. Evaluating the microbial quality and safety for reuse of greywater, Rose et al. (1991) investigated the persistence of Salmonella, Shigella and Poliovirus type 1. Findings from these studies are presented in Appendix J.

Based on the above review it might be inferred that greywater, being a wastewater, would have similar microbiological pathogens of concern, although they might occur in smaller numbers and more rarely. More specifically, the microorganisms of concern can be identified as enteric viruses, Giardia, Cryptosporidium, Campylobacter and Salmonella. A detailed description of these pathogenic microorganisms is provided in Appendix I. As greywater can vary substantially in quality it might be expected that in some cases it may contain a number of other pathogens. A summary of adverse effects from a wider range of pathogens is presented in Table 9.5.

Table 9.5.- Major Pathogens Potentially Present in Greywater

Group	Micro-organisms	Diseases caused	Source
Virus			
	Enteroviruses (polio, echo, Coxsackie)	Gastrointestinal symptoms, meningitis, paralysis, cardiac systems, conjunctivitis, hand, feet and mouth diseases	Faeces
	Rotavirus	Gastroenteritis, diarrhoea (especially in infants)	Faeces
	Adenovirus	Respiratory disease, conjunctivitis, gastroenteritis	Faeces
	Norwalk Virus	Gastroenteritis, winter vomiting disease	Faeces
	Hepatitis A virus	Infectious hepatitis	Faeces
Bacteria			
	Salmonella	Gastroenteritis, diarrhoea, typhoid fever (S.typhi)	Faeces
	Shigella	Bacterial dysentery	Faeces
	Camplylobacter	Gastroenteritis, diarrhoea	Faeces
	Yersinia enterocolitica	Acute gastroenteritis, diarrhoea	Faeces
	Pseudomonas aeruginosa	Skin and ear infections	Mucous membranes, skin lesions etc.
	Clostridium perfringens	Gastroenteritis, gas gangrene	Faeces, soil
	Clostridium tetani	Tetanus	Soil containing spores, possibly associated with vegetables
	Aeromonas sp.	Gastroenteritis	Faeces
	Escherichia coli	Gastroenteritis	Faeces, possibly soil
	Vibrio cholerae	Cholera	Faeces
	Leptospira	Leptospirosis	Faeces
Protozoa			
	Giardia lambia	Diarrhoea, nausea, vomiting, fever	Faeces
	Cryptosporidium	Diarrhoea, nausea, vomiting, fever	Faeces
	Entamoeba histolytica	Amebic dysentery	Faeces
Helminths			
	Ascaris lumbricoides	Ascariasis (round worm)	Faeces, soil
	Strongyloides stercoralis	Strongyloidiasis (thread worm)	Faeces, soil
	Trichuris trichiura	Trichuriasis (whip worm)	Faeces, soil

Source: Brisbane City Council, 1994.

Pathogenic contamination that could occur in greywater would reflect the numbers of people in the community infected by enteric pathogens, as infected people excrete the pathogens causing the infection. These will vary seasonally and from community to community. To give an indication of the predominant infectious diseases in Victoria over the period 1991-1993, a review of the diseases with 500 or more cases notified per year was carried out. A summary of the results is presented in Table 9.6.

Table 9.6 - Predominant Infectious Diseases in Victoria in 1991 - 1993

	Year 1991	**Year 1992**	**Year 1993**
Arbovirus infection	408	191	1298
Campylobacter infection	**2466**	**2129**	**2122**
Giardiasis	**913**	**921**	**1029**
Hepatitis B	1798	2077	2330
Hepatitis C	1735	1265	2662
Pertussis	71	149	527
Rubella	181	2236	500
Salmonellosis	**932**	**743**	**712**
Chlamydial infection	NS	1227	NS

Source: H&CS, (1991, 1992, 1993).

It appears that the dominant enteric pathogens in Victoria over this period were: Campylobacter, Giardia and Salmonella. Some details about the manifestation of these infections (H&CS, 1991,1992,1993) are provided below.

Campylobacter infection

Campylobacter infection has been the most commonly notified gastrointestinal disease in Victoria in the period 1991-1993. It is more common in summer months. Campylobacter infections in 1991 outnumbered the combined total of all other notifiable bacterial causes of gastroenteritis. The highest age specific incidence rate was for children under 5 years of age - 197 cases/ 100,000 population/year in 1991, while the overall incidence in Victoria was 55 cases/ 100,000/ year. Public health prevention measures include attention to hygiene and hand-washing especially in the kitchen or after handling pets.

Giardiasis

In the analysed data for age distribution of giardiasis in 1991 there are two peaks in number of infections, the first in children under 5 years and the second in adults from 25 to 39 years. It is possible that water-borne giardiasis is more common in country regions and person to person transmission more common in the metropolitan regions, where day care centres provide suitable conditions for transmission. In 1993 there were 1029 cases of giardiasis reported, which is slightly higher than for 1991 and 1992.

Salmonellosis

Out of 932 cases of Salmonellosis reported in 1991, 229 were in children under 5 years of age (this constitudes 36.3% of the total cases). Fewer cases were reported in 1992 and 1993 (743 and 712 cases respectively), but children under 5 years of age were still the most infected group.

The main points relevant to greywater risk assessment can be summarised as

(i) Campylobacter infections are more common in summer when greywater would be used;

(ii) Children under 5 are the most often infected individuals for the three types of pathogens;

(iii) Handling of pets can be a source of Campylobacter infection.

It should be noted that the occurence of infectious disease could vary substantially in different countries, under different climatic conditions and with a range of other factors. For example, a comparison made by Gibbs and Ho (1993) between Perth, Melbourne and the Kimberley region of Western Australia showed that the incidence of reported enteric infections in Melbourne was approximately half that of Perth. Gibbs and Ho have expressed doubt about the validity of the data stating that the variations between Melbourne and Perth were "more likely to have been due to difference in notification rates". Still it is important to note that the Kimberley region is almost unsewered, Perth is 70% sewered while Melbourne is nearly 100% sewered and that the difference in incidence of diseases for the different regions can be related to the method of wastewater disposal. However, the relative infection rates for different pathogens in Perth and Melbourne were similar.

9.2.2 DOSE - RESPONSE ASSESSMENT

Important in any health risk assessment is the degree of concentration of a contaminant which affects health. But there are other factors that influence infectious doses. For example, in the case of enteric viruses, several outcomes are possible depending upon pre-existing immunity, age, nutrition, ability to elicit an immune response, and some other nonspecific host factors (Gerba and Rose, 1993). Not all individuals who become infected will develop clinical illness.

Information on infectious dose is scarce because infectious dose studies depend on human volunteers. Infectious doses for different organisms were summarised by Gibbs and Ho (1993) and some are presented in Table 9.7.

Table 9.7 - Infectious Dose for Some Enteric Pathogens

Pathogen	Probability of Infection from Exposure to 1 organism	Dose to cause Incidence of 1%
Poliovirus 1	$1.49x10^{-2}$	0.67
Poliovirus 3	$3.1x10^{-2}$	0.32
Echovirus 12	$1.7x10^{-2}$	0.59
Rotavirus	$3.1x10^{-1}$	0.03
Salmonella species	$2.3x10^{-3}$	4.3
Salmonella typhi	$3.8x10^{-5}$	263
Shigella dysenteriae	$4.97x10^{-4}$	20
Shigella flexneri	$1x10^{-4}$	100
Campylobacter	$7x10^{-3}$	1.4
Entamoeba histolytica	$2.8x10^{-1}$	0.04
Giardia lamblia	$1.98x10^{-2}$	0.5

Source: Gibbs and Ho, 1993

According to Rose (1992) water-borne transmission has been documented with many enteric pathogens, but evidence supporting the spread of disease through wastewater irrigation is scarce.

9.2.3 EXPOSURE ASSESSMENT

In the process of determining the magnitude, frequency, duration, route and extent of exposure to a contaminant, the exposure pathways and the most exposed individuals have to be identified.

With respect to greywater, conditions of exposure can be subdivided into three groups according to the type of application:

A. Greywater reuse for toilet flushing;

B. Greywater reuse for subsurface irrigation:

C. Greywater reuse for surface irrigation.

The last option is included to identify and assess problems arising from a wider range of possible applications. An attempt has been made to list all the possible pathways associated with the reuse of greywater. Detailed tables are presented in Appendix I. A summary of these pathways is presented in Table 9.8.

Table 9.8 - Summary of More Important Greywater Health Risk Exposure Pathways

No	Pathway	Description/Examples
A	<u>Greywater reuse for toilet flushing</u>	
1.	GW - Human	Changing/cleaning flushing tank filters or toilet, splash of greywater on skin, toddlers playing with toilet water.
2.	GW - Air - Human	Inhalation of aerosols from toilet flushing.
B.	<u>Greywater reuse for subsurface irrigation</u>	
1.	GW - Human	Changing/cleaning filters.
2.	GW - Soil - Human	Toddlers digging in/eating soil, planting activities in garden.
3.	GW - Soil - Plant - Human	Subsurface seepage into (raw) vegetable-growing patch, fruit trees.
4.	GW - Soil - Animal - Human	Children/adults playing with dogs/pets which might dig into soil.
5.	GW - Soil - (Surface Water)	Possible saturation to soil surface, surface ponding/runoff, then as for C1, C3 below.
C.	<u>Greywater reuse for surface irrigation:</u> (as for B1-B4, plus pathways below)	
1.	GW - Human	Increased opportunity for direct contact, eg by playing/lying on grass
2.	GW - Air - Human	Inhalation of aerosols from any form of spray irrigation.
3.	GW - Animal - Human	Children/adults playing with pets which might roll on wet grass, etc.

There will be a number of different subgroups of people (eg, family members, visitors, neighbours, children, adults) that will be exposed to different levels of risk. Generally, people at risk from exposure to greywater can be divided into two groups, those directly exposed and those indirectly exposed. Directly exposed people include those who will change and clean the filters and maintain the greywater system, people who work in the garden irrigated with greywater, and people who use a toilet flushed with greywater. People directly exposed to greywater could ingest pathogens contaminating their hands or clothes. Children exposed to greywater, (and especially those under 5 years of age who are most susceptible to a number of enteric pathogens) are probably most at risk because they are more likely to directly ingest soil irrigated with greywater or eat without removing contamination from their hands. Visitors to households with a greywater system are also exposed to greywater when using a toilet flushed with greywater, or when their children play outside in the garden. Neighbours and their children could be exposed to greywater if there is surface runoff from the property using greywater for irrigation.

Indirect exposure to greywater might occur from contact with pets playing on the lawn (if surfacing or ponding has occurred). The people exposed to this indirect contact could be homeowners, children, visitors, or neighbours. Indirect exposure can also occur from consuming water or vegetables indirectly contaminated with greywater, that is, if greywater should contaminate a groundwater stream, or if greywater comes in contact with the vegetables in the garden.

It is apparent that if greywater is applied on the surface of the ground the risk associated with exposure to pathogens by contact with the wet soil, eating soil, handling pets, etc. will be higher. In general, the magnitude of exposure will depend on factors such as the density of pathogens in greywater (that is the number of pathogens excreted per ml in the greywater) and the persistence of these pathogens in the environment (in a surge tank, in soil, etc.). The nature of the environment does influence the survival of microorganisms (Rose, 1986). Water is a more hospitable environment for enteric pathogens than soils and crops. When greywater is used for irrigation, a variety of circumstances may influence the survival of the pathogens. According to Rose (1986), organisms which infiltrate into the soil survive longer than those remaining on plant surfaces.

Generally increased moisture content, higher organic matter and cooler temperatures promote the survival of enteric microorganisms in soil. On the contrary, extreme acidic or alkaline soil conditions, presence of antagonistic microflora and exposure to sunlight reduce the survival time of these pathogens. According to Brisbane City Council (1994) "pathogens in soil could survive long enough to potentially pass to a person who comes in contact with that soil".

As greywater for irrigation is expected to be used immediately to water a garden or lawn, it is important to consider the survival time of pathogenic microrganisms in soil. A summary of the survival time of some pathogens in soils is presented in Table 9.9.

Table 9.9 - Survival of Pathogens in Soils

Pathogen	Survival time (days)
Coliforms	38
Streptococci	35 to 63
Faecal streptococci	26 to 77
Salmonella	15 to > 280
Salmonella typhi	1 to 120
Tubercle bacilli	> 180
Lestospira	15 to 43
Entamoeba histolytica cysts	6 to 8
Enteroviruses	8 to 175
Ascaris ova	up to 7 years
Hookworm larvae	< 90 but usually < 30
Brucella abortus	30 to 125
Q-fever organisms	148
Vibrio cholerae	< 20 but usually < 10

Source: Brisbane City Council, 1994.

9.2.4 RISK CHARACTERISATION

To use the quantitative risk assessment (QRA) approach the levels of the different pathogens of concern must be determined. Most of the studies that have analysed the quality of greywater provided information about total and faecal coliforms. Faecal coliforms and E. coli are indicators of faecal contamination and possible presence of intestinal pathogens such as Salmonella and enteric viruses. However, more recent opinion is "the coliform system is now known to be an inadequate measure for pathogenic water quality" (Rose, 1992), and therefore no reliable estimate of pathogen numbers can be derived from faecal coliform and E.coli counts.

In this study greywater was tested for a number of pathogens: Giardia, Cryptosporidium, Salmonella and Campylobacter. None of these pathogens was found in the greywater samples. The City of Los Angeles (1992) monitored eight greywater system sites for 12 months. Tests were carried out for the presence of four disease organisms - Salmonella, Shigella, Entamoeba hystolitica, and Ascaris lumbricoides - and none was detected. Because of the relatively small samples involved, this is not sufficient proof that these microorganisms do not occur in greywater. Up to the present, no studies are known to have reported on tests for the presence of viruses in greywater.

Rose et al. (1991) investigated the survival of Salmonella atyphomurium, Shigella dysenteriae and Poliovirus type 1 artificially seeded into greywater. No regrowth of Salmonella or Shigella was observed in greywater. Salmonella numbers remained stable for 2 days, while a more rapid decrease was observed for Shigella. Poliovirus was found to have a similar survival rate to Salmonella during the first 3 - 4 days. The results showed that these microorganisms persist in greywater at least for several days, therefore there may be some risk associated with reuse of greywater when these pathogenic bacteria and viruses are being excreted by an individual producing greywater. Due to the low infectious dose of viruses, even low concentration would be of concern.

Rose et al. (1991) concluded that greywater may contain microbial agents which present a public health hazard with reuse. The microbial profiles indicate that greywater can support a high concentration of aerobic heterotrophic microorganisms. Concentrations in greywater as high as 10^5 faecal coliforms per 100ml indicate that enteric pathogens, if being excreted by an individual in the household, would also be found in greywater. The same study concluded that depending on the number of family members infected and the number of family units producing the greywater, a wide range of pathogens might be recovered from greywater.

Regarding microbial contamination of soils irrigated with greywater no investigation was carried out in this research. In a previous study (City of Los Angeles, 1992) it was concluded that the subsurface application of greywater does not elevate the health risks from handling garden soil, as long as sanitary practices are followed. The soil was already so heavily contaminated with faecal matter from pets and other animals that the additional contribution from greywater was considered not to be significant. The results of this study indicated that there may be minimal additional risk of exposure from use of greywater for irrigation of landscaping.

9.2.5 CONCLUSIONS

The information available regarding pathogenic microorganisms in greywater allows only a qualitative assessment of the health risk associated with greywater reuse to be accomplished. Based on qualitative risk assessments from previous studies it can be suggested that the pathogens of most concern might be enteric viruses, Giardia, Cryptosporidium, Salmonella, Campylobacter and possibly Shigella. Based on the exposure pathways developed (see Table 9.8) it can be concluded that subsurface irrigation involves less exposure pathways and fewer opportunities for direct contact with greywater, and thus a reduced risk. Soil can be used as a barrier to reduce the exposure.

In the case of toilet flushing the risk of disease transmission by aerosols and splashes could be reduced by greywater disinfection. In addition the aerosol distribution can be minimised by closing the lid of the toilet before flushing. However, children and visitors in particular could not be relied on to carry out this practice.

At present no further progress can be made on quantification of the actual risk associated with greywater reuse. This is due to a lack of information on various pathogens present and their concentrations in greywater. Further research needs to be carried out on identification of the critical contaminants, the most exposed individuals (MEI) and the most important exposure pathways.

9.2.6 DIFFICULTIES AND WEAKNESSES

A number of difficulties have been encountered in the attempt to carry out a quantitative risk assessment on greywater reuse applications. These are:

- lack of sufficient data on pathogen presence and concentrations,
- the small sample population size used in this study,
- financial and time restrictions on continued or wider scale testing,
- need to base the analysis on data from the literature review,
- large number of factors involved due to the high variability of greywater quality,
- need to make a large number of assumptions which would detract from the credibility of some conclusions reached.

The heterogeneity in greywater composition and the limited information available makes the assessment of health risks associated with greywater reuse extremely difficult. A similar opinion was expressed by the City of Los Angeles (1992) that a statistical risk assessment would have little credibility as it would be based on too many assumptions, with the margin for error being compounded with each subsequent assumption.

As an introduction to possible future research, a number of studies involving QRA were reviewed in order to identify the methodology which might be most appropriate for greywater reuse risk assessment. Two studies (Rose, 1992, Enferadi et al., 1986) and their results are presented in Appendix I.

9.3 ENVIRONMENTAL RISK ASSESSMENT

Environmental risk assessment focuses on the harmful effects of a project or practice on individual environmental elements such as vegetation, soil, groundwater, soil biota. In this project attention was mainly focused on comparing measured greywater quality parameters with acceptable values identified in the existing guidelines for reuse of wastewater which were summarised in Section 2.5.4.

9.3.1 HAZARD IDENTIFICATION

The possible agents of concern with regard to adverse effects on soil and vegetation were outlined in detail in the review of the relevant literature (Section 2.5.3). Actual agents of concern for soils were identified on the basis of the analysis of greywater quality parameters and results from the soil tests (see Sections 6.3 and 6.4). More specifically for the receiving soils these were pH, alkalinity, sodium, copper, zinc, and aluminium.

Regarding plant growth and health, possible agents of concern include pH, TDS, and trace elements which can be potentially toxic, as their availability and toxicity are strongly dependant on pH. Phosphorus is also of particular concern for some native plants and trees. A list of these plants is presented in Table 2.17.

The adverse effects on groundwater and soil biota were not investigated in this research. In principle major agents of concern for groundwater are high phosphorus and nitrogen concentrations that might occur in greywater.

9.3.2 DOSE RESPONSE ASSESSMENT

The acceptable limits for different quality parameters were outlined in detail in Section 2.5.3. The time limitation of this two year program did not allow adequate observation of the possible effects associated with greywater reuse on soil and plants. A discussion on the known effects on soils is provided in Section.6.4.

9.3.3 EXPOSURE ASSESSMENT

Conditions of exposure can be subdivided into two groups according to the type of application of greywater:

A. Greywater reuse for subsurface irrigation.

B. Greywater reuse for surface irrigation.

The second option is included to identify and assess problems arising from a wider range of possible applications. An attempt has been made to list the possible pathways associated with reuse of greywater. Detailed tables are presented in Appendix I. A summary of these pathways is presented in Table 9.10.

Table 9.10 - Summary of Greywater Environmental Risk Exposure Pathways

No	Pathway	Description/Examples
A.	Greywater reuse for subsurface irrigation	
1.	GW - Soil	Any adverse effects on soil structure and composition.
2.	GW - Soil - Plant	Native trees, fruit trees or plants irrigated with greywater.
3.	GW - Soil - Animal	Dogs/other pets which might dig into soil.
4.	GW - Soil - Soil biota	Earthworms, slugs, bacteria, fungi living in the soil which might be affected
5.	GW - Soil - Groundwater	Possible contamination of groundwater through seepage or direct flow through cracks in the ground.
6.	GW - Soil - Plant - Animal	Pets (eg. rabbits or chickens) being fed with grass from greywater irrigated area.
7.	GW - Soil - Surface water - Animal	Possible ponding of greywater on the surface and pets which might roll on wet grass.
B.	Greywater reuse for surface irrigation: (as for A1-A7, plus pathways below)	
1.	GW - Animal	Increased opportunity for direct contact by pets playing/lying on grass.
2.	GW - Plant	Spray on the surface of the leaves of plants from any form of spray irrigation.

Based on the identification of the critical element of concern for soil, a number of analyses were made in respect to selection of appropriate detergents and irrigation practices so that the greywater reuse systems would present minimal environmental risk to soil (see Section 6.5.1).

9.3.4 RISK CHARACTERISATION

Based on the exposure assessment pathways the three most exposed elements could be identified: soil, plants and animals. With regard to soil contamination, published figures for addition of contaminants to soil have been set which can be considered as acceptable levels of risk. Similar figures exists for plant uptake of some elements. However, acceptable levels for some of the contaminants identified in this project do not appear to be well established. In some cases potable water guidelines are used to set acceptable values from a risk viewpoint regarding uptake by animals.

CHAPTER 10: CONCLUSIONS AND RECOMMENDATIONS

10.1 GENERAL CONCLUSIONS AND RECOMMENDATIONS

The general conclusions and recommendations set out below are largely based on assessment of the relatively simple, minimal treatment type systems identified as a priority in this research program.

1. The diversion, transfer and distribution of domestic greywater for garden watering is technically feasible but for health reasons the application of greywater onto lawns and gardens should be by subsurface distribution systems only.

2. The diversion, storage and supply of greywater for toilet flushing is technically feasible but poses potential risks to health. This study, using the traditional faecal coliform indicator system, showed that greywater can be successfully disinfected to minimise the risk of infection through direct contact with the liquid or any aerosol produced in the flushing process. Risk of contact with the aerosol can be further reduced by flushing with the toilet seat cover down. Effective chlorination would depend on continual regular monitoring by the householder and this is only likely to be achieved with dedicated individuals.

3. Although technically feasible, the reuse of greywater on typical urban allotments is not economically viable from the home owner's point of view now or in the foreseeable future, although the adoption of the practice could produce a community benefit as a result of reductions in water demand. The high cost/benefit ratio suggests that the domestic reuse of greywater cannot be recommended for community-wide adoption at this time; however, this should not prevent enthusiastic property owners from installing approved systems.

4. It is important to use environmentally friendly laundry products to avoid problems associated with changes to soil pH, salinity, availability of heavy metals and other specific ions which might affect soil structure and vegetation.

5. It is recommended that the Water Authority be responsible for educating the public about the potential value of reusing greywater and providing technical information about typical greywater reuse systems and basic design criteria.

6. Under current regulations, separate approvals from three Authorities (ie EPA, Melbourne Water, Local Council) are required before a permit can be issued for the installation of a greywater system in Melbourne. It would be desirable that the approval process including the issuing of permits and the inspection of completed works be administered by one Authority based on a single application from a property owner.

10.2 SPECIFIC CONCLUSIONS

In the experimental part of this program four greywater installations were designed, constructed and monitored over a period of fourteen months. Greywater quantities and quality parameters were analysed and a number of products such as disposable filters, detergents and disinfectants were tested. An evaluation of the greywater systems and a qualitative assessment of the possible public health and environmental risks were carried out. Based on the findings of this study the following conclusions have been drawn:

Water Savings

1. Water savings that can be achieved by reusing greywater depend greatly on site specific features such as the type of household water appliances used, individual habits, and irrigation area available. In retrofit situations, the accessibility of fixtures for diversion and the opportunity for maximum utilisation of greywater (eg, supplying all household toilets with greywater and satisfying all the irrigation demand) are additional factors affecting potential savings. As an aid for greywater system design and the determination of potential greywater production and demand for households of varing occupancy, a

design and costing graph has been produced and examples of the sizing process provided (see Section 7.2 and Appendix F).

2. The maximum possible water savings (based on a three person household) are in the range of 20% to 29%, on the assumption that all the bathroom and laundry greywater is diverted for reuse and that all the toilet flushing and irrigation demands can be efficiently met with greywater. The water savings achieved at the four experimental sites were in the range of 12% to 28%. The results also indicated that newly built houses offer the best opportunity to achieve the maximum savings, while in the majority of retrofit situations technical constraints are likely to preclude this.

Greywater Quality

3. Values determined in this project indicated that greywater quality shows high variability, due to such factors as greywater source, type of products used, composition of family (ie. age distribution of members), individual lifestyle, and specific house characteristics such as type of water appliances used. The results are consistent with the wide range of values reported in the literature.

4. A comparison of tap water and greywater showed that the tap water deteriorates significantly after the first use. An increase in the concentration of a number of parameters such as turbidity, electrical conductivity, sodium, phosphorus, nitrogen, some heavy metals and microbiological pollutants was observed and in many cases greywater exhibits several of the characteristics of weak to medium domestic sewage. This indicates that greywater reuse should be approached with caution and that the typical watering methods and practices used for potable water cannot be readily applied with greywater.

5. Physical and chemical parameters such as pH, salinity, sodium and aluminium content reached unacceptably high levels when compared with standard wastewater irrigation guidelines (eg., Environment Protection Authority Victoria, 1991). These levels were observed particularly in the laundry greywater samples and were clearly related to the

compounds in the laundry detergents. Based on these findings, it can be concluded that in general, laundry greywater would contain more contaminants of concern when used for irrigation, and would therefore be more suitable for toilet flushing. Bathroom greywater has comparatively lower levels of these contaminants and it is generally less harmful to the environment and thus more suitable for irrigation than laundry greywater. Although bathroom products used in this program presented no significant problems, it cannot be guaranteed that all bathroom products would be safe for the environment.

6. In some cases, there were excessively high levels of metals such as iron, zinc, lead and copper irrespective of greywater source. The probable source for copper was plumbing materials whereas the iron and zinc were leached from the galvanised steel tank walls. Tanks should be constructed from non corrosive (eg. plastic, fibreglass, etc.) materials or at least should be coated to prevent corrosion. Most of the highest levels of the metals (Al, Cu, Fe, Pb, and Zn) were observed in the greywater samples from the household utilising low water use appliances resulting in high levels of contaminant concentration.

7. From an irrigation point of view high pH and sodium concentrations in conjunction with medium to high salinity (EC values) and sodium adsorption ratio, particularly in laundry greywater, and the high levels of trace metals indicated potential problems with soil and plant degradation. These findings clearly indicated the need for careful selection of detergents, appropriate choice of tank and equipment materials, and prevention of harmful chemicals from entering the greywater flow.

8. With regard to microbiological quality , no statistically significant difference between bathroom and laundry greywater quality could be calculated because of the relatively small number of samples tested. However, from general observation of the results, there did appear to be some difference in the quality from the two sources. Typical ranges for total coliforms were from 10^4 - 10^7 and 10^5 - 10^8 cfu/100mL for bathroom and laundry sources respectively, while the corresponding ranges for faecal coliforms were 10^3 - 10^5 and 10^4 - 10^6 cfu/100mL, and for faecal streptococci were 10 - 10^3 and <2 - $5x10^3$

cfu/100 mL. Counts both lower and higher than these ranges were however observed for both sources of greywater. These results indicate high microbiological contamination, and potential presence of pathogens. As might be expected, the highest levels of total and faecal coliforms were generally observed in laundry water from the family with a small baby.

9. None of the disease-causing pathogens Salmonella, Campylobacter, Giardia and Cryptosporidia was found in the greywater samples. This can be attributed to the fact that none of the residents shed these organisms during the time of the sampling. This does not imply the absence of pathogens in greywater from other households or even from the same households at another time.

10. Compared with existing wastewater reuse guidelines (eg., NSW Recycled Water Coordination Committee, 1993) the levels of total and faecal coliforms were significantly higher than the levels recommended for water used in domestic surface irrigation. Other parameters such as BOD, SS, colour, turbidity and in some cases pH were well outside the same guidelines. From a health point of view, these findings lead to the conclusion that any irrigation should be subsurface, and indicate a serious potential problem with toilet flushing, unless the water is adequately treated.

Receiving Soils

11. After two irrigation seasons with greywater at one of the experimental sites, changes were observed in soil parameters such as pH, aluminium, sodium, and calcium levels, but these changes could be only partially attributed to the greywater application, as the influence of natural processes in the soil appeared to be more dominant. At the remaining three sites no significant changes in the levels of the tested parameters were observed.

Detergents

12. Three detergents were tested in regards to the quality of greywater for irrigation. It was found that "Cold Power" contributes to extremely high pH, salinity and sodium levels and

should not be used if greywater is to be applied for irrigation. The second detergent Bio-Z presented some concerns regarding high pH and presence of aluminium and requires further investigation regarding its suitability. It was concluded that the liquid potassium based "Pure Laundry" detergent was the most suitable detergent of these three for use with greywater reuse systems. If chlorine tablets are used to disinfect greywater for toilet flushing the optimum range of pH is considered to be 7.2 to 7.6; however, even above this range when using "Cold Power" with a typical range of pH 7.4 to 10, chlorination proved to be effective.

Disinfectants

13. The heterogenic nature of greywater poses a major difficulty in identifying an optimum disinfectant. The difference in the greywater volumes produced and volumes needed and the patterns of production and usage make the dosing of the disinfectant a challenging task. Of the two disinfectants tested, chlorine tablets provided an effective means of disinfecting greywater as no microorganisms were isolated after treatment. An additional advantage of using chlorine tablets is that they are already widely and successfully used for disinfecting domestic swimming pools.

14. Greywater that overflows a toilet flushing tank containing disinfectant is not recommended for irrigation use as it could have harmful effects on the environment (plants, soil, soil biota, etc.). Arrangements should be made in the design of toilet flushing tanks to prevent surplus raw greywater from entering the tank by diverting it for irrigation.

Disposable Filters

15. It can be concluded that both "Nylon stocking" and "Geotextile" filtersock types of filters can be successfully used with greywater reuse systems. The use of disposable filters minimises contact with greywater and hence the risk of infection.

System Design, Installation and Operational Considerations

16. The following points should be noted when considering the design, installation and operation of greywater reuse systems.

A. Design and Installation:

- In many cases there will be insufficient hydraulic head to allow gravity irrigation or toilet flushing, and a pumped system incorporating a collection tank and separate toilet flushing tank will be required.
- Floor level greywater discharge outlets in low ground clearance situations will often necessitate that collection tanks be installed below ground level, with a consequent need for ground anchoring.
- Collection and diversion systems must be fail-safe so that greywater is automatically directed to the sewer (in sewered areas) whenever a blockage or system malfunction occurs.
- It will be necessary to comply with AS 1345 (1982), AS 2845(1991) and AS 3500(1991) to ensure that cross connections and accidental ingestion problems are avoided.
- If greywater is to be used for toilet flushing, it will be necessary to provide an adequate pipe size (or sufficient hydraulic head) between a flushing tank and the toilet cistern if excessive cistern filling times are to be avoided.
- It will be necessary to provide a low pressure float control inlet valve for toilet cisterns supplied by gravity with greywater.
- Greywater must be adequately screened, filtered and disinfected if it is to be used for toilet flushing.
- If greywater is to be used for irrigation, it must be screened and/or filtered to a level consistent with the water emitting devices used.
- It is desirable in greywater irrigation systems to incorporate adequate control arrangements to prevent overwatering and allow reasonably uniform flow distribution. A rain-sensor pump cut-off arrangement can be useful for pressure systems, while adequate valving is desirable in both pressure and gravity systems.

- Subsurface irrigation systems must be used, and methods developed to minimise their installation costs.
- Root intrusion may be a problem with subsurface irrigation systems, and should be controlled (in pressure systems) by using distribution lines with emitters impregnated with root inhibiter. (Slime development should be similarly controlled by use of appropriately treated distribution lines).
- The irrigation system design at any site will be dependent on site specific features such as soil type, slope, vegetation and climate. Typically, spacing between distribution lines will range from 0.6 m for sandy soils to 1.0 m for clay soils. Depths of pressure distribution lines will normally range from 100 - 200 mm, whereas mini-leach field trench depths will range from 200 - 300 mm.
- An irrigation buffer zone of at least 1 m should be used around buildings and property boundaries. (A 2 m buffer zone is required in some US code provisions).
- In retrofit situations some of the following difficulties might occur:
    - Limited or no floor clearance precluding utilisation of all greywater sources,
    - Site specific tank inlet and outlet requirements may inhibit the development of a one-design all-purpose tank,
    - The need for long collection, distribution and overflow pipe lines,
    - Difficulties in connecting the surge tank scour back to sewer, and possible conflict of these lines with existing services eg. gas, sewer, water, stormwater.

Many of these difficulties should be largely avoidable where the greywater reuse system is incorporated in the initial design of a new house.

B. Operation and Maintenance:

- Regular and time-consuming filter maintenance activities will be required. Other maintenance will be required from time to time.
- Access to screens and filters in under-floor tanks may prove difficult if they are constrained to locations that result in restrictions or limitations on clearances.

- Adequate skin and face protection measures should be used by persons servicing filters (and other components of the system which are "dirty").
- Filter residues (or disposable filters) must be disposed of in a safe manner.
- If greywater is to be used for toilet flushing, it will be necessary to check and maintain adequate disinfectant concentrations in a toilet flushing tank.
- Even with appropriate screening/filtration and disinfection, there may still be occasional occurrences of odours, foam, colouring and scum layers in the WC bowl.
- If greywater is to be used for irrigation, it is essential that appropriate soaps and detergents are used to minimise any likely environmental problems.
- Strong owner/resident interest and motivation will be required if systems are to be properly operated and maintained.

Economic Evaluation

17. The factors that influence the cost of greywater systems can be summarised as suitability of the site, complexity and level of automation of the system, number of greywater sources that can be tapped, area available for irrigation and whether the greywater system is installed by the householder or a professional tradesperson.

18. Greywater systems have the potential for saving water, but at present are not economic in individual domestic dwellings. The total cost for installation and operation is very high in relation to the likely annual water cost savings at the current price for water; therefore there is no economic advantage for householders who install such systems. However, further studies may indicate that widespread adoption of greywater reuse systems may have a significant community benefit.

Social Surveys on Greywater Reuse

19. Two social surveys were conducted to assess public opinion on greywater reuse. The results indicated that in Melbourne around 40% of residents were interested in reusing

bathroom or laundry greywater for garden watering, but only about 11% in using this water for toilet flushing. In the Melton survey, corresponding percentages were about 85 and 64 respectively, and general awareness of the concept of greywater was much higher amongst this "interested" group. In both cases there was a significantly greater demand for information on the garden watering option, and the major reasons given for interest were water conservation and cost savings. Aspects of concern to respondents were detergents and their effects on soils, development of unhygienic or smelly conditions, and problems with grease and fats for kitchen greywater (which was also included in the survey). Acceptable costs were generally related to a payback period of 2-4 years. Interest in water conservation and greywater reuse was most evident amongst home owners and retirees, those in the 40-49 year age group, and in the professional, manager/administrator and home duties occupational categories. These results indicated that there is significant community interest in reusing greywater, but there is also a substantial need for community education and technical information about reuse systems. There were respondents who have had experience with reusing water from the laundry for garden watering , but had not heard the term "greywater". In the Melbourne survey, the public awareness of the term "Greywater" was about 7%, with correct understanding being just 4%.

20. An additional survey conducted amongst the residents of the experimental sites indicated that the actual greywater reuse systems were more complicated than expected and that there was a need for a manual for operating the systems. Although interested in reusing greywater, the residents still find the servicing of the system (ie. changing of filters) too demanding of their time.

Risk Assessment

21. A complete risk assessment of the potential public health and environmental risks associated with greywater reuse will require a complex and separate major research effort. Based on qualitative risk assessments from previous studies it can be suggested that the

pathogens of most concern with greywater reuse might be enteric viruses, Giardia, Cryptosporidium, Salmonella, Campylobacter and possibly Shigella.

22. Based on the exposure pathways developed it can be concluded that subsurface irrigation with greywater presents a low health risk as it involves fewer exposure pathways and minimises the opportunity for direct human contact. Soil and well maintained grass provides a barrier to reduce the risk of exposure. In the case of toilet flushing the risk of disease transmission by aerosols and splashes could be reduced by disinfection. In addition the aerosol effect can be minimised by closing the lid of the toilet prior to flushing.

23. The results of this study lead to the general conclusion that, although the potential health risk associated with exposure to greywater is unquantified, it is important to take a cautious approach and avoid any contact with greywater. It can be recommended that for the purposes of irrigation the safest method of reusing greywater is by subsurface application immediately after being produced. Selecting appropriate washing products, especially in the laundry, is essential in order to minimise potential adverse effects on the environment. For toilet flushing purposes additional treatment (eg. filtration, disinfection, etc.) has to be provided to minimise the risk of infection.

10.3 POINTERS FOR FUTURE RESEARCH AND DEVELOPMENT

This research has been successful in assessing the technical and economic feasibility of reusing greywater from laundry and bathroom, in establishing the areas of concern, and in determining public perceptions about greywater reuse. There are however a number of areas derived from this study that deserve further investigation.

Design

1. Greywater systems could be simplified and made more economic if clothes washing machine pumps were sufficiently powerful to pump waste via a two-way valve either to the sewer or direct to the distribution system. Alternatively, the incorporation of rinse and wash

cycle programs that allow waste to be directed for reuse or to sewer could be further investigated.

Greywater Quality

2. Further systematic testing needs to be carried out on the microbiological quality of greywater in order to identify types and numbers of microorganisms of concern.

Soils

3. The receiving soil analysis needs to be extended beyond the two year period for a complete assessment of the long term effects on soils.

Detergents

4. For Bio-Z detergent further research is needed to identify the soluble and insoluble proportions of aluminium and its suitability for use with greywater systems.
5. More local laundry and bathroom products need be investigated to determine their suitability for use with greywater systems for irrigation.

Economic Aspects

6. There is a need to investigate whether large scale commercial production of greywater reuse components will reduce system cost and possibly ensure a greater market penetration.
7. The use of larger systems (for hotels, motels, and cluster housing) may present less maintenance problems and prove more economic than single family dwelling systems. Further research is needed to assess appropriate systems which may prove to be viable even at present water prices.

Risk Assessment

8. At present no further progress can be made on quantification of the health risk associated with greywater reuse. This is due to a lack of information on pathogens present and their concentrations in greywater. Further research needs to be carried out on identification of the

critical contaminants, the most exposed individuals (MEI) and the most important exposure pathways based on the framework developed in this study.

Reuse of Roof Runoff

9. As a by-product of the present study, substantial consideration has been given to the possibility of overcoming a number of the problems associated with greywater reuse by conjunctively using not only potable water and greywater, but also roof runoff water. Such conjunctive use could lead to a significantly better economic outcome than indicated by previous studies where collected rainwater has been assumed as a sole supply source with a high volumetric reliability requirement. Preliminary estimates suggest that reuse of rainwater for toilet flushing, laundry needs and/or garden watering could not only avoid some of the greywater quality problems, but also save from 20-35% of annual household water consumption. On-site collection and storage of rainwater could also have a significant impact on limiting excessive stormwater drainage flows. There is therefore a need to assess the technical, economic, environmental and social feasibility of conjunctively using the above water sources in a large system, both from the viewpoint of an individual property owner and also from that of the community at large.

PLATES

Plate 1 - Toilet flushing tank with greywater pumped by CWM pump at site 3 (Malvern).

Plate 2 - Toilet flushing tank with greywater gravity fed from upstairs b'rm at site 1 (Balwyn).

Plate 3 - Collection/surge tanks above ground and semi-buried at site 2 (Clifton Hill).

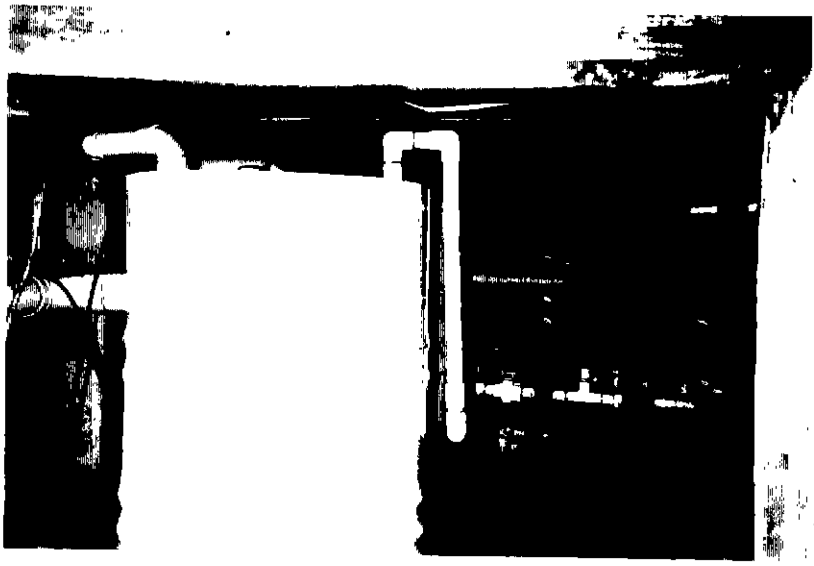


Plate 4 - Collection/surge tanks located in under-floor space at site 1 (Balwyn).

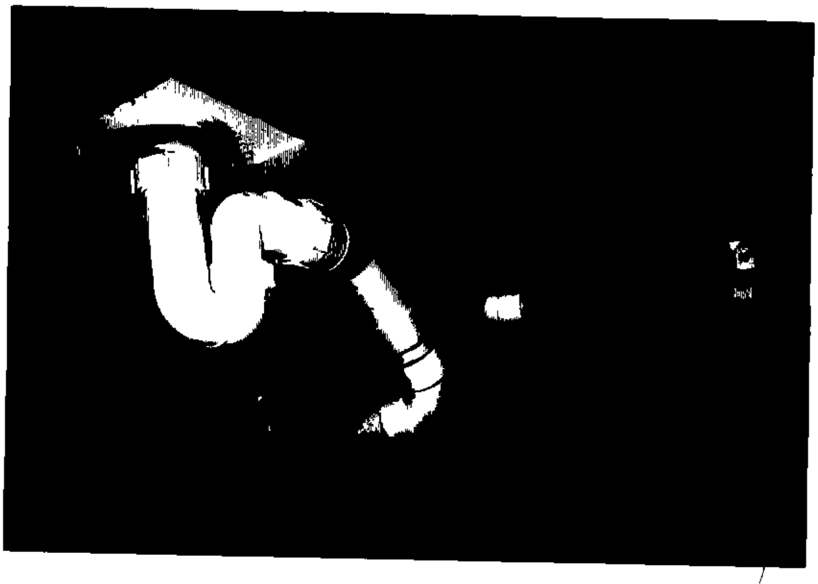


Plate 5 - Diversion arrangement from a shower under floor at site 4 (Strathmore).

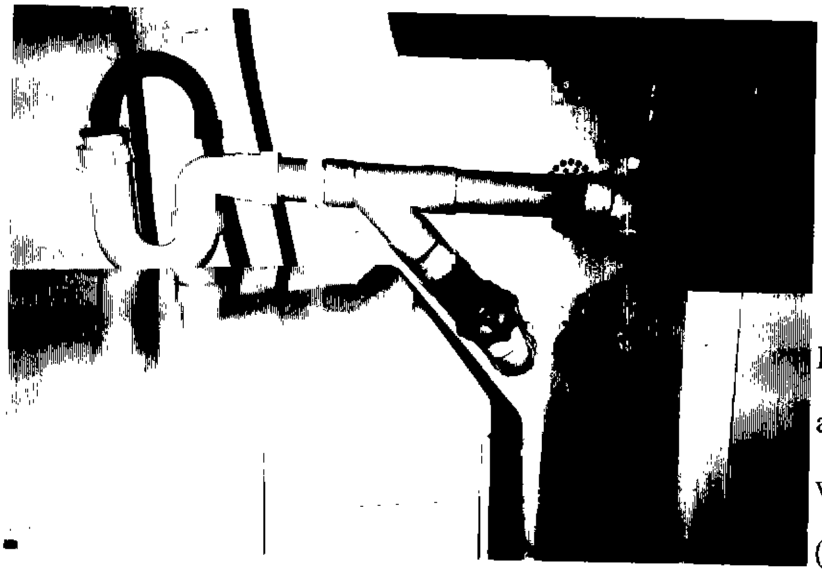


Plate 6 - Diversion arrangement from CWM with overflow to tub at site 4 (Strathmore).

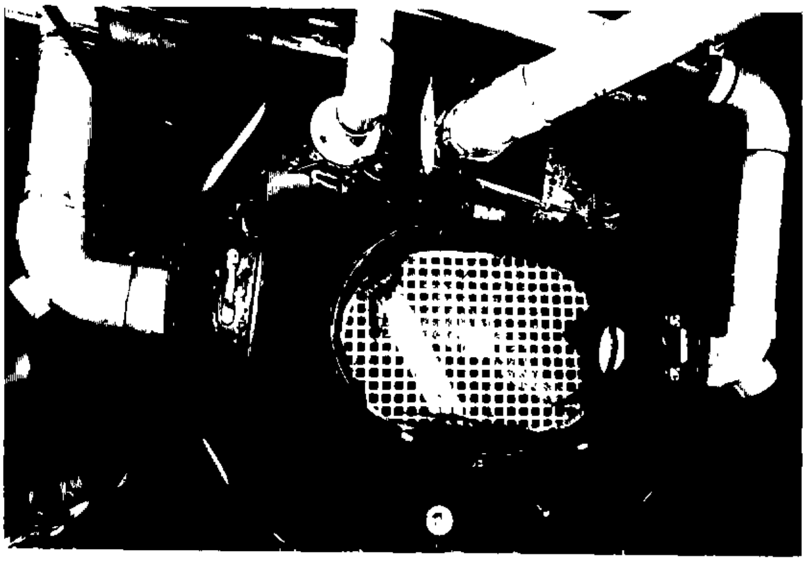


Plate 7 - Fly wire mesh filter installed in a surge tank at site 2 (Clifton Hill).

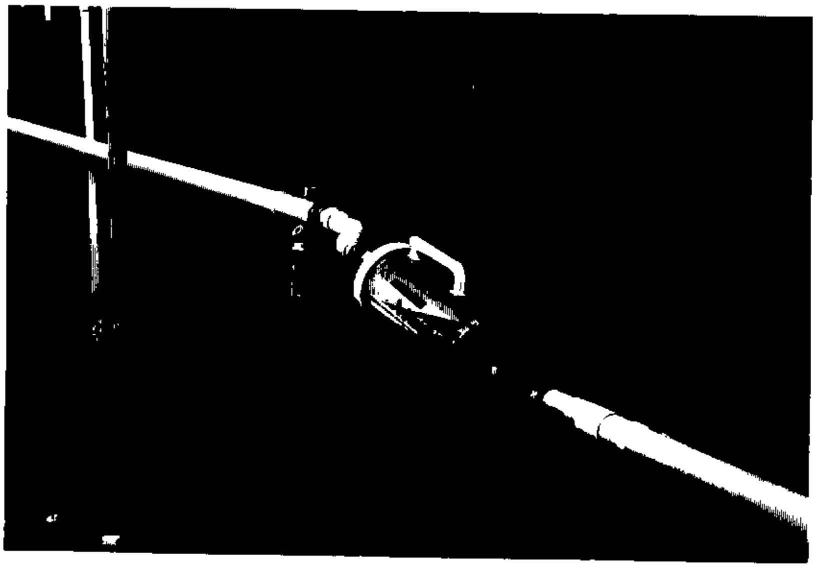


Plate 8 - "Leaf canister" in-line gravity filter on l'dry greywater line at site 4 (Strathmore).

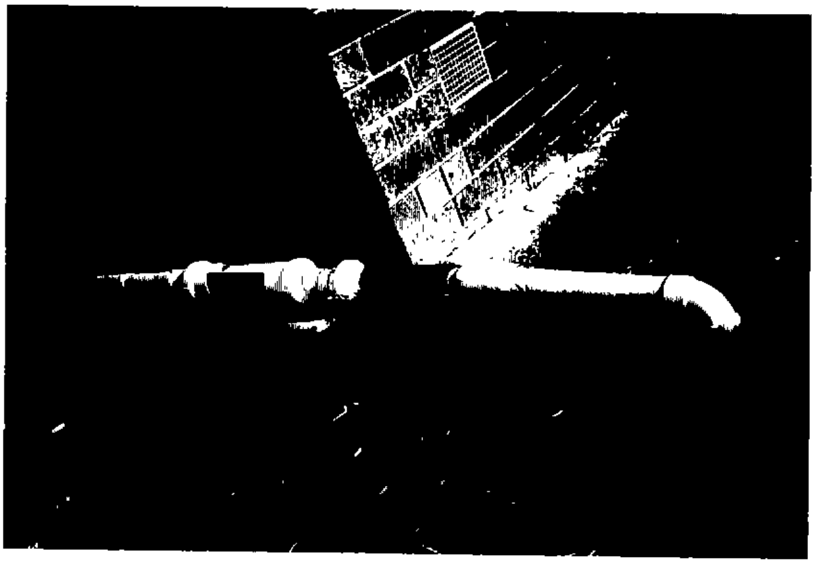


Plate 9 - "HI-FLO" in-line gravity filter on b'rm greywater line at site 4 (Strathmore).

Plate 10 - "Nylon stocking" type disposable filter.

Plate 11 - "Geotextile" filtersock type disposable filter.

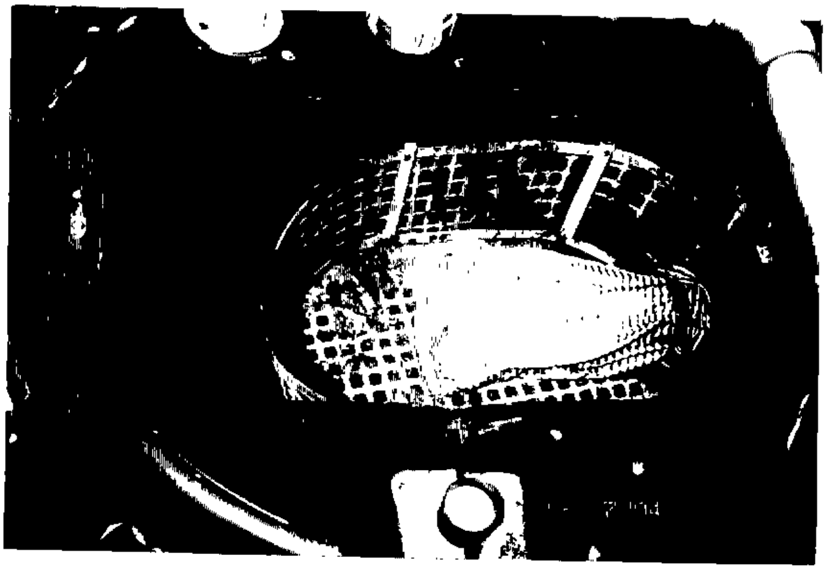


Plate 12 - "Cleaning Cloth" type disposable filter.

Plate 13 - Installation of gravity fed irrigation system at site 4 (Strathmore).

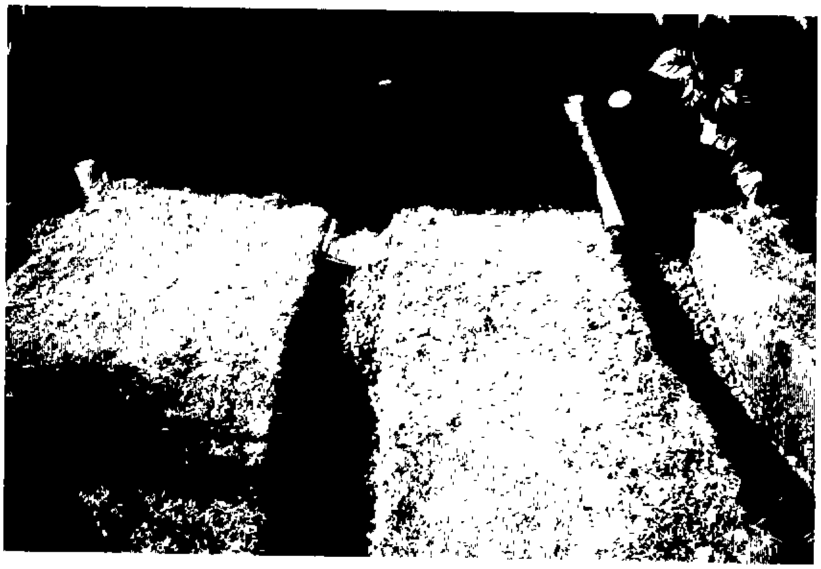


Plate 14 - Kourik type gravity irrigation system at site 4 (Strathmore).

Plate 15 - Gravity irrigation system manually controlled by valves at site 4 (Strathmore).

Plate 16 - Pressure irrigation system using drip lines at site 1 (Balwyn).

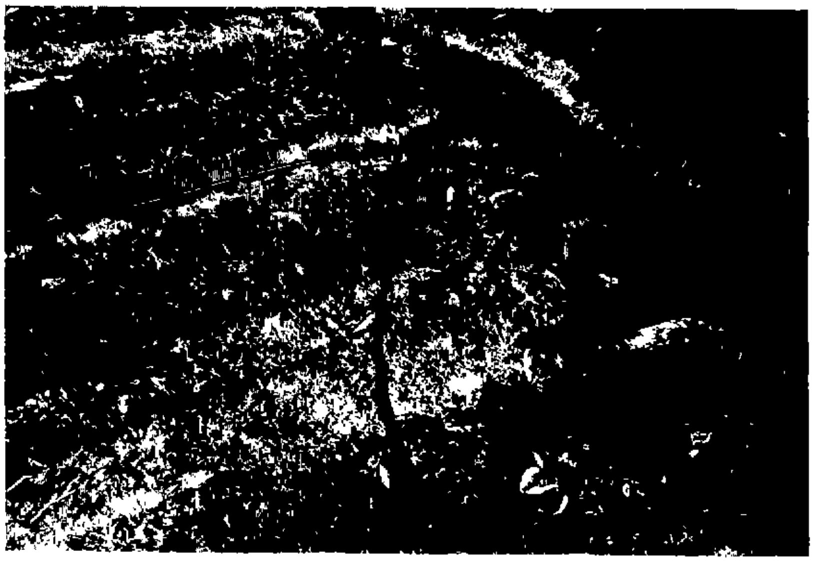


Plate 17 - Testing of drip line irrigation system before backfilling.

Plate 18 - Rusting of galvanised steel toilet flushing tank walls at site 2 (Clifton Hill).

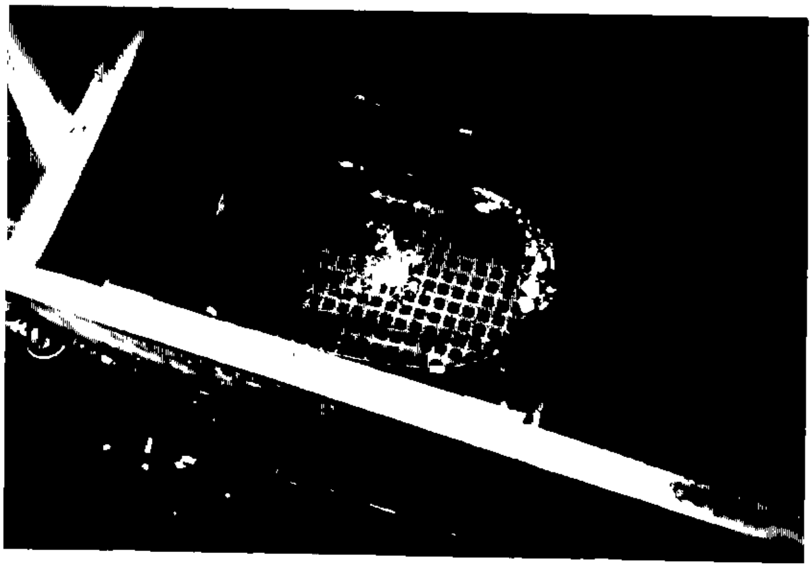


Plate 19 - Large particles transported by bathroom greywater trapped in mesh filter.

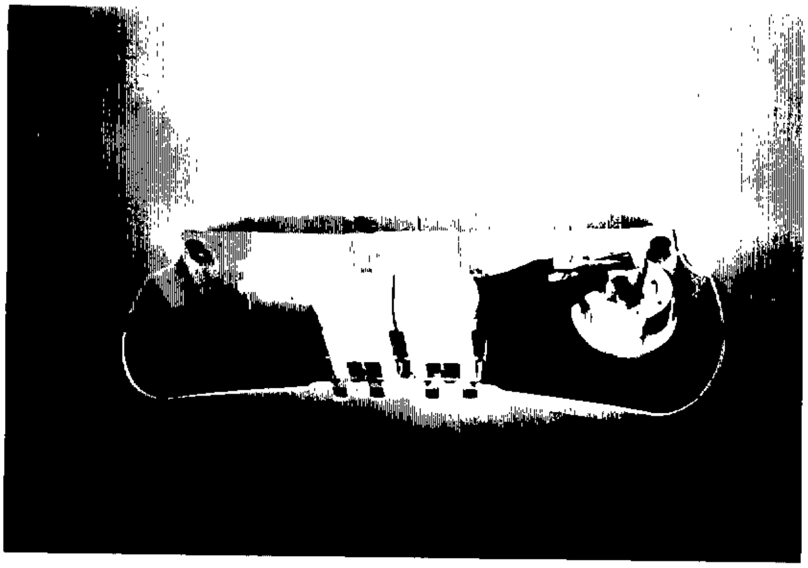


Plate 20 - Thin slime film build up on toilet cistern walls.

Plate 21 - Scum and floating particles in discoloured greywater.

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APPENDIX A

TYPICAL MELBOURNE HOUSEHOLD TYPES

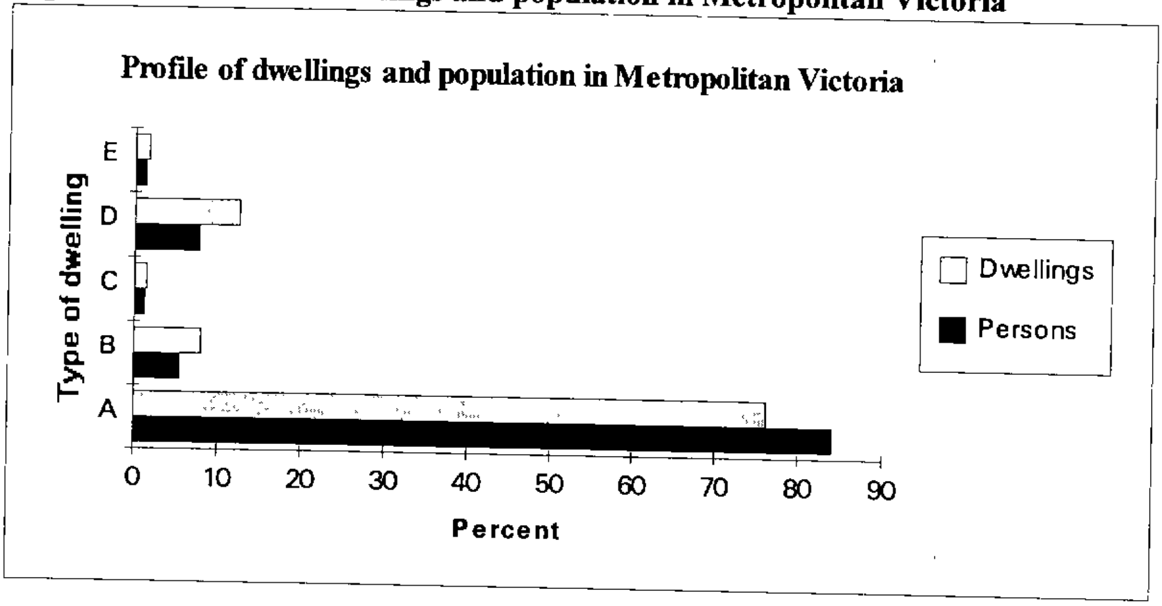
An examination of the 1991 Census data reveals the following information about dwelling types and occupancy for Metropolitan Victoria (census classification) and Victoria State:

(1) For Metropolitan Victoria - 76.2% of the dwellings were detached (separate) houses in which 84.1% of the population lived (see Fig.1).

(2) For Victoria State - 79.8% of the dwellings were detached (separate) houses in which 86.5% of the population lived.

Dwellings such as caravans and " non-stated" were not presented in Figure 1 as they are insignificant in number.

Figure A.1: Profile of dwellings and population in Metropolitan Victoria



Note: A - (Detached) separate house.

B - Semi-detached, row or terrace house, townhouse with 1 storey.

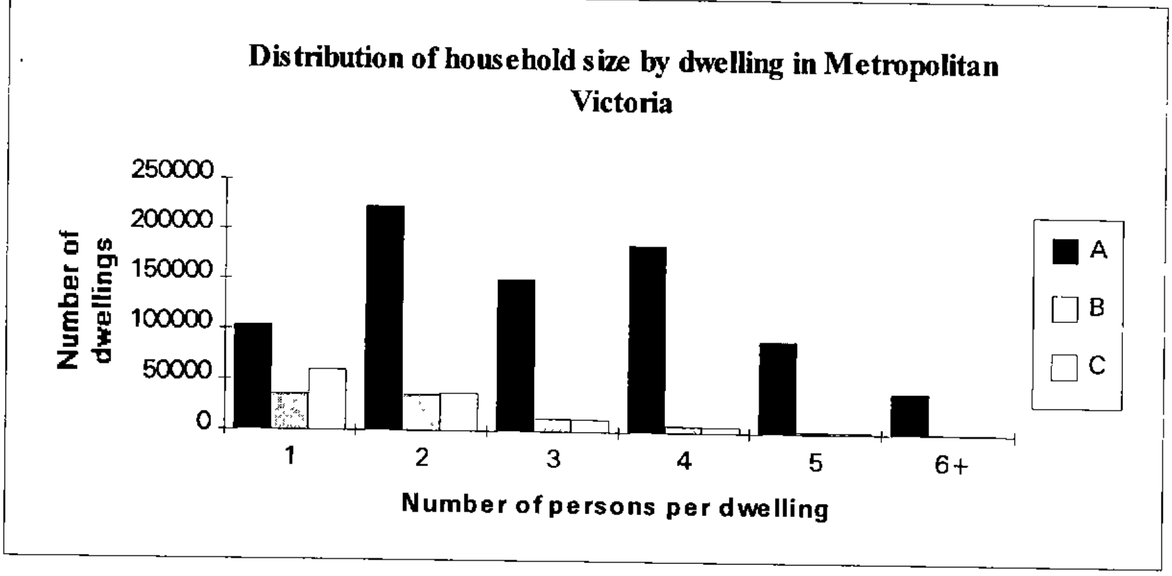
C - Semi-detached, row or terrace house, townhouse with 2 or more storeys.

D - Flat or apartment.

E - Other.

(3) The most common family sizes for detached (separate) houses are of 2, 3 or 4 persons (see Fig.2).

Figure A.2: Distribution of household size by dwelling in Metropolitan Victoria



Note: A - Detached (separate) house.

B - Semi-detached, row or terrace house, townhouse with 1, 2 or more storeys.

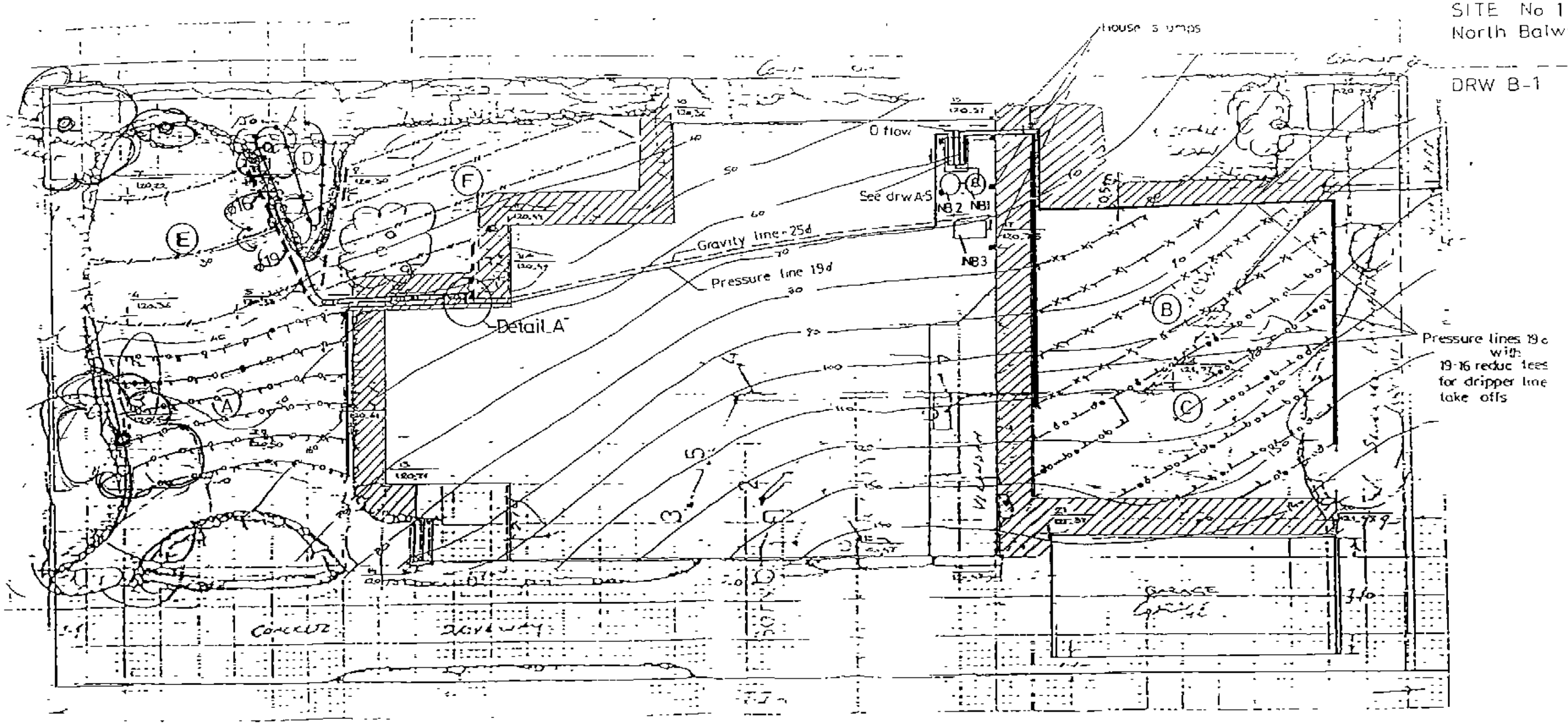
C - Flat or apartment.

APPENDIX B

GREYWATER DISTRIBUTION SYSTEMS ARRANGEMENTS

SITE No 1
North Balwyn

DRW B-1



DISTRIBUTION SYSTEM ARRANGMENTS

Note:

Pumped irrig.

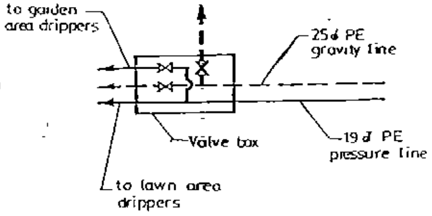
AREA A – —o—o— – 17ø Dripmaster, 0.6 m spacing, 1.0m emitter spacing, 2.3l/em/hr, cover 75 mm
AREA B – —x—x— – 17ø – – , 1.0m – – , 0.8m – – – , 3.5l/em/hr – 100 mm
AREA C – —oo—oo— – 17ø – – , 0.8m – – , 0.6m – – – , 2.3l/em/hr – 100 mm
AREA D – —•—•— – 17ø – – , 0.6 m – – , 1.0m – – – , 2.3l/em/hr, 50 mm
—— – Pressure line 19ø (with 19/16 reducing tees when required)

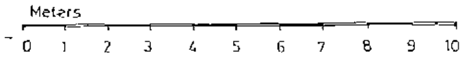
Gravity irrig.

AREA E – —'—'— – 50ø corr. slotted pipe, 16m spacing
AREA F – —"—"— – 25ø perf. PE pipe , 1.0m – – –
— — – Gravity line 25ø 19ø, 16ø, with branches to 50ø laterals

▨ – Buffer zone – 1m unless otherwise shown

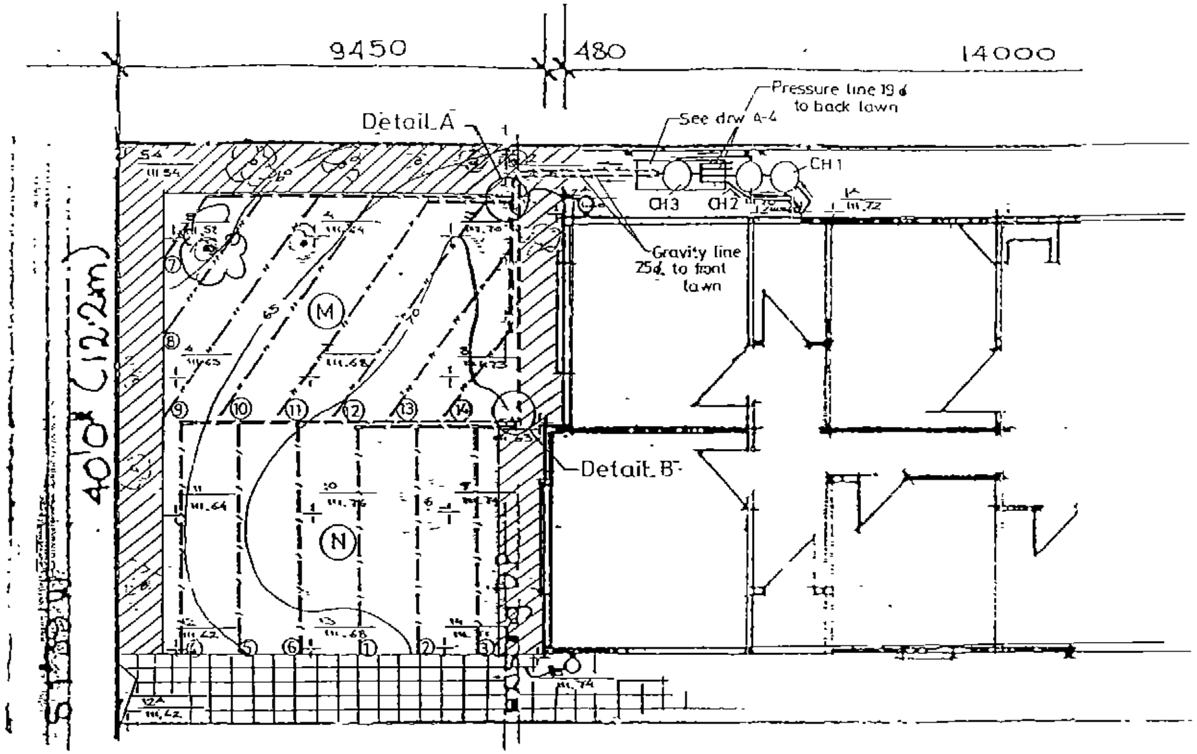
Detail A





SITE No: 2
CLIFTON HILL

DRW B-2



DISTRIBUTION SYSTEM ARRANGMENTS

FRONT LAWN

Note:

Gravity irrig.

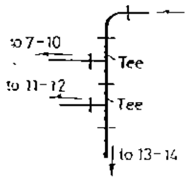
AREA M – —"—"— – 25 ø perf. PE pipe, 1.0m spacing

AREA N – —/—/— – 50 ø corr. slotted pipe, 1.3 m spacing

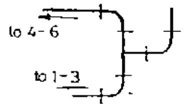
– – – – Gravity line 25ø with branches to 25 ø or 50ø Laterals

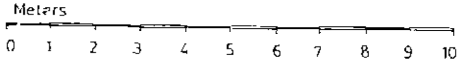
▨ – Buffer zone – 1 m

Detail A



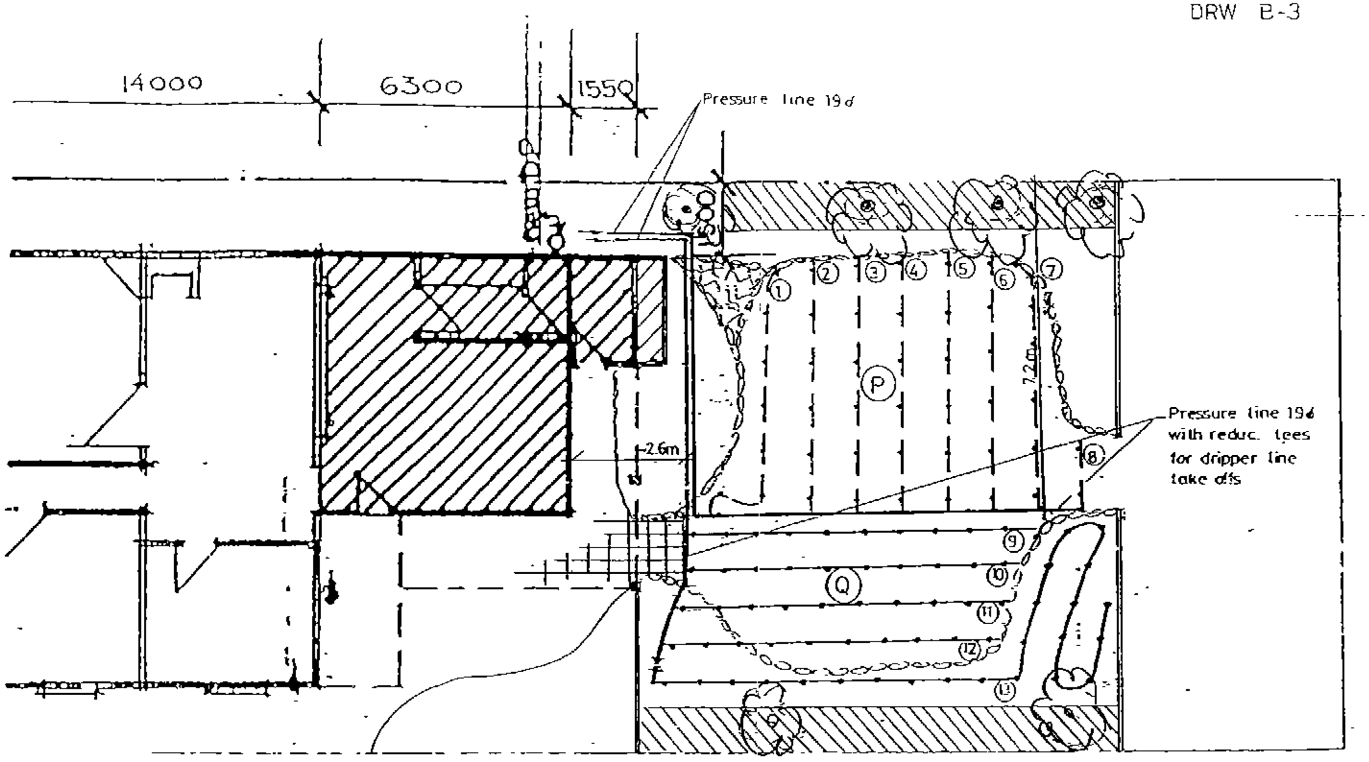
Detail B





SITE No 2
CLIFTON HILL

DRW B-3



DISTRIBUTION SYSTEM ARRANGMENTS

BACK LAWN & GARDEN

Note

Pumped irrig.

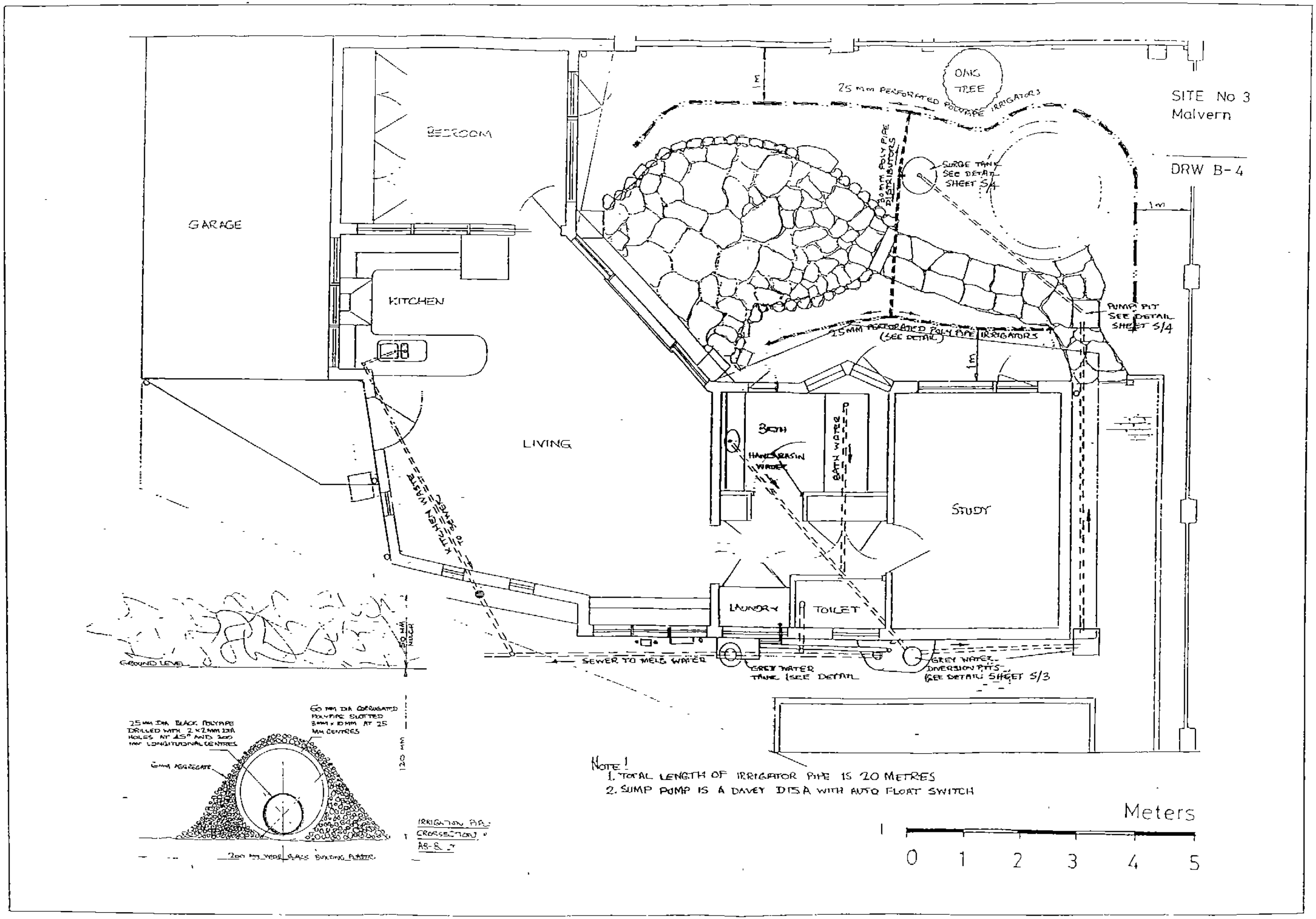
AREA P – –+– –+– – 17ø Dripmaster, -1.0 m spacing, 1.0 m emitter spacing, 2.3 l/em/hr, cover 100mm for 1-4 & cover 75mm for 5-8

AREA Q – –+——+— – 17ø Dripmaster, ~0.5 m spacing, 1.0 m emitter spacing, 2.3 l/em/hr, cover 100mm for 9 10, cover 75 mm for 11-12 & cover 50mm for 13

——— – Pressure line 19ø (with 19/16 reducing tees as required)

▨ – Buffer zone - 1m

Meters
0 1 2 3 4 5 6 7 8 9 10



SITE No 3
Malvern

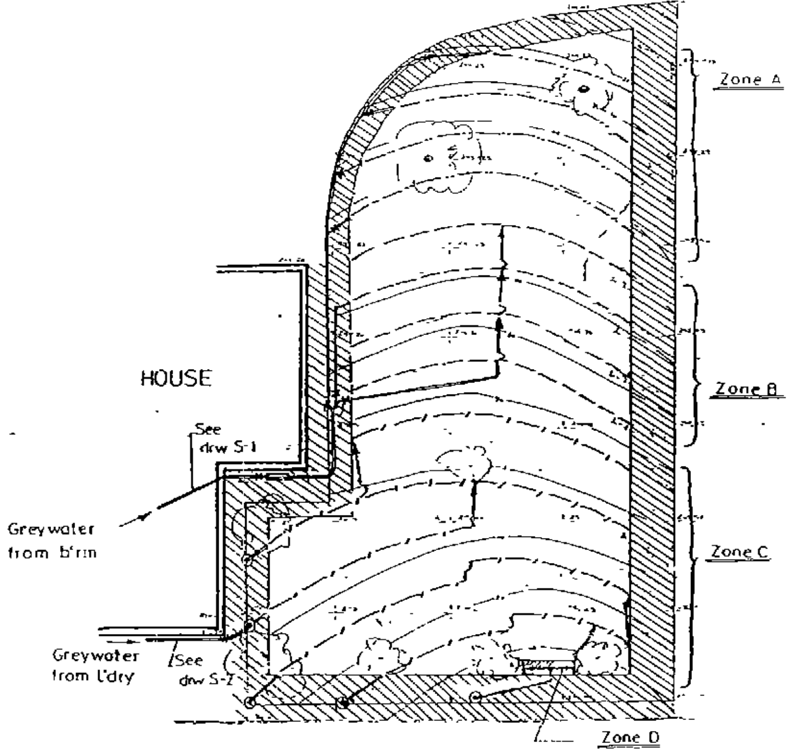
DRW B-4

Note !
1. TOTAL LENGTH OF IRRIGATOR PIPE IS 20 METRES
2. SUMP PUMP IS A DAVEY D15A WITH AUTO FLOAT SWITCH

SITE No 4
Strathmore

DRW B-5

DISTRIBUTION SYSTEM ARRANGMENTS
FRONT LAWN



Note

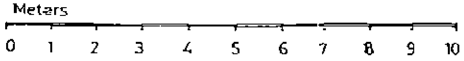
Zone A – has 4 lines with total L= 22 m
—··— DN80 corr slotted pipe, cross section Ⓛ
0.80 m spacing, 100 mm cover

Zone B – has 4 lines with total L= 26 m
—·—·— DN80 corr. slotted pipe, cross section Ⓛ
1.00 m spacing, 100 mm cover

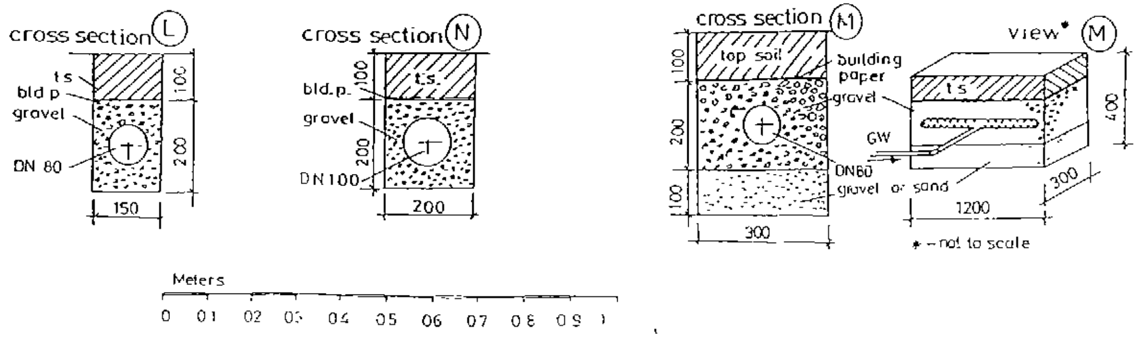
Zone C – has 5 lines with total L= 18 + 22 = 40 m
—/—/ 100 mm slotted subsoil drainage pipe
1.20 m spacing, 100 mm cover, cr. s. Ⓝ

Zone D – has 1 line with L = 1.20 m, cr. s. Ⓜ
▨ DN80 corr. slotted pipe, 180 mm cover
⊗ – entry point to irr. pipes in zones C & D

▧ Buffer zone – 1 m from buildings and property lines.



Cross sections



APPENDIX C

MONTHLY WATER CONSUMPTION AT THE EXPERIMENTAL SITES

Table C.1 - Monthly Water Consumption at Site 1

Site 1(Balwyn)	March'94 - Feb.'95									
Date	Potable water use Main meter	Greywater reuse for irrigation						Toilet flushing		Total GW volume reused
		Zone B Meter 1	Zone C Meter 2	O'flow Meter 3	Zone A Meter 4	Zone E Meter 5	Total GW for irr.	Make-up Meter 6	GW Meter 7	
	kL	kL	kL	kL	kL	kL	kL	kL	kL	kL
March	20.393	0.837	0.913	0	0.782	3.200	5.732	0.084	0.955	6.687
April	23.451	0.604	0.677	0	0.622	1.525	3.428	0.000	0.969	4.398
May	19.934	0	0	0	0	0	0	0	0.798	0.798
June	21.917	0	0	0	0	0	0	0	0.888	0.888
July	24.957	0	0	0	0	0	0	0	1.007	1.007
August	19.105	0	0	0	0	0	0	0	0.916	0.916
September	18.983	0	0	0	0	0	0	0	0.656	0.656
October	20.157	0	0	0	0	0	0	0	0.351	0.351
November	28.915	0.870	0.968	0.034	1.059	3.604	6.501	0.017	0.124	6.625
December	43.293	0.809	1.515	0.141	1.225	1.055	4.604	0.041	0.562	5.167
January	17.231	0.502	0.707	0.000	0.526	1.457	3.192	0.166	0.743	3.935
February	21.744	1.403	2.011	0.000	1.491	0.965	5.869	0.260	0.173	6.042
Total (kL)	280.080	5.026	6.791	0.175	5.705	11.806	29.327	0.568	8.143	37.471

Table C.2 - Monthly Water Consumption at Site 2

Site 1(Clifton Hill)	March'94 - Feb.'95									
Date	Potable water use Main meter	Greywater reuse for irrigation						Toilet flushing		Total GW volume reused
		Zone P Meter 1	Zone Q Meter 2	O'flow Meter 3	Zone M Meter 4	Zone N Meter 5	Total GW for irr.	Make-up Meter 6	GW Meter 7	
	kL	kL	kL	kL	kL	kL	kL	kL	kL	kL
March	8.961	0.313	0.326	0	1.086	1.151	2.875	0	0.725	3.600
April	8.582	0.406	0.449	0	0.823	1.100	2.777	0	0.684	3.461
May	10.674	0	0	0	0	0	0	0	0.854	0.854
June	10.176	0	0	0	0	0	0	0	0.893	0.893
July	10.544	0	0	0	0	0	0	0	0.919	0.919
August	10.340	0	0	0	0	0	0	0	1.108	1.108
September	7.075	0	0	0	0	0	0	0.051	0.696	0.696
October	8.716	0	0	0	0	0	0	0.037	0.666	0.666
November	14.084	0.590	0.427	0	1.306	1.922	4.244	0.118	1.179	5.422
December	17.921	0.706	1.098	0	0.760	1.884	4.449	0.151	1.076	5.525
January	2.418	0.098	0.152	0	0.167	0.302	0.719	0.135	0.034	0.753
February	12.053	0.487	0.935	0	0.746	1.411	3.580	0	0.724	4.304
Total (kL)	121.544	2.600	3.387	0	4.887	7.770	18.645	0.493	9.558	28.203

Table C.3 - Monthly Water Consumption at Site 3

Site 3 (Malvern)			March '94 - Feb.'95		
Date	Rain water Main meter	L'dry GW Meter 1	Bath GW Meter 2	Make-up Meter 3	Total GW volume
	L	L	L	L	L
Mar	5253.86	769.68	0	530.3	769.68
Apr	4846.36	769.28	0	452	769.28
May	4674.28	649.84	0	654.1	649.84
Jun	5929.1	955	0	1071.3	955
Jul	4477.9	659.5	0	793.1	659.5
Aug	6358	1285	2242.3	411.6	3527.3
Sep	4968.9	1080.9	1880.1	0	2961
Oct	4519.5	914.9	1946.9	0	2861.8
Nov	4569.3	910.6	1601.1	54.8	2511.7
Dec	5565.3	942.7	2169.6	367.6	3112.3
Jan	4782.4	903	1430.1	107.3	2333.1
Feb	6273.2	1164.5	2005.6	705.7	3170.1
Total (L)	62218.1	11004.9	13275.7	5147.8	24280.6
Total (kL)	62.218	11.005	13.276	5.148	24.281

Table C.4 - Monthly Water Consumption at Site 4

Site 4 (Strathmore)		Jan.'95-March'95		
	Potable water use	Greywater reuse for irrigation		
		B'rm GW	L'dry GW	Total GW
Date	Main meter	Volume calculated		
	kL	kL	kL	kL
Jan	16.470	2.470	4.064	6.534
Feb	15.385	2.470	3.624	6.094
Mar	20.835	3.380	4.917	8.297
Total	52.690	8.320	12.605	20.925

APPENDIX D

GREYWATER QUALITY ANALYSIS RESULTS

Table D.1 - Analysis Results of Physical Parameters of Greywater

PHYSICAL PARAMETERS										
Parameters		**Round**	**Bathroom greywater**				**Laundry greywater**			
	Date		Balwyn	Cl Hill	Malvern	Strath	Balwyn	Cl Hill	Malvern	Strathmore
TDS, mg/L										
	27 01 94	I	52.48	160	-	-	217 6	896	-	-
	17 03 94	II	53 76	89 6	-	-	121 6	563 2	-	-
	9/10 11.94	III	70 4	70 4	268 8	-	121 6	204.8	307 2	224
	7/8 12 94	IV	57 6	55.04	128	-	53 12	249 6	140 8	243 2
	8/9 02 95	V	60 16	76 8	76 8	-	70 4	307 2	556 8	76 8
	22/23.02.95	VI	62 08	70 4	108 8	-	70 4	563 2	217 6	60 8
Suspended Solids										
	27 01 94	I	48	120	-	-	250	88	-	-
	17 03 94	II	100	72	-	-	130	160	-	-
	9/10 11 94	III	380	200	500	-	320	130	640	200
	7/8 12 94	IV	67	46	330	-	74	120	205	98
	8/9 02 95	V	52	84	34	-	86	140	380	48
	22/23.02 95	VI	150	56	160	-	110	60	400	26
Settleable Matter (vol),ml/l/h										
	27 01 94	I	<0 5	<0 5	-	-	0 5	0 5	-	-
	17 03 94	II	<0 5	<0 5	-	-	0 5	2	-	-
	9/10 11 94	III	broken*	13	<1	-	<1	broken*	10	4
	7/8 12 94	IV	<1	<1	5	-	<1	<1	1	<1
	8/9 02.95	V	<0 2	0 3	0 2	-	0 7	0 2	0 6	<0 2
	22/23 02 95	VI	0 4	0 2	0 6	-	0 8	<0 2	2	<0 2
Colour,Pt/Co units										
	27 01.94	I	70	60	-	-	60	55	-	-
	17 03 94	II	70	100	-	-	50	70	-	-
	9/10 11 94	III	15	15	20	-	20	15	15	15
	7/8.12 94	IV	40	40	40	-	20	60	60	40
	8/9 02 95	V	20	40	20	-	40	60	160	40
	22/23 02 95	VI	50	60	60	-	40	60	400	20
Turbidity, NTU										
	27 01 94	I	60	240	-	-	210	50	-	-
	17 03 94	II	76	82	-	-	65	120	-	-
	9/10 11 94	III	270	180	460	-	260	79	1200	220
	7/8 12.94	IV	36	82	230	-	22	83	220	110
	8/9 02 95	V	50	60	15	-	58	240	350	51
	22/23 02 95	VI	96	60	110	-	70	64	300	23

Results are in mg/L unless specified otherwise

* - sample container broken or lost in the laboratory.

Table D.2 - Analysis Results of Chemical Parameters of Greywater

CHEMICAL PARAMETERS									
Parameters	**Round**	**Bathroom greywater**				**Laundry greywater**			
Date		Balwyn	Cl Hill	Malvern	Strath	Balwyn	Cl Hill	Malvern	Strathmore
pH, units									
27.01.94	I	8	8.1	-	-	9.3	10	-	-
17.03.94	II	6.4	7	-	-	9.4	9.5	-	-
9/10.11.94	III	6.7	6.6	7	-	8.6	8.1	8.3	8.9
7/8.12.94	IV	6.2	6.4	6.6	-	6.3	7.4	7.2	6.5
8/9.02.95	V	6.8	6.5	6.8	-	6.8	5.5	7.2	6.4
22/23.02.95	VI	6.5	6.7	6.9	-	6.6	6.6	7	6.4
Total Alkalinity									
27.01.94	I	-	-	-	-	-	-	-	-
17.03.94	II	24	43	-	-	83	200	-	-
9/10.11.94	III	38	28	110	-	100	66	220	150
7/8.12.94	IV	19	39	60	-	24	150	120	81
8/9.02.95	V	26	31	39	-	37	19	150	21
22/23.02.95	VI	28	34	55	-	31	98	90	27
Chloride									
27.01.94	I	9	18	-	-	22	88	-	-
17.03.94	II	9	14	-	-	9	26	-	-
9/10.11.94	III	12	18	67	-	11	11	42	13
7/8.12.94	IV	12	14	33	-	10	21	34	28
8/9.02.95	V	10	15	10	-	10	91	int	11
22/23.02.95	VI	13	13	int**	-	10	83	int**	9
Nitrate & Nitrite									
27.01.94	I	0.19	<0.05	-	-	0.1	0.31	-	-
17.03.94	II	0.16	0.2	-	-	0.14	0.27	-	-
9/10.11.94	III	0.1	<0.02	<0.2	-	<0.2	0.18	0.05	0.023
7/8.12.94	IV	0.18	0.12	0.08	-	0.19	<0.05	0.16	0.44
8/9.02.95	V	0.14	0.13	0.13	-	0.21	1.8	0.22	0.19
22/23.02.95	VI	<0.02	<0.02	0.07	-	0.15	0.18	0.32	0.17
Ammonia									
27.01.94	I	0.9	15	-	-	0.2	1.9	-	-
17.03.94	II	<0.1	3	-	-	<0.1	1.9	-	-
9/10.11.94	III	0.74	1.2	7.8	-	0.27	2.3	0.55	1.2
7/8.12.94	IV	<0.1	2.2	1.8	-	0.2	3.1	2.1	11
8/9.02.95	V	1.1	1.2	1	-	0.3	<0.1	6.7	2.4
22/23.02.95	VI	0.6	1.8	3.9	-	<0.1	<0.1	7.4	3.1
Total Kjeldahl Nitrogen									
27.01.94	I	4.6	20	-	-	11	40	-	-
17.03.94	II	6.6	8.7	-	-	1	20	-	-
9/10.11.94	III	3.2	9.2	23	-	3.6	10	29	16
7/8.12.94	IV	2.4	3.7	12	-	2.5	15	13	33
8/9.02.95	V	3.5	6.8	4.2	-	3.4	48	26	14
22/23.02.95	VI	13	6.7	12	-	6.8	48	25	8.4
Phosphorus (reactive)									
27.01.94	I	0.1	1.4	-	-	0.24	2.6	-	-
17.03.94	II	0.04	0.2	-	-	<0.003	12	-	-
9/10.11.94	III	0.04	0.04	0.39	-	0.16	2.4	0.39	0.16
7/8.12.94	IV	0.017	0.035	0.34	-	0.019	22	0.14	0.13
8/9.02.95	V	0.034	0.092	0.25	-	0.032	3.3	3	0.13
22/23.02.95	VI	0.22	0.075	0.21	-	0.022	8.1	0.41	0.054
Phosphorus (total)									
27.01.94	I	0.17	1.8	-	-	1.2	3	-	-
17.03.94	II	0.11	0.31	-	-	0.062	42	-	-
9/10.11.94	III	0.22	0.35	0.27	-	1.1	11	4.4	0.56
7/8.12.94	IV	0.1	0.12	0.88	-	0.1	31	0.59	0.63
8/9.02.95	V	0.14	0.3	0.53	-	0.14	7.8	24	0.2
22/23.02.95	VI	0.67	0.25	0.54	-	0.22	36	0.91	0.22
Potassium									
27.01.94	I	1.5	5.2	-	-	3.5	17	-	-
17.03.94	II	1.8	3.8	-	-	1.1	4.1	-	-
9/10.11.94	III	2.9	2	8.9	-	3.4	2.3	11	5.3
7/8.12.94	IV	1.9	2.9	6.4	-	3.5	7	6.3	23
8/9.02.95	V	1.7	2.1	2.1	-	3.6	5.1	12	7.1
22/23.02.95	VI	1.3	2	4.3	-	4.1	4.6	15	5.4
Sulphate									
27.01.94	I	6.3	9.9	-	-	48	30	-	-
17.03.94	II	3.6	8.1	-	-	28.5	120	-	-
9/10.11.94	III	5.1	12.9	30	-	26.4	72	84	42
7/8.12.94	IV	9.6	9.9	9.3	-	7.8	138	29.1	18.6
8/9.02.95	V	<0.3	3.3	2.7	-	10.5	48	261	7.2
22/23.02.95	VI	2.7	4.2	4.5	-	7.2	168	54	4.2
Fluoride									
27.01.94	I	0.93	0.8	-	-	0.96	0.78	-	-
17.03.94	II	0.86	0.65	-	-	1.6	1.2	-	-
9/10.11.94	III	0.8	0.78	0.07	-	0.73	0.81	0.08	0.94
7/8.12.94	IV	1.05	0.99	0.06	-	1	1.05	0.15	1
8/9.02.95	V	0.92	0.67	0.05	-	0.93	0.57	0.07	0.84
22/23.02.95	VI	0.95	0.49	<0.05	-	0.88	0.68	0.07	0.88

Results are in mg/L unless specified otherwise.

** - result rejected due to interference caused by sample composition.

Table D.2 - Analysis Results of Chemical Parameters of Greywater (continued)

CHEMICAL PARAMETERS									
Parameters	**Round**	**Bathroom greywater**				**Laundry greywater**			
Date		Balwyn	Cl.Hill	Malvern	Strath	Balwyn	Cl.Hill	Malvern	Strathmore
Sodium									
27.01.94	I	7.4	18	-	-	93	480	-	-
17.03.94	II	8.6	11	-	-	49	140	-	-
9/10.11.94	III	13	14	66	-	62	65	150	100
7/8.12.94	IV	13	17	27	-	14	150	84	44
8/9.02.95	V	8	11	20	-	20	72	190	13
22/23.02.95	VI	15	13	29	-	19	200	61	12
Calcium									
27.01.94	I	3 5	7.2	-	-	12	7.7	-	-
17.03.94	II	3 9	7.9	-	-	3.9	8.4	-	-
9/10 11.94	III	6 1	7.2	30	-	11	3.8	27	7.3
7/8.12.94	IV	3.5	5.4	8	-	4.7	5.7	6 3	3.7
8/9 02.95	V	5 1	5 5	2.7	-	5.4	11	12	4.7
22/23 02 95	VI	8 6	6.8	4.3	-	5.5	6.6	9	2.3
Magnesium									
27 01.94	I	1 4	2.3	-	-	2.2	2 9	-	-
17.03.94	II	1.4	1.8	-	-	1.1	2.6	-	-
9/10.11.94	III	1 6	2	3 3	-	2.4	1 4	5.3	0.9
7/8.12.94	IV	1.4	1.7	3	-	1 8	2.6	1.5	1.2
8/9 02.95	V	1.6	1 8	1 2	-	2.5	3 2	4.6	1.5
22/23.02.95	VI	1.8	1.9	1.2	-	2	2	2.1	0 7
SAR (calculated)									
27.01.94	I	0.84	1.49	-	-	6.46	37.30	-	-
17 03.94	II	0.95	0.92	-	-	5 63	10.79	-	-
9/10.11 94	III	1.21	1.19	3.05	-	4 40	7.22	6.89	9.27
7/8.12.94	IV	1.48	1.63	2.06	-	1.39	13 03	7.79	5.07
8/9.02.95	V	0.79	1.04	2.54	-	1.78	4.90	11.79	1.33
22/23.02.95	VI	1.21	1.13	3.18	-	1.76	17.46	4.75	1.77
Aluminium									
27.01.94	I	<1.0	<1.0	-	-	21	<1.0	-	-
17.03.94	II	<1.0	<1.0	-	-	14	<1.0	-	-
9/10.11.94	III	<1.0	1 4	18	-	44	1.2	96	21
7/8.12.94	IV	<1.0	<1.0	18	-	8.6	<1.0	19	<1.0
8/9.02.95	V	<1.0	<1.0	<1.0	-	7 6	<1.0	34	<1.0
22/23.02.95	VI	<1.0	<1.0	<1.0	-	9.4	<1.0	15	<1.0
Arsenic									
27.01.94	I	<0.5	<0.5	-	-	<0 5	<0.5	-	-
17.03.94	II	0.001	0 001	-	-	0.001	0.007	-	-
9/10.11.94	III	0.001	0.001	0.013	-	0.001	0.003	0.006	0.001
7/8.12.94	IV	<0.001	<0.001	0.004	-	0.0001	0.004	0.003	<0.001
8/9.02.95	V	0.001	0 001	0.003	-	0.002	0.004	0 007	0.001
22/23.02.95	VI	0.001	<0.001	0.003	-	0.001	0.006	0.005	<0.001
Boron									
27.01.94	I	<0 1	<0.1	-	-	<0.1	<0 1	-	-
17.03.94	II	<0.1	<0.1	-	-	<0.1	0.5	-	-
9/10.11.94	III	<0.1	<0.1	<0 1	-	<0.1	0.3	<0.1	0.1
7/8 12.94	IV	<0.1	<0.1	<0.1	-	<0.1	0.6	<0 1	0.2
8/9.02.95	V	<0.1	<0.1	<0.1	-	0.1	3.2	0.1	0.3
22/23 02.95	VI	<0 1	<0.1	<0.1	-	0.2	4.4	0.5	<0.1
Cadmium									
27 01.94	I	<0 05	<0.05	-	-	<0 05	<0.05	-	-
17 03.94	II	<0 01	<0.01	-	-	<0.01	<0.01	-	-
9/10.11.94	III	<0.05	<0.05	<0 05	-	<0.05	<0.05	<0 05	<0.05
7/8 12 94	IV	<0.05	<0.05	<0.05	-	<0.05	<0.05	<0.05	<0.05
8/9.02.95	V	<0.05	<0.05	<0.05	-	<0 05	<0.05	<0.05	<0.05
22/23.02.95	VI	<0 05	<0 05	<0.05	-	<0.05	<0.05	<0.05	<0 05
Chromium									
27.01 94	I	<0.05	<0.05	-	-	<0.05	<0.05	-	-
17.03.94	II	<0 01	<0.01	-	-	<0.01	<0.01	-	-
9/10.11.94	III	<0 05	<0.05	<0.05	-	<0.05	<0 05	<0 05	<0 05
7/8.12.94	IV	<0.05	<0.05	<0.05	-	<0.05	<0 05	<0 05	<0.05
8/9.02.95	V	<0.05	<0.05	<0 05	-	<0.05	<0.05	<0.05	<0 05
22/23.02.95	VI	<0 05	<0.05	<0.05	-	<0.05	<0 05	<0 05	<0.05
Copper									
27.01.94	I	0 09	0.12	-	-	0 27	0 14		-
17.03.94	II	0.06	0.08	-	-	<0.05	0.1	-	-
9/10.11 94	III	0.17	0.2	1	-	<0.05	0.08	0.49	0 15
7/8.12 94	IV	<0.05	0.08	0.32	-	<0.05	0 12	0 27	0 13
8/9.02.95	V	0 07	0.05	0.07	-	<0.05	0 2	0 21	0 06
22/23.02.95	VI	0.21	0.06	0 12	-	0.06	0.32	0 31	0.05

Results are in mg/L unless specified otherwise.

Table D.2 - Analysis Results of Chemical Parameters of Greywater (continued)

CHEMICAL PARAMETERS									
Parameters	**Round**	**Bathroom greywater**				**Laundry greywater**			
Date		Balwyn	Cl Hill	Malvern	Strath	Balwyn	Cl.Hill	Malvern	Strathmore
Iron									
27.01.94	I	0.59	0.97		-	0 75	0.96	-	-
17.03 94	II	0.34	1.1	-	-	0.29	1	-	-
9/10 11.94	III	0.71	8	6.2	-	0 78	1	4.2	0 47
7/8.12.94	IV	<0.05	1.2	2	-	<0.05	<0 05	1.2	<0.05
8/9 02 95	V	0.22	1 4	0.9	-	0.4	0.51	3.6	0.67
22/23.02.95	VI	0.35	1.3	0.92	-	0 66	0.38	3	0.15
Lead									
27.01 94	I	<0.05	<0.05	-	-	<0.05	<0.05	-	-
17.03.94	II	<0.05	<0.05	-	-	<0.05	<0.05	-	-
9/10.11.94	III	0.05	<0.05	0.56	-	<0.05	<0.05	0.84	<0.05
7/8.12.94	IV	<0.05	<0.05	0.37	-	<0.05	<0.05	0.18	<0.05
8/9.02.95	V	<0 05	<0.05	<0.05	-	<0.05	<0.05	0 49	<0.05
22/23.02.95	VI	<0.05	0 05	0.28	-	0.08	0:06	1.3	<0.05
Manganese									
27.01.94	I	<0.05	<0 05	-	-	<0.05	<0.05	-	-
17 03.94	II	<0 05	<0.05	-	-	<0.05	<0.05	-	-
9/10 11.94	III	<0.05	<0.05	0.14	-	<0.05	0.15	0.16	<0.05
7/8.12.94	IV	<0.05	<0.05	0.06	-	<0.05	<0.05	<0.05	<0.05
8/9.02.95	V	<0.05	<0.05	<0.05	-	<0.05	<0.05	0.12	<0.05
22/23.02 95	VI	<0.05	<0.05	<0.05	-	<0.05	<0.05	0.06	<0.05
Nickel									
27.01.94	I	<0.05	<0.05	-	-	<0 05	<0.05	-	-
17.03.94	II	<0.05	<0.05	-	-	<0 05	<0.05	-	-
9/10 11.94	III	<0.05	<0.05	0.07	-	<0.05	<0.05	<0.05	<0.05
7/8 12.94	IV	<0.05	<0.05	<0.05	-	<0.05	<0.05	<0.05	<0.05
8/9 02 95	V	<0.05	<0.05	<0.05	-	<0 05	<0.05	<0.05	<0.05
22/23 02 95	VI	<0.05	<0.05	<0.05	-	<0.05	<0.05	<0.05	<0.05
Selenium									
27 01.94	I	<0.001	<0.001		-	<0.001	<0.001	-	-
17.03.94	II	<0.001	<0.001	-	-	<0.001	<0.001	-	-
9/10 11 94	III	<0.001	<0.001	<0.001	-	<0.001	<0.001	<0.001	<0 001
7/8.12.94	IV	<0.001	<0.001	<0.001	-	<0.001	<0.001	<0 001	<0.001
8/9.02.95	V	<0.001	<0.001	<0.001	-	<0.001	<0.001	<0.001	<0.001
22/23.02.95	VI	<0.001	<0.001	<0.001	-	<0.001	<0.001	<0.001	<0 001
Zinc									
27.01.94	I	6.3	0.45	-	-	0.32	0.17	-	-
17.03.94	II	4.2	0.2	-	-	0.09	0.27	-	-
9/10.11.94	III	12	0.94	4 6	-	0.32	0.16	11	0.33
7/8.12.94	IV	0.7	0.18	13	-	0.13	0 24	5 4	0.34
8/9.02.95	V	1.5	0.18	0.96	-	0.13	31	7.5	0.18
22/23.02.95	VI	6	0.13	1.3	-	0.19	19	5.1	0.1
BOD, 5 day									
27.01.94	I	76	200	-	-	270	140	-	-
17.03.94	II	140	110	-	-	48	290	-	-
9/10.11.94	III	330	250	440	-	190	105	740	520
7/8.12.94	IV	195	215	330	-	95	210	420	220
8/9.02.95	V	84	200	45	-	94	<10	270	>160
22/23 02.95	VI	>280	97	300	-	110	<10	460	50
Azure-A Active Substances									
27.01.94	I	10	1.2	-	-	150	30	-	-
17.03 94	II	3 4	2.4	-	-	60	70	-	-
9/10.11.94	III	3.1	7 3	35	-	69	36	150	130
7/8 12 94	IV	6.1	7.1	8.1	-	14	33	90	29
8/9.02.95	V	2.2	4.7	0.8	-	20	20	71	29
22/23.02.95	VI	<0.1	8	13	-	22	8	94	20
Oil & Grease									
27.01 94	I	37	78	-	-	35	32	-	-
17.03.94	II	51	54	-	-	8	28	-	-
9/10.11.94	III	50	180	170	-	50	95	170	95
7/8.12.94	IV	54	63	94	-	14	47	49	49
8/9 02.95	V	20	60	10	-	25	55	30	30
22/23.02.95	VI	90	35	55	-	20	35	130	25

Results are in mg/L unless specified otherwise.

Table D.3 - Analysis Results of Microbiological Parameters of Greywater

MICROBIOLOGICAL PARAMETERS									
Parameters	**Round**	**Bathroom greywater**				**Laundry greywater**			
Date		Balwyn	Cl.Hill	Malvern	Strath	Balwyn	Cl.Hill	Malvern	Strathmore
Total Coliforms									
27.01.94	I	< 2	2.4x10*7	-	-	3.3x10*5	2.3x10*3	-	-
17.03.94	II	5x10*2	4 9x10*5	-	-	4.9x10*4	1.72x10*5	-	-
9/10.11 94	III	>2.4x10*7	>2.4x10*7	>2.4x10*7	-	>2.4x10*7	>2.4x10*7	>2.4x10*7	>2.4x10*7
7/8.12.94	IV	3.3x10*5	1.41x10*7	3.5x10*6	-	7.0x10*7	1 6x10*6	1 4x10*5	3.4x10*7
8/9.02 95	V	2 78x10*6	1.75x10*7	7.9x10*6	-	1.6x10*8	no growth*	9.18x10*7	1.6x10*5
22/23.02.95	VI	1.3x10*4	4.9x10*4	2.2x10*6	-	2.4x10*5	no growth*	5.4x10*6	>2.4x10*8
Faecal Coliforms									
27.01.94	I	< 2	< 2	-	-	< 2	< 2	-	-
17.03 94	II	1.7x10*2	3.3x10*3	-	-	1.1x10*2	1 09x10*3	-	-
9/10.11 94	III	1.6x10*3	3.3x10*3	3 4x10*4	-	9 2x10*2	3.4x10*4	1 6x10*5	>2.4x10*7
7/8.12.94	IV	9x10*4	3.4x10*6	2.7x10*4	-	1.1x10*6	5 4x10*6	3.3x10*4	2.2x10*7
8/9.02.95	V	9.4x10*4	6.3x10*4	1 7x10*4	-	9.2x10*7	no growth*	2.4x10*6	4.9x10*4
22/23.02.95	VI	5.24x10*2	1.72x10*4	1.61x10*4	-	3.45x10*4	no growth*	5.42x10*5	2.2x10*5
Faecal Streptococci									
27.01.94	I	< 2	>2.4x10*3	-	-	< 2	>2.4x10*3	-	-
17.03.94	II	79	7x10*2	-	-	23	3 3x10*3	-	-
9/10.11.94	III	3 3x10*2	3 5x10*2	3 5x10*2	-	< 2	< 2	< 2	< 2
7/8.12.94	IV	< 10*2	< 10*2	1.41x10*2	-	< 10*2	< 10*2	33	1.3x10*4
8/9.02.95	V	23	23	45	-	5.42x10*2	no growth*	23	49
22/23.02.95	VI	14	2.4x10*2	79	-	49	no growth*	70	5.42x10*2
Salmonella sp.									
27.01.94	I	negative	negative	negative	-	negative	negative	-	-
17 03.94	II	negative	negative	negative	-	negative	negative	-	-
9/10.11.94	III	negative	negative	negative	-	negative	negative	negative	negative
7/8 12.94	IV	negative	negative	negative	-	negative	negative	negative	negative
8/9.02 95	V	negative	negative	negative	-	negative	negative	negative	negative
22/23.02.95	VI	negative	negative	negative	-	negative	negative	negative	negative
Campylobacter sp.									
27.01.94	I	negative	negative	negative	-	negative	negative	-	-
17.03 94	II	negative	negative	negative	-	negative	negative	-	-
9/10.11.94	III	negative	negative	negative	-	negative	negative	negative	negative
7/8.12.94	IV	negative	negative	negative	-	negative	negative	negative	negative
8/9.02.95	V	negative	negative	negative	-	negative	negative	**positive****	negative
22/23.02.95	VI	negative	negative	negative	-	negative	negative	negative	negative
Giardia									
27.01.94	I	negative	negative	negative	-	negative	negative	-	-
17.03.94	II	negative	negative	negative	-	negative	negative	-	-
9/10.11.94	III	negative	negative	negative	-	negative	negative	negative	negative
7/8.12.94	IV	negative	negative	negative	-	negative	negative	negative	negative
8/9.02.95	V	negative	negative	negative	-	negative	negative	negative	negative
22/23.02.95	VI	negative	negative	negative	-	negative	negative	negative	negative
Cryptosporidium									
27.01.94	I	negative	negative	negative	-	negative	negative	-	-
17.03.94	II	negative	negative	negative	-	negative	negative	-	-
9/10 11.94	III	negative	negative	negative	-	negative	negative	negative	negative
7/8.12 94	IV	negative	negative	negative	-	negative	negative	negative	negative
8/9.02.95	V	negative	negative	negative	-	negative	negative	negative	negative
22/23.02.95	VI	negative	negative	negative	-	negative	negative	negative	negative

Results are in cfu/100mL unless specified otherwise

Values are as quoted by testing laboratory.

* - This sample was chlorinated, no growth of microorganisms was observed

** - an environmental species.

Table D.4 - Potable water quality at Site 1 (Balwyn)

POTABLE WATER QUALITY	SOURCE: SURREY HILLS - SILVAN RESERVOIR			
Site	BALWYN			
Date	27/28.01.94	.11.94	.12.94	.02.95
Round	1st round	3rd round	4th round	5/6th round
Parameters				
pH, units	7.4	8.2	7.4	7.3
EC 25C, microS/cm	56	58	57	50
Colour, Pt/Co units	12	14	12	11
Turbidity, FTU	1.6	1.7	1.5	2.3
Total Cl	<0.1	<0.1	<0.01	<0.1
Total solids	45	42	42	42
Total Alkalinity, as $CaCO_3$	10	7.9	10.6	18.9
Hardness	17.4	13	16	25
Chloride, as Cl	6.8	8.1	7.1	16
Fluoride, as F	0.82	0.97	0.83	0.9
Silica	7	7	6.3	5.3
Selenium, as Se	<0.001	<0.001	<0.001	<0.001
Total Organic Carbon	2		2.1	1.6
Nitrate , as N	0.16	0.14	0.2	0.15
Total Kjeldahl Nitrogen, as N	0.1	0.05	0.1	0.1
Phosphorus, total as P	0.012	0.02	0.01	0.007
Sulphate	1.4	1.6	2.5	1.8
Calcium (Ca)	2.4	2.7	2	1.8
Magnesium (Mg)	1.4	1.4	1.3	0.1
Sodium (Na)	4.4	6.6	4.9	5.2
Potassium (K)	0.47	0.4	0.52	0.7
Iron (Fe)	0.19	0.1	0.11	0.12
Manganese (Mn)	<0.02	<0.02	<0.02	<0.02
Zinc (Zn)	<0.01	<0.01	<0.01	<0.05
Cadmium (Cd)	<0.0005	<0.0002	<0.0002	<0.0002
Copper (Cu)	0.05	0.03	0.04	<0.05
Lead (Pb)		<0.001	<0.001	<0.001
Nickel (Ni)				
Chromium (Cr)	<0.002	<0.001	<0.001	<0.001
Mercury (Hg)	<0.00005	<0.00005	<0.00005	<0.0005
Arsenic (As)	<0.001	<0.001	<0.001	<0.001
Aluminium (Al)	0.15	0.092	0.2	0.13
Boron (B)				
PC @ 37°C, orgs/mL	26	32	123	3
T.coliforms, orgs/100mL	<1	4	7	2
F.coliforms, orgs/100mL	<1	0	0	<1

Results are in mg/L unless specified otherwise.

Table D.5 - Potable water quality at Site 2 (Clifton Hill)

POTABLE WATER QUALITY	SOURCE: PRESTON - SILVAN RESERVOIR			
Site	CLIFTON HILL			
Date	27/28.01.94	.11.94	.12.94	.02.95
Round	1st round	3rd round	4th round	5/6th round
Parameters				
pH, units	7.4	7.5	7.9	7.7
EC 25C, microS/cm	76	70	87	70
Colour, Pt/Co units	8	12	5	7
Turbidity, FTU	1.5	1.3	1	1.8
Total Cl	<0.1	<0.1	<0.1	<0.1
Total solids	60	65	55	39
Total Alkalinity, as CaCO3	9.6	8.9	10	11.7
Hardness	19.5	17.1	21	18.3
Chloride, as Cl	10.6	14	11	8.4
Fluoride, as F	0.68	0.81	0.87	0.88
Silica	4.7	4.1	5	5.3
Selenium, as Se	<0.001	<0.001	<0.001	<0.001
Total Organic Carbon	2	1.9	3	1.6
Nitrate , as N	0.14	0.17	0.15	0.02
Total Kjeldahl Nitrogen, as N	0.13	0.12	0.12	0.1
Phosphorus, total as P	<0.005	<0.005	<0.005	0.01
Sulphate	3.9	3.9	4	1.5
Calcium (Ca)	3.1	2.4	3	0.5
Magnesium (Mg)	1.4	1.2	1.6	1.5
Sodium (Na)	7.6	7.4	8	6
Potassium (K)	0.7	0.5	0.6	0.7
Iron (Fe)	0.09	0.09	0.06	0.12
Manganese (Mn)	<0.02	<0.02	<0.02	<0.02
Zinc (Zn)	0.04	<0.01	<0.01	<0.05
Cadmium (Cd)	<0.0005	<0.0002	<0.0002	<0.0002
Copper (Cu)	<0.02	0.03	0.03	<0.05
Lead (Pb)		<0.001	<0.001	<0.001
Nickel (Ni)				
Chromium (Cr)	<0.002	<0.001	<0.001	<0.001
Mercury (Hg)	<0.00005	<0.00005	<0.00005	<0.0005
Arsenic (As)	<0.001	<0.001	<0.001	<0.001
Aluminium (Al)	0.1	0.04	0.1	0.05
Boron (B)				
PC @ 37°C, orgs/mL	9	11	143	21
T.coliforms, orgs/100mL	<1	<1	0	7
F.coliforms, orgs/100mL	<1	0	0	<1

Results are in mg/L unless specified otherwise.

Table D.6 - Potable water quality at Site 3 (Malvern)

POTABLE WATER QUALITY	SOURCE: KITCHEN TAP		
Site	MALVERN		
Date	03.10.94	16.11.94	NHMRC*
Round		4th round	values
Parameters			
pH, units	6.4	9.1	6.5 to 8.5
Apparent Colour, Pt/Co units	6	16	15**
Turbidity, NTU	1	2.7	5
Zinc (Zn)	1.1	1.3	5
Cadmium (Cd)	<0.005	<0.01	0.005
Lead (Pb)	<0.05	<0.05	0.05
Aluminium (Al)	0.012	0.03	0.2
T.coliforms, orgs/100mL	24	<1	10
F.coliforms, orgs/100mL	13	<1	<1

POTABLE WATER QUALITY	SOURCE: RAIN TANK SURFACE		
Site	MALVERN		
Date		16.11.94	NHMRC*
Round		4th round	values
Parameters			
pH, units		6.7	6.5 to 8.5
Apparent Colour, Pt/Co units		36	15**
Turbidity, NTU		6	5
Zinc (Zn)		1.3	5
Cadmium (Cd)		<0.01	0.005
Lead (Pb)		<0.05	0.05
Aluminium (Al)		0.038	0.2
T.coliforms, orgs/100mL		<1	10
F.coliforms, orgs/100mL		<1	<1

*National Health & Medical Research Council GUIDELINES FOR DRINKING WATER QUALITY IN AUSTRALIA (1987)

Results are in mg/L unless specified otherwise.

** True colour

Table D.7 - Potable water quality at Site 4 (Strathmore)

POTABLE WATER QUALITY	SOURCE: PRESTON RESERVOIR	
Site	STRATHMORE	
Date	.12.94	.02.95
Round	4th round	5/6th round
Parameters		
pH, units	7.2	7.3
EC 25C, microS/cm	57	52
Colour, Pt/Co units	7	9
Turbidity, FTU	1.3	1.9
Total Cl	<0.01	<0.1
Total solids	50	48
Total Alkalinity, as CaCO3	10.2	10.6
Hardness	12	12
Chloride, as Cl	19	7.4
Fluoride, as F	0.8	0.89
Silica	6.9	7.2
Selenium, as Se	<0.001	<0.001
Total Organic Carbon	2.4	2.2
Nitrate , as N	0.38	0.16
Total Kjeldahl Nitrogen, as N	0.05	0.05
Phosphorus, total as P	0.02	0.02
Sulphate	1.4	1.4
Calcium (Ca)	0.05	3.3
Magnesium (Mg)	1.2	1.3
Sodium (Na)	18	4.2
Potassium (K)	0.72	0.4
Iron (Fe)	<0.05	0.1
Manganese (Mn)	<0.02	<0.02
Zinc (Zn)	<0.01	<0.05
Cadmium (Cd)	<0.0002	<0.0002
Copper (Cu)	0.04	<0.05
Lead (Pb)	<0.001	<0.001
Nickel (Ni)		
Chromium (Cr)	<0.001	<0.001
Mercury (Hg)	<0.00005	<0.0005
Arsenic (As)	<0.001	<0.001
Aluminium (Al)	0.82	0.12
Boron (B)		
PC @ 37°C, orgs/mL	<1	<1
T.coliforms, orgs/100mL	0	1
F.coliforms, orgs/100mL	0	0

Results are in mg/L unless specified otherwise.

APPENDIX E

RECEIVING SOILS ANALYSIS RESULTS

Table E.1 - Analysis Results of Receiving Soils Parameters at Site 1 (Balwyn)

SOIL SAMPLES		SITE 1 BALWYN															
Greywater source		Bathroom greywater								Laundry greywater							
Soil location		Top soil (0 mm-250mm)				Subsoil (250mm-400mm)				Top soil				Subsoil (250mm-400mm)			
Sampling round		I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV
Date		06.08.93	01.06.94	02.11.94	07.03.95	06.08.93	01.06.94	02.11.94	07.03.95	06.08.93	01.06.94	02.11.94	07.03.95	06.08.93	01.06.94	02.11.94	07.03.95
Parameter	units																
pH (water) - acidity or alkalinity		7	5.7	5.6	6	5.8	5	4.8	5.2	7	4.9	5.1	5.9	5.8	5.3	5	6.4
pH (CaCl2) - acidity or alkalinity		6.6	5.1	5	5.2	4.8	4.3	4	4.3	6.6	4.3	4.4	4.7	4.8	4.2	4	4.6
Electrical Conductivity (1 5)	dS/m	0.14	0.17	0.1	< 0.05	0.02	0.1	59	< 0.05	0.14	0.16	0.1	0.11	0.02	< 0.05	54	0.05
Total soluble Salts	mg/kg	0.05	505	297	150	0.01	297	150	150	0.05	475	297	327	0.01	150	505	150
Chloride Salts - as NaCl	%	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Phosphorus (P) - Olsen Method	ug/g	15.7	24	17.4	15.2	1.4	17.3	2.5	8.6	15.7	23	16.8	17.8	1.4	< 1	2.1	14.1
Total Phosphorus (P)	%	0.017	0.029	0.0027	0.031	0.037	0.035	0.005	0.012	0.017	0.028	0.023	0.03	0.037	0.009	0.007	0.016
Potassium (K) - Stene Method	ug/g	90	162	76	38	6	155	18	28	90	180	84	62	6	130	13	59
Available Boron (B)	ug/g	4 (t)	1.04	0.4	0.5	< 1 (t)	0.71	0.2	0.5	4 (t)	0.71	0.5	1	< 1 (t)	0.25	0.2	0.7
Total Iron (Fe)	%	0.27	0.31	0.45	0.34	0.21	0.44	0.44	0.39	0.27	0.38	0.43	0.4	0.21	0.47	0.43	0.47
Total Nitrogen (N)	%	0.26	0.23	0.19	0.21	< 0.05	0.21	0.03	0.07	0.26	0.25	0.2	0.12	< 0.05	< 0.05	0.04	0.05
Oxidizable Organic Carbon (C)	%	4.6	0.86	2.8	2	0.89	0.86	0.5	1.1	4.6	2.2	2.8	1.2	0.89	0.51	0.65	0.63
Organic Matter	%	7.6	1.7	5.3	3.8	1.7	1.7	1	2.1	7.6	4.2	5.3	2.3	1.7	1	1.3	1.2
Aluminium (Al) - KCl Exchangeable	ug/g	< 5	< 10	< 10	<10	14	10	59	29	< 5	13	< 10	< 10	14	31	54	< 10
Exch Manganese (Mn)	mg/kg	< 5	13	NA	NA	< 5	50	NA	NA	< 5	52	NA	NA	< 5	9	NA	NA
Extractable Calcium (Ca) - Amm.Acet	meq/100g	10	5.5	3.7	4	0.3	2.8	0.21	0.87	10	2.2	2.3	2.8	0.3	0.4	0.27	0.55
Extractable Magnesium (Mg) - Amm Acet	meq/100g	0.8	0.7	0.5	0.4	< 0.1	0.5	0.07	0.19	0.8	0.5	0.52	0.57	< 0.1	0.1	0.09	0.48
Extractable Sodium (Na) - Amm.Acet	meq/100g	0.1	0.1	0.09	0.06	< 0.1	0.1	< 0.05	0.06	0.1	2.1	0.15	0.63	< 0.1	0.1	0.09	0.64
Extractable Potassium (K) - Amm Acet	meq/100g	0.2	0.2	0.15	0.09	< 0.1	0.1	0.07	0.07	0.2	0.1	0.17	0.17	< 0.1	< 0.1	0.05	0.15
Sum of 4 cations	meq/100g	NA	6.5	4.5	4.6	NA	3.5	0.4	1.2	NA	2.9	3.2	4.2	NA	0.7	0.5	1.9
Calcium Magnesium (Ca Mg) Ratio		NA	7.9	7.4	10	NA	5.6	3	4.6	NA	4.4	4.5	5	NA	4	3	1.2
Calcium as % of Cations	%	90	85	84	88	*	80	53	74	90	76	74	68	*	58	54	31
Magnesium as % of Cations	%	7	11	12	9	*	15	18	16	7	18	17	14	*	15	18	27
Sodium as % of Cations	%	1	2	2	2	*	3	13	5	1	4	5	16	*	15	18	36
Potassium as % of Cations	%	2	3	4	2	*	3	18	6	2	4	6	4	*	15	10	9
Total Selenium (Se)	mg/kg	0.08	< 0.1	< 0.1	0.1	0.04	< 0.1	0.1	0.1	0.08	0.1	0.1	0.1	0.04	< 0.1	0.1	0.1
Total Copper (Cu)	mg/kg	< 10	6	7	7	< 10	5	< 3	4	< 10	4	5	5	< 10	16	3	4
Total Zinc (Zn)	mg/kg	47	41	35	29	< 10	29	6	19	47	22	23	27	< 10	10	10	10
Oil and Grease	mg/kg	< 0.1(%)	NA	< 100	< 100	< 0.1 (%)	NA	< 100	< 100	< 0.1(%)	NA	< 100	< 100	< 0.1 (%)	NA	< 100	< 100

* Calcium dominant and other cations below detectable levels

Results are as quoted by testing laboratory

Table E.2 - Analysis Results of Receiving Soils Parameters at Site 2 (Clifton Hill)

SOIL SAMPLES		SITE 2 CLIFTON HILL							
Greywater source		Bathroom greywater							
Soil location		Top soil (0 mm-250mm)				Subsoil (250mm-400mm)			
Sampling round		I	II	III	IV	I	II	III	IV
Date		06.08.93	01.06.94	02.11.94	07.03.95	06.08.93	01.06.94	02.11.94	07.03.95
Parameter	units								
pH (water) - acidity or alkalinity		6.9	6.3	6.2	6.2	7.5	7	6.5	6.5
pH (CaCl2) - acidity or alkalinity		6.2	5.9	5.7	5.6	6.6	6.1	5.8	5.8
Electrical Conductivity (1.5)	dS/m	0.11	0.25	< 10	0.19	0.06	0.09	< 10	0.11
Total soluble Salts	mg/kg	0.04	742	505	564	0.02	267	267	327
Chloride Salts - as NaCl	%	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Phosphorus (P) - Olsen Method	ug/g	11.3	16.2	17.2	24	13.5	6.9	10	11.8
Total Phosphorus (P)	%	0.07	0.069	0.067	0.086	0.066	0.071	0.053	0.073
Potassium (K) - Stene Method	ug/g	140	377	189	216	66	370	81	129
Available Boron (B)	ug/g	6 (t)	0.8	0.8	0.9	5 (t)	0.44	0.5	0.8
Total Iron (Fe)	%	1.4	2	2.3	1.7	2	2.7	1.4	2.3
Total Nitrogen (N)	%	0.38	0.5	0.35	0.36	0.17	0.25	0.18	0.32
Oxidizable Organic Carbon (C)	%	5.5	4	4.3	5.6	2.1	1.8	2.1	4.2
Organic Matter	%	10.4	7.6	8.2	10.6	4	3.4	4	8
Aluminium (Al) - KCl Exchangeable	ug/g	< 5	< 10	< 10	< 10	< 5	< 10	< 10	< 10
Exch Manganese (Mn)	mg/kg	< 5	18	NA	NA	< 5	13	NA	NA
Extractable Calcium (Ca) - Amm Acet	meq/100g	14.6	13	12	12	17.3	14.5	6.8	11
Extractable Magnesium (Mg) - Amm Acet	meq/100g	5.9	5.1	5.3	4.9	7.6	7.5	2.7	5
Extractable Sodium (Na) - Amm Acet	meq/100g	0.8	0.3	0.38	0.45	0.4	0.3	0.15	0.36
Extractable Potassium (K) - Amm Acet	meq/100g	0.3	0.4	0.5	0.56	0.2	0.3	0.19	0.34
Sum of 4 cations	meq/100g	NA	18.8	18.2	18	NA	22.6	9.9	16.7
Calcium Magnesium (Ca Mg) Ratio		NA	2.6	2.3	2.5	NA	2	2.6	2.2
Calcium as % of Cations	%	69	70	66	67	67	65	70	66
Magnesium as % of Cations	%	28	28	30	28	30	34	28	30
Sodium as % of Cations	%	1	2	2	3	2	2	2	3
Potassium as % of Cations	%	1	3	3	4	1	2	2	2
Total Selenium (Se)	mg/kg	0.31	0.3	0.2	0.2	0.4	0.3	< 0.1	0.2
Total Copper (Cu)	mg/kg	55	32	35	35	18	19	15	32
Total Zinc (Zn)	mg/kg	200	230	280	250	120	100	73	170
Oil and Grease	mg/kg	0.1(%)	NA	< 100	< 100	0.1(%)	NA	< 100	120

Results are as quoted by testing laboratory

Table E.3 - Analysis Results of Receiving Soils Parameters at Site 3 (Malvern)

SOIL SAMPLES		SITE 3 MALVERN			
Greywater source		Combined greywater			
Soil location		Top soil (0 mm-250mm)		Subsoil (250mm-400mm)	
Sampling round		I	II	I	II
Date		14.05.94	07.03.95	14.05.94	07.03.95
Parameter	units				
pH (water) - acidity or alkalinity		7.2	6.9	7.2	7
pH (CaCl2) - acidity or alkalinity		6.7	6.5	6.7	6.4
Electrical Conductivity (1:5)	dS/m	0.22	0.26	0.22	0.12
Total soluble Salts	mg/kg	653	772	653	356
Chloride Salts - as NaCl	%	< 0.05	< 0.05	< 0.05	< 0.05
Phosphorus (P) - Olsen Method	ug/g	66	52	66	39
Total Phosphorus (P)	%	0.084	0.069	0.084	0.0063
Potassium (K) - Stene Method	ug/g	196	233	196	172
Available Boron (B)	ug/g	0.95	0.4	0.95	0.6
Total Iron (Fe)	%	1.3	1.3	1.3	1.9
Total Nitrogen (N)	%	0.22	0.15	0.22	0.19
Oxidizable Organic Carbon (C)	%	2.9	3.2	2.9	3.7
Organic Matter	%	5.5	6.1	5.5	7
Aluminium (Al) - KCl Exchangeable	ug/g	< 10	< 10	< 10	< 10
Exch.Manganese (Mn)	mg/kg	< 5	NA	< 5	NA
Extractable Calcium (Ca) - Amm.Acet.	meq/100g	11.5	8.2	11.5	6.2
Extractable Magnesium (Mg) - Amm.Acet.	meq/100g	1.2	1.4	1.2	0.88
Extractable Sodium (Na) - Amm.Acet.	meq/100g	0.17	0.17	0.17	0.14
Extractable Potassium (K) - Amm.Acet.	meq/100g	0.46	0.43	0.46	0.31
Sum of 4 cations	meq/100g	13.3	10.2	13.3	7.6
Calcium:Magnesium (Ca:Mg) Ratio		9.7	5.9	9.7	7.1
Calcium as % of Cations	%	87	81	87	83
Magnesium as % of Cations	%	9	14	9	12
Sodium as % of Cations	%	2	2	2	2
Potassium as % of Cations	%	4	5	4	5
Total Selenium (Se)	mg/kg		0.1		0.1
Total Copper (Cu)	mg/kg	86	62	86	87
Total Zinc (Zn)	mg/kg	500	250	500	320
Oil and Grease	mg/kg	NA	< 100	NA	< 100

Results are as quoted by testing laboratory.

Table E.4 - Analysis Results of Receiving Soils Parameters at Site 4 (Strathmore)

SOIL SAMPLES		SITE 4 STRATHMORE							
Greywater source		**Bathroom greywater**				**Laundry greywater**			
Soil location		Top soil (0 mm-250mm)		Subsoil (250mm-400mm)		Top soil (0 mm-250mm)		Subsoil (250mm-400mm)	
Sampling round		I	II	I	II	I	II	I	II
Date		06.07.94	07.03.95	06.07.94	07.03.95	06.07.94	07.03.95	06.07.94	07.03.95
Parameter	units								
pH (water) - acidity or alkalinity		6.2	5.4	6.8	5.9	6.2	6.1	6.8	6.6
pH (CaCl2) - acidity or alkalinity		5.4	4.9	5.8	5.3	5.4	5.4	5.8	5.8
Electrical Conductivity (1:5)	dS/m	0.07	0.22	0.07	0.17	0.07	0.1	0.07	0.1
Total soluble Salts	mg/kg	208	653	208	505	208	297	208	297
Chloride Salts - as NaCl	%	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Phosphorus (P) - Olsen Method	ug/g	3.5	41	2.9	27	3.5	25	2.9	7.1
Total Phosphorus (P)	%	0.056	0.042	0.078	0.08	0.056	0.058	0.078	0.067
Potassium (K) - Stene Method	ug/g	167	143	172	145	167	170	172	131
Available Boron (B)	ug/g	0.78	0.9	0.68	1	0.78	0.8	0.68	0.8
Total Iron (Fe)	%	2.6	2.4	5.1	3	2.6	2.3	5.1	3.7
Total Nitrogen (N)	%	0.3	0.12	0.23	0.21	0.3	0.27	0.23	0.16
Oxidizable Organic Carbon (C)	%	3.4	1.5	2.7	2.9	3.4	3.3	2.7	2.2
Organic Matter	%	6.5	2.9	5.1	5.5	6.5	6.3	5.1	4.2
Aluminium (Al) - KCl Exchangeable	ug/g	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
Exch.Manganese (Mn)	mg/kg	36	NA	26	NA	36	NA	26	NA
Extractable Calcium (Ca) - Amm.Acet.	meq/100g	16.4	7.5	20.6	10	16.4	11	20.6	15
Extractable Magnesium (Mg) - Amm.Acet.	meq/100g	8.1	3.4	11.9	4.5	8.1	3.6	11.9	5.5
Extractable Sodium (Na) - Amm Acet.	meq/100g	0.33	0.21	0.82	0.37	0.33	0.21	0.82	0.48
Extractable Potassium (K) - Amm.Acet.	meq/100g	0.6	0.44	0.68	0.45	0.6	0.47	0.68	0.38
Sum of 4 cations	meq/100g	25.5	11.6	34	15.4	25.5	15.3	34	21.4
Calcium:Magnesium (Ca:Mg) Ratio		2.1	2.2	1.8	2.3	2.1	3.1	1.8	2.8
Calcium as % of Cations	%	65	65	61	66	65	72	61	71
Magnesium as % of Cations	%	32	30	35	30	32	24	35	26
Sodium as % of Cations	%	2	2	3	3	2	2	3	3
Potassium as % of Cations	%	3	4	2	3	3	3	2	2
Total Selenium (Se)	mg/kg		0.2		< 0.1		0.2		< 0.1
Total Copper (Cu)	mg/kg	23	19	32	29	23	20	32	28
Total Zinc (Zn)	mg/kg	30	41	50	44	30	41	50	44
Oil and Grease	mg/kg	NA	< 100	NA	< 100	NA	< 100	NA	< 100

Results are as quoted by testing laboratory.

Table E.5 - Analysis Results of Microbiological Tests of Soils at Sites 1 & 2

SITE	**Site 1 (Balwyn)**		**Site 2 (Clifton Hill)**	
Soil location	Top soil	Subsoil	Top soil	Subsoil
Parameter				
Salmonella sp.	negative	negative	negative	negative
Campylobacter	negative	negative	negative	negative
Giardia	negative	negative	negative	negative
Cryptosporidium	negative	negative	negative	negative

Results are as quoted by testing laboratory.

APPENDIX F

GRAPHS FOR DESIGN AND COSTING
OF
GREYWATER REUSE SYSTEMS

CASE STUDIES OF PRELIMINARY DESIGN AND COSTING OF GREYWATER REUSE SYSTEMS

The following three case studies illustrate the procedure for using Figure 7.1, Table 7.2 and Table 7.5 for preliminary sizing and costing of a greywater reuse system. Table 7.2 describes typical greywater system diversion arrangements and ranges of costs and Table 7.5 gives typical operating costs. Figure 7.1 includes three graphs as follows:

Graph A - Greywater demand graph

Based on an irrigation area available and an average application rate one can determine the quantity of water required in l/d. A number of application rates are included to serve for different climatic conditions. Typical figures for Melbourne are 1.0 mm/d to 2 mm/d.

The bottom half of the graph provides information for toilet flushing water requirements based on different cistern volumes. One full flush and four half flushes for person per day has been assumed for a dual flush toilet.

Graph B - Greywater production graph

An estimate of the greywater available for reuse can be determined from the characteristics of the household appliances and habits of the householders. Typical figures are provided for full cycle CWM volumes and shower flow rates. The volumes of water used in a bath depend on the bath dimensions and the depth of water required. For example, a bath having approximate dimensions of 700 mm by 1400 mm would require 50 L for a depth of 100 mm and 125 L for a depth of 200 mm. For cases that are not included in the graph interpolation can be used.

Graph C - Costs Graph

The cost of the irrigation system can be determined using the irrigation area and the typical ranges of costs given, ie. \$5 to \$8 per square meter for self installed systems and \$15 to \$20 per square meter for professionally installed systems.

This graph also provides information for the net annual water cost savings based on the volume of water saved and the current price per kL for water.

The Annual Water Cost Savings can be determined by using Figure 7.1 Graph C.

The Total Capital Cost (TCC) of a greywater reuse system can be determined from Table 7.2 and Figure 7.1 graph C as follows,

$$TCC = P + Q + R \qquad \text{(F.1)}$$

where P = diversion arrangement costs for irrigation (if applicable) from Table 7.2.

Q = diversion arrangement costs for toilet flushing (if applicable) from Table 7.2.

R = irrigation distribution system costs from Figure 7.1 graph C.

The footnote to Table 7.2 should be noted if both P and Q are included as part of an overall system.

Economic Evaluation

The total capital costs are converted to equivalent annual costs (EAC) using the expression

$$EAC = \sum(CC_c \times i \times C_n) \quad \text{for all components of the system} \qquad \text{(F.2)}$$

where CCc = capital cost of component,

i = effective interest rate,

C_n = capitalisation factor for life of component in years.

In the case studies a 15 years life has been assumed for pumps, tanks, filters and irrigation system components, and a 50 years life for diversion plumbing works, valves, power points, and stands. Effective interest rates of 4% and 8% have been used.

The total annual cost is the sum of the EAC, and the operating costs from Table 7.5.

The benefit/cost ratio is the annual water cost savings divided by the total annual cost. For these examples $ 0.65 per kL is used as the water charge. The benefit/cost ratio is used to determine the required cost for water in $/kL in order to break even, ie the total annual cost balances against the water costs saved.

Table 7.2 - Typical Greywater System Diversion Arrangements and Range of Costs

Code	DESCRIPTION OF THE ELEMENTS INCLUDED	Total cost $
	FOR IRRIGATION PURPOSES**	
D 1	Gravity greywater system diversion arrangement from either bathroom or laundry including pipework, in-line filter, and labour.	**300- 450**
D 2	Gravity greywater system diversion arrangement from both bathroom and laundry including pipework, in-line filter, and labour.	**450 - 650**
D 3	Pressurised greywater system diversion arrangement from either bathroom or laundry including pipework, pump, tank(s) and filters, power point installation and labour.	**750 - 1000**
D 4	Pressurised greywater system diversion arrangement from both bathroom and laundry including pipework, pump, tank(s) and filters, power point installation and labour.	**1050 - 1300**
	FOR TOILET FLUSHING PURPOSES	
D 5	Gravity greywater system diversion arrangement from either upper floor bathroom or laundry including pipework, tank, filter and labour.	**500 - 650**
D 6	Pressurised greywater system diversion arrangement from either bathroom or laundry including pipework, pump, tanks and filters, power point installation and labour.	**1100 - 1350**

** - irrigation distribution system pipework not included (for this component see Fig. 7.1)

Note: Where irrigation and toilet flushing reuse systems are both installed, it may be expected that the total cost would be somewhat less than the sum of two values taken from the table above, because of savings resulting from combined pipework and other components.

Table 7.5 - Operating Costs

	Cost/item	Typical life	Annual cost
Disposable filter	$ 0.32	3 wk	$ 5.55
Disinfectant (chlorine tablets)	$ 2.00	1 month	$ 24.00
Electricity for a pump (irrig. only)	-	-	$ 6.00

Case Study 1

This first example presents a greywater system for a household of two people. The greywater is used for gravity irrigation and pumped toilet flushing. It is assumed that reusable filters would be used in the system.

Greywater production (see graph B)

1. Bathroom greywater generated using 6 L/min shower for 10 minutes for each person (equivalent to 5 minutes for each of 4 persons) is 120 L/d.
2. Laundry greywater generated from 4 washes/wk and CWM with 65 L/wsh is about 37 L/d.

Greywater required (see graph A)

1. For toilet flushing about 40 L/d are required for two people if using a 6/3 L toilet cistern. It can be suggested that the laundry greywater could efficiently cover this amount with little additional supply of make-up water.
2. The remaining 120 L/d from the bathroom can be used for irrigation of 60 sq.m. if 2 mm/d application rate is adopted.

Annual water savings (see graph A)

The annual water savings from irrigation with greywater for five months would be about 18 kL/a, and from toilet flushing through the whole year would be about 14 kL/a. In total, this is about 32 kL/a.

Annual water cost savings (see graph C)

The annual water cost savings at the cost of water of $ 0.65/kL would be about $ 21.

Costing of the system (Table 7.2 and graph C)

The components of the greywater system include:

(i) Irrigation diversion arrangements (type D 1, Table 7.2) costing $ 300,

(ii) Householder-installed irrigation distribution system for 60 sq.m. at $ 5/sq.m (graph C) costing $ 300, and

(iii) Toilet flushing diversion arrangements (type D 6, Table 7.2) costing $ 1100.

The total capital cost would be $ 1700.

As this system involves diversion for both irrigation and toilet flushing, the lowest cost estimates for D1 and D6 have been used. Even with this assumption, it is probable that the total capital cost of $1700 represents an upper estimate (based on the footnote to Table 7.2).

Economic evaluation

Analysis of the greywater system indicated that the components with a life of 15 years cost $ 550 and the components with 50 years life cost $ 1150. The annual operation cost is $ 24 for chlorine tablets and $ 6 for electricity.

Using expression (F.2) for EAC and including operation costs, the total annual cost of this greywater system with a 4% effective interest rate would be $ 130 p.a. and with an 8% effective interest rate would be $ 190 p.a. For these values and water cost savings of $ 21 p.a. the benefit/cost ratios would be 0.16 and 0.11, respectively. Consequently the required water cost would need to be $4 to $6 per kL to break even. A summary of the above information is presented in Table F.1.

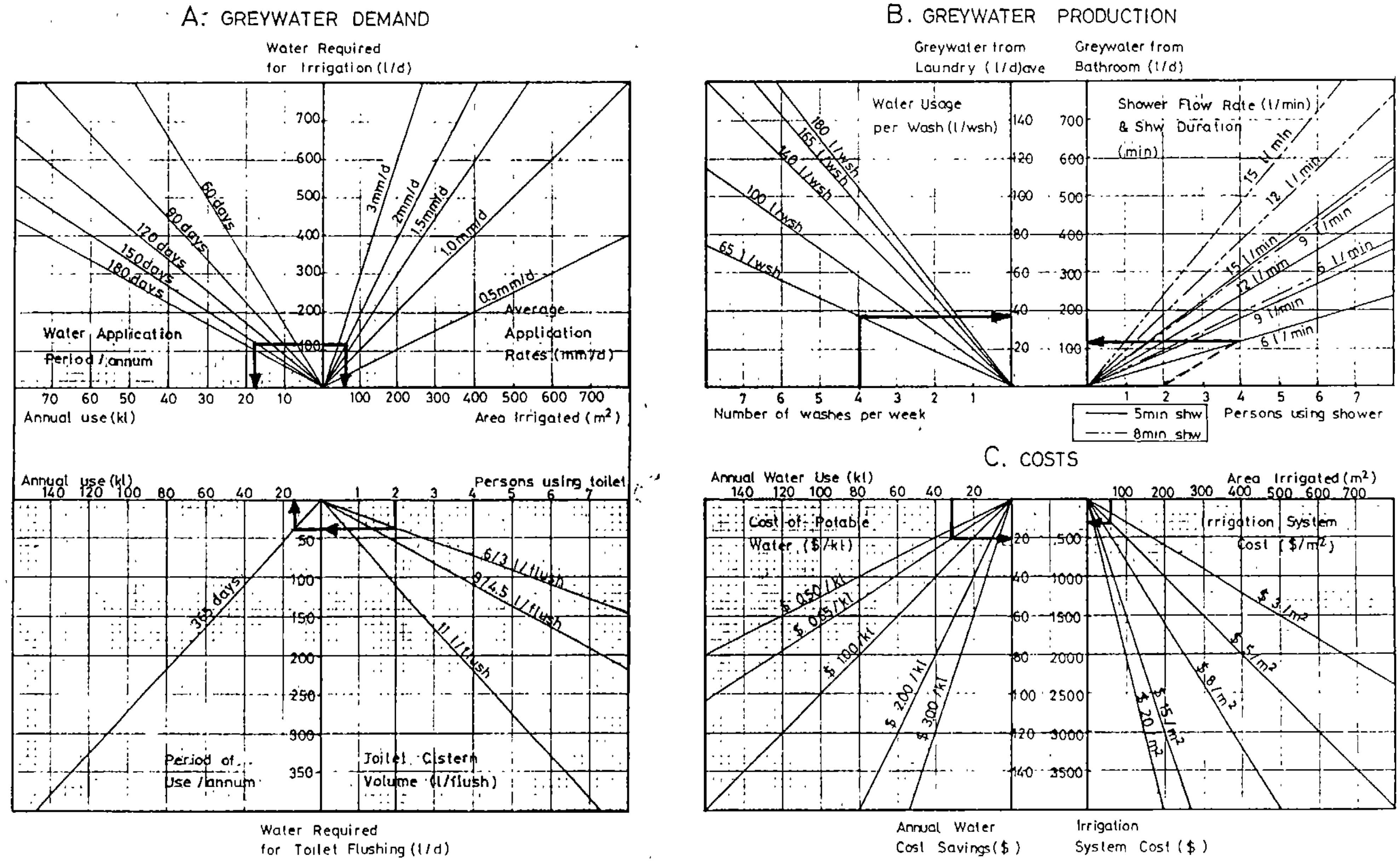
Table F.1 - Summary of Some Finding from Case Study 1.

Effective interest rate	Total annual cost of system *	Annual water cost saving ($)	Benefit/cost ratio	Required water charge ($/kL)*
4 %	$ 130	$ 21	0.16	$ 4
8 %	$ 190	$ 21	0.11	$ 6

* Rounded values

A graphic presentation of this case study is provided on the following page.

Case study 1


A: GREYWATER DEMAND

B. GREYWATER PRODUCTION

C. COSTS

Figure 7.1: Greywater system design & costing graphs

Case Study 2

The household presented in this example consists of two people and a baby. The greywater would be used only for irrigation and a pump is required to provide sufficient pressure.

Greywater production (see graph B)

1. Bathroom greywater generated using 15 L/min shower for 5 minutes for each person and a 30 L bath for the baby is 180 L/d.
2. Laundry greywater generated from 5 washes/wk and CWM with 135 L/wsh is about 90 L/d.

The total amount of greywater produced is 270 L/d.

Greywater required (see graph A)

Available area for irrigation is 100 sq.m., with an application rate of 2 mm/d this area would require 200 l/d. When compared with the greywater produced, it appears that using the whole amount of greywater 270 L/d would exceed the 2 mm/d requirement for the climatic condition of Melbourne, whereas diverting only bathroom greywater would be sufficient for irrigating this area at 1.8 mm/d application rate. This last option is more economically effective.

Annual water savings (see graph A)

The annual water savings for five months would be about 27 kL/a.

Annual water cost savings (see graph C)

The annual water cost savings at the cost of water of $ 0.65/kL would be about $ 18.

Costing of the system (Table 7.2 and graph C)

The components of the greywater system include:

(i) Irrigation diversion arrangements (type D 3, Table 7.2) costing $ 750, and

(ii) Householder-installed irrigation distribution system for 100 sq.m. at
$ 8/sq.m (graph C) costing $ 800.

The total capital cost would be $ 1550.

In this case, estimates have been taken from the low end (diversion) and the high end (distribution) of the cost range, so that the final figure of $ 1550 should be reasonably representative.

Economic evaluation

Analysis of the greywater system indicated that the components with a life of 15 years cost $ 550 and the components with 50 years life cost $ 1000. The annual operation cost is $ 6 for disposable filters and $ 6 for electricity.

Using expression (F.2) for EAC and including operation costs, the total annual cost of this greywater system with a 4% effective interest rate would be $ 110 p.a. and with an 8% effective interest rate would be $ 160 p.a. For these values and water cost savings of $ 18 p.a. the benefit/cost ratios would be 0.16 and 0.11, respectively. Consequently the required water cost would need to be $4 to $6 per kL to break even. A summary of the above information is presented in Table F.2.

Table F.2 - Summary of Finding from Case Study 2.

Effective interest rate	**Total annual cost of system ***	**Annual water cost saving ($)**	**Benefit/cost ratio**	**Required water charge ($/kL)***
4 %	$ 110	$ 18	0.16	$ 4
8 %	$ 160	$ 18	0.11	$ 6

* Rounded values

A graphic presentation of this case study is provided on the following page.

Case study 2

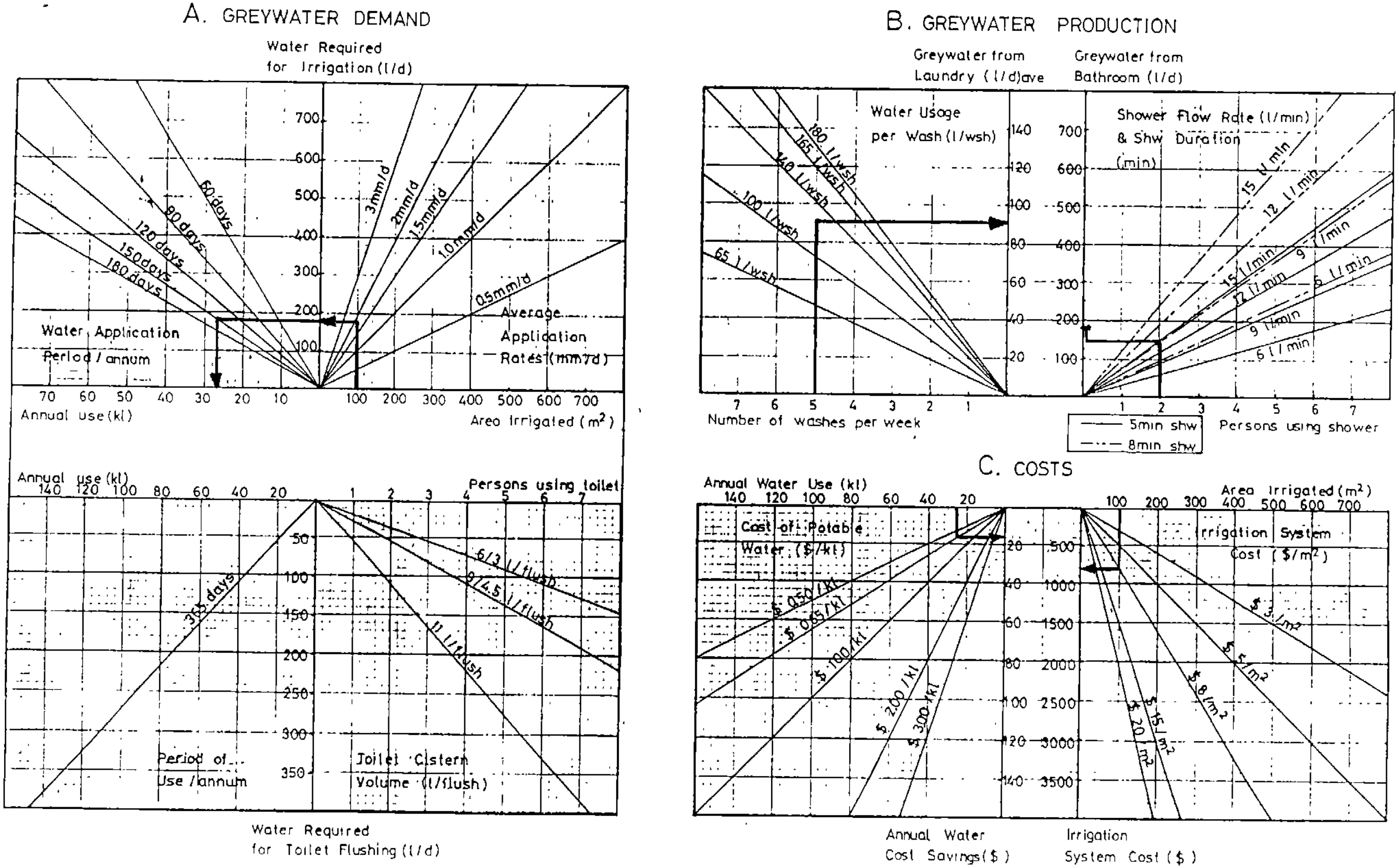


Figure 7.1: Greywater system design & costing graphs

Case Study 3

The household presented in this example consists of four people. The greywater would be used only for irrigation and a pump is required to provide sufficient pressure. It is assumed that reusable filters would be used in the system.

Greywater production (see graph B)

1. Bathroom greywater generated using 9 L/min shower for 8 minutes for each person is 288 L/d.

2. Laundry greywater generated from 6 washes/wk and CWM with 107 L/wsh is about 92 L/d.

The total amount of greywater produced is 380 L/d.

Greywater required (see graph A)

The area available for irrigation is 400 sq.m.. With an application rate of 2 mm/d this area would require 800 l/d. This amount exceeds the available greywater. There are two options: (i) install a greywater-only irrigation system for the whole area which would provide less than 1mm/d. This would not be sufficient and would require supplementation with fresh water, or (ii) install a greywater-only irrigation system on an area of say 250 sq.m. which would provide an application rate of about 1.5 mm/d, and the remaining 150 sq.m. would be irrigated independently with fresh water. When considering the price of irrigation system installation, the second option appears to be economically more effective.

Annual water savings (see graph A)

The annual water savings over five months would be about 57 kL/a.

Annual water cost savings (see graph C)

The annual water cost savings at the cost of water of $ 0.65/kL would be about $ 37.

Costing of the system (Table 7.2 and graph C)

The components of the greywater system include:

(i) Irrigation diversion arrangements (type D 4, Table 7.2) costing $ 1050, and

(ii) Householder-installed irrigation distribution system for 250 sq.m. at $ 5/sq.m (graph C) costing $ 1250.

The total capital cost would be $ 2300.

In this case, a cost estimate from the bottom of the range has been taken for each component, so that the final figure of $ 2300 may be somewhat underestimated.

Economic evaluation

Analysis of the greywater system indicated that the components with a life of 15 years cost $ 800 and the components with 50 years life cost $ 1500. The annual operating cost is $ 6 for electricity.

Using expression (F.2) for EAC and including operation costs, the total annual cost of this greywater system with a 4% effective interest rate would be $ 150 p.a. and with an 8% effective interest rate would be $ 220 p.a. For these values and water cost savings of $ 37 p.a. the benefit/cost ratios would be 0.25 and 0.17, respectively. Consequently the required water cost would need to be $3 to $4 per kL to break even. A summary of the above information is presented in Table F.3.

Table F.3 - Summary of Finding from Case Study 3.

Effective interest rate	Total annual cost of system *	Annual water cost saving ($)	Benefit/cost ratio	Required water charge ($/kL)*
4 %	$ 150	$ 37	0.25	$ 3
8 %	$ 220	$ 37	0.17	$ 4

* Rounded values

A graphic presentation of this case study is provided on the following page.

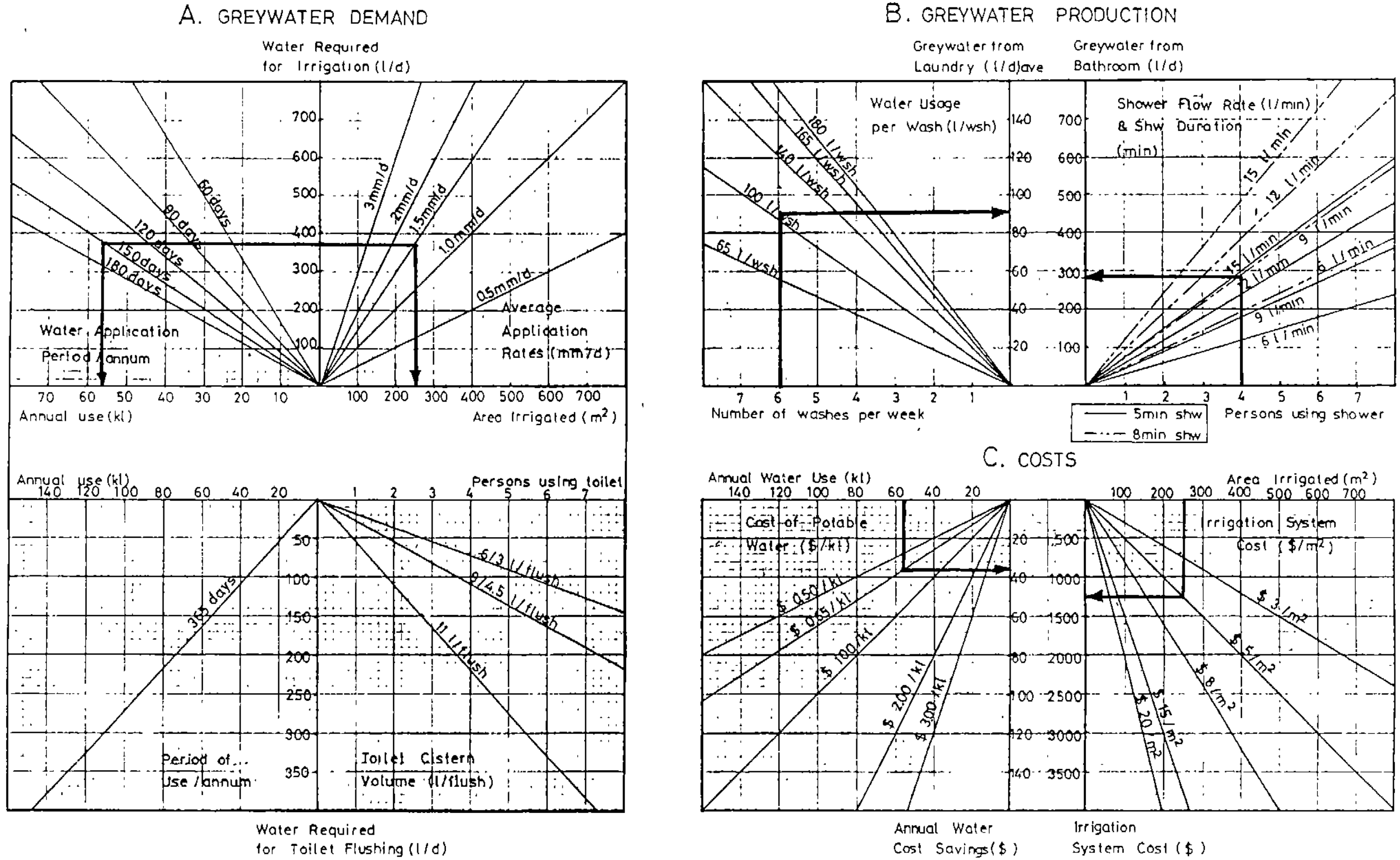


Figure 7.1: Greywater system design & costing graphs

APPENDIX G

SURVEY QUESTIONNAIRE FOR MELBOURNE

ID Number: ____________

GREYWATER REUSE SURVEY

THIS SURVEY IS TO BE ANSWERED BY A HOUSEHOLD MEMBER OVER THE AGE OF SIXTEEN YEARS.

1 Do you have or share a garden? (please circle one)

	Q1
Yes	1
No	2

If **no**, please go to question 3.

2. What system do you use for watering ?
(please read out alternative answers;
NB - can provide more than one answer)

	Q2	
	your lawn	your garden
Hand held hose	1	1
Moveable sprinklers	2	2
Hand held bucket or watering can	3	3
Fixed in ground sprinklers	4	4
Drip irrigation system	5	5
Don't water	6	6

3. Which of these best describes the size of your block of land?
(please read out alternative answers and circle one)

	Q3
Small (about 15 x 30m or 450 sq.m) (50 x 100 ft or 5000 sq.ft)	1
Medium (about 16 x 44m or 700 sq.m) (50 x 150 ft or 7500 sq.ft)	2
Large (about 20 x 50m or 1000 sq.m) (70 x 150 ft or 10500 sq.ft)	3
Don't know	4
Don't have(e.g. live in a flat)	5

4. Are you interested in conserving water in and around the home?
(please circle one)

	Q4
Yes	1
No	2

If **no**, please go to question 6.

5. Have you done anything to conserve water in and around the home within the last few years?(please circle one)

	Q5
Yes	1
No	2

If yes, **(NB - can provide more than one answer)**

Do you reuse water from laundry or bath for watering the garden	1
Have you installed dual flush toilet cistern	2
Have you installed low flow shower head	3
Other	4

If other, please specify ______________________________

____

6. Have you had experience in recycling any of the following materials? (please read out each material, NB - can provide more than one answer)

Q6

	Yes	No
Food (eg. by composting)	1	1
Paper or Cardboard	2	2
Other (eg Glass, Plastic, Aluminium containers)	3	3

7. Have you previously heard the term "GREYWATER"?

	Q7
Yes	1
No	2

If yes, what does it mean?______________________________

____

EDITORS ONLY. **7A. Code if correct answer to Q7**

Correct	1
Incorrect	2
Partially correct	3

If no, <u>INTERVIEWER TO READ FOLLOWING INFORMATION.</u>

GREYWATER IS THE WASTEWATER FROM THE LAUNDRY, BATHROOM AND KITCHEN, BUT DOES NOT INCLUDE TOILET WASTEWATER.

In a number of overseas countries with limited water resources GREYWATER has been used particularly for lawn and garden watering and toilet flushing. Leading countries in this area are USA and Japan.

A typical GREYWATER reuse system requires modified wastewater collection plumbing and a small collection tank. Greywater may then be piped from this tank to the toilet cistern for toilet flushing purposes, or to a subsurface distribution system for irrigation. The owner of such a system would normally have to carry out simple but regular maintenance tasks on parts of the system.

8. If GREYWATER was available <u>from the laundry</u> would you use it for WATERING LAWNS or GARDENS?
(please circle one)

	Q8
Yes	1
No	2
Don't know	3

If **no**, why not ?

If yes, why ?

9. If GREYWATER was available <u>from the bathroom</u> would you use it for WATERING LAWNS or GARDENS?
(please circle one)

	Q9
Yes	1
No	2
Don't know	3

If **no**, why not ?

If yes, why ?

10. If GREYWATER was available <u>from the kitchen</u> would you use it for WATERING LAWNS or GARDENS?
(please circle one)

	Q10
Yes	1
No	2
Don't know	3

If **no**, why not ?

If yes, why ?

11. Would you be interested in finding out more about HOW TO USE GREYWATER for WATERING LAWNS and GARDENS?
(please circle one)

	Q11
Yes	1
No	2

12. If GREYWATER was available <u>from the laundry</u> would you use it for FLUSHING THE TOILET?
(please circle one)

	Q12
Yes	1
No	2
Don't know	3

If no, why not ? ____________________

If yes, why ? ____________________

13. If GREYWATER was available <u>from the bathroom</u> would you use it for FLUSHING THE TOILET?
(please circle one)

	Q13
Yes	1
No	2
Don't know	3

If no, why not ? ____________________

If yes, why ? ____________________

14. If GREYWATER was available <u>from the kitchen</u> would you use it for FLUSHING THE TOILET?
(please circle one)

	Q14
Yes	1
No	2
Don't know	3

If no, why not ? ____________________

If yes, why ? ____________________

15. Would you be interested in finding out more about HOW TO USE GREYWATER for FLUSHING THE TOILET?
(please circle one)

	Q15
Yes	1
No	2

SAVINGS OF ABOUT 16% of HOUSEHOLD WATER CONSUMPTION COULD BE ACHIEVED IF A GREYWATER SYSTEM IS USED EITHER FOR WATERING LAWNS AND GARDENS OR FLUSHING THE TOILET. Thus in a number of years the system could pay for itself.

16. What is the longest period you would accept for installation costs to be balanced by savings in water costs?
(please circle one)

	Q16
More than 12 years	1
12 years	2
10 years	3
8 years	4
6 years	5
4 years	6
3 years	7
2 years	8
1 years	9

17. Which of these age categories do you belong to ?
(please read out and circle one)

		Q17
Age Group	Less than 20	1
	20 - 29	2
	30 - 39	3
	40 - 49	4
	50 - 59	5
	60 - 69	6
	70 - 79	7
	80 +	8

Please circle the answer identifying sex of the respondent.

Gender	Male	1
	Female	2

18. What is your country of birth? (please answer for yourself and your parents)

Q18

Yourself________________________

Your mother______________________

Your father_______________________

Q19

19. What suburb do you live in? ____________________

If don't know name of the suburb, **postcode?** __________

EDITORS ONLY.

19A. Code the answer to Q19

Record region:	Maribyrnong	1
	Yarra	2
	South Eastern	3
Area:	Inner suburban	1
	Central suburban	2
	Outer suburban	3

Q20

20. Do you currently :

(please circle one)

Own your home (without a mortgage)	1
Pay off a home mortgage	2
A tenant	3
Other	4

What other ? ____________________

21. Are you the person responsible for paying the water bill in your household?(please circle one)

Q21

Yes	1
No	2

Q22

22. What is the usual number of people living at your home? __________

Q23

23. How many children under three years of age live at your home? __________

24 What is your employment status?(please circle one)

Q24

Employed	1
Unemployed	2
Home duties	3
Student	4
Retired	5
Pensioner	6
Other	7

Q25

25 What is your main occupation? (e.g. builder, teacher) __________

THANK YOU FOR YOUR TIME AND CONTRIBUTION TO THIS IMPORTANT MATTER - SAVING OF WATER.

If you have any other comments please make them.

____
____
____
____
____
____

Your opinion is most valuable and highly appreciated.

As the project proceeds we may seek further information. If so, and if you would be prepared to participate in any follow-up survey or like to receive more information on GREYWATER REUSE, please provide your name and address and/or telephone number:______________________________________
____
____

G 1

SAMPLE CHARACTERISTICS OF MELBOURNE SURVEY

Sample characteristics - Melbourne survey

	Respondents in	
	Number	%
Melbourne Regions		
Core	35	11.7%
Inner	91	30.4%
Middle	53	17.7%
Outer	81	27.0%
Fringe	37	12.4%
Not stated	2	0.7%
Gender		
Male	138	46.0%
Female	155	51.7%
Not stated	7	2.3%
Age		
Less than 20	9	3.0%
20 - 29	92	30.7%
30 - 39	80	26.7%
40 - 49	52	17.3%
50 - 59	34	11.3%
60 - 69	16	5.3%
70 - 79	12	4.0%
80+	3	1.0%
Not stated	2	0.7%
Respondents' Origin		
Australia	263	87.7%
United Kingdom	6	2.0%
Italy	7	2.3%
Greece	3	1.0%
Other	17	5.7%
Not stated	4	1.3%
Origin Mother		
Australia	180	60.0%
United Kingdom	31	10.3%
Italy	25	8.3%
Greece	8	2.7%
Malta	10	3.3%
Other	42	14.0%
Not stated	4	1.3%
Origin Father		
Australia	168	56.0%
United Kingdom	32	10.7%
Italy	28	9.3%
Greece	9	3.0%
Malta	9	3.0%
Other	50	18.2%
Not stated	4	1.3%

	Respondents in	
	Number	**%**
Tenure		
Owning the home without a mortgage	38	12.7%
Paying off a home mortgage	170	56.7%
Paying rent	86	28.7%
Other	2	0.7%
Not stated	4	1.3%
Number of People in the Household		
One	27	9.0%
Two	64	21.3%
Three	75	25.0%
Four	107	35.7%
Five	19	6.3%
Six	6	2.0%
Not stated	2	0.7%
Number of Children under 3 years		
None	186	62.0%
One	90	30.0%
Two	12	4.0%
Not stated	12	4.0%
Employment Status		
Employed	157	52.3%
Unemployed	15	5.0%
Home duties	72	24.0%
Student	16	5.3%
Retired	20	6.7%
Pensioner	17	5.7%
Other	3	1.0%
Occupation Type		
Managers & Administrators	17	5.7%
Professionals	35	11.7%
Para-professionals	19	6.3%
Tradesmen	17	5.7%
Clerks	33	11.0%
Salespersons & Personal service workers	20	6.7%
Plant & Machine operators & Drivers	11	3.7%
Labourers & Related workers	9	3.0%
Not stated	139	46.3%

G 2

FULL DEFINITIONS OF THE TERM 'GREYWATER' AS GIVEN BY THE RESPONDENTS

FULL LISTING - DEFINITIONS OF GREYWATER

- Waste water from kitchen and laundry.
- Reusing water.
- Reusing water.
- Water from bathroom and laundry.
- Using water from laundry and bathroom for watering.
- Reusing water from bathroom and laundry.
- Recycling water for gardens and lawn.
- Dirty water.
- Recycling household water.
- Using bath and laundry water.
- Recycled household water.
- Reusing household water for gardens.
- Bathroom and laundry water.
- Recycling bathroom and laundry water.
- Reusing bathroom and laundry water.

G 3

MAP OF REGIONS & RINGS OF MELBOURNE

	Core	Inner	Middle	Outer	Fringe
CENTRAL	1 South Melbourne 2 Port Melbourne 3 Melbourne 4 Fitzroy 5 Collingwood 6 Richmond 7 Prahran 8 St Kilda				
WEST		9 Williamstown 10 Footscray 11 Essendon 12 Brunswick	**	31 Altona 32 Sunshine 33 Keilor	44 Werribee 45 Melton
NORTH		13 Coburg 14 Northcote	22 Preston 23 Heidelberg	34 Broadmeadows 35 Diamond Valley 36 Eltham	46 Whittlesea 47 Bulla
EAST		15 Kew 16 Hawthorn 17 Camberwell	24 Box Hill 25 Doncaster & Templestowe 26 Waverley 27 Nunawading	37 Croydon 38 Knox 39 Ringwood	48 Healesville 49 Lillydale 50 Sherbrooke
SOUTH		18 Malvern 19 Caulfield 20 Brighton 21 Sandringham	28 Oakleigh 29 Moorabbin 30 Mordialloc	40 Dandenong 41 Springvale 42 Frankston 43 Chelsea	51 Berwick 52 Pakenham 53 Cranbourne 54 Mornington 55 Flinders 56 Hastings

**see outer west

REGIONS & RINGS — L.G.A. COMPARISON

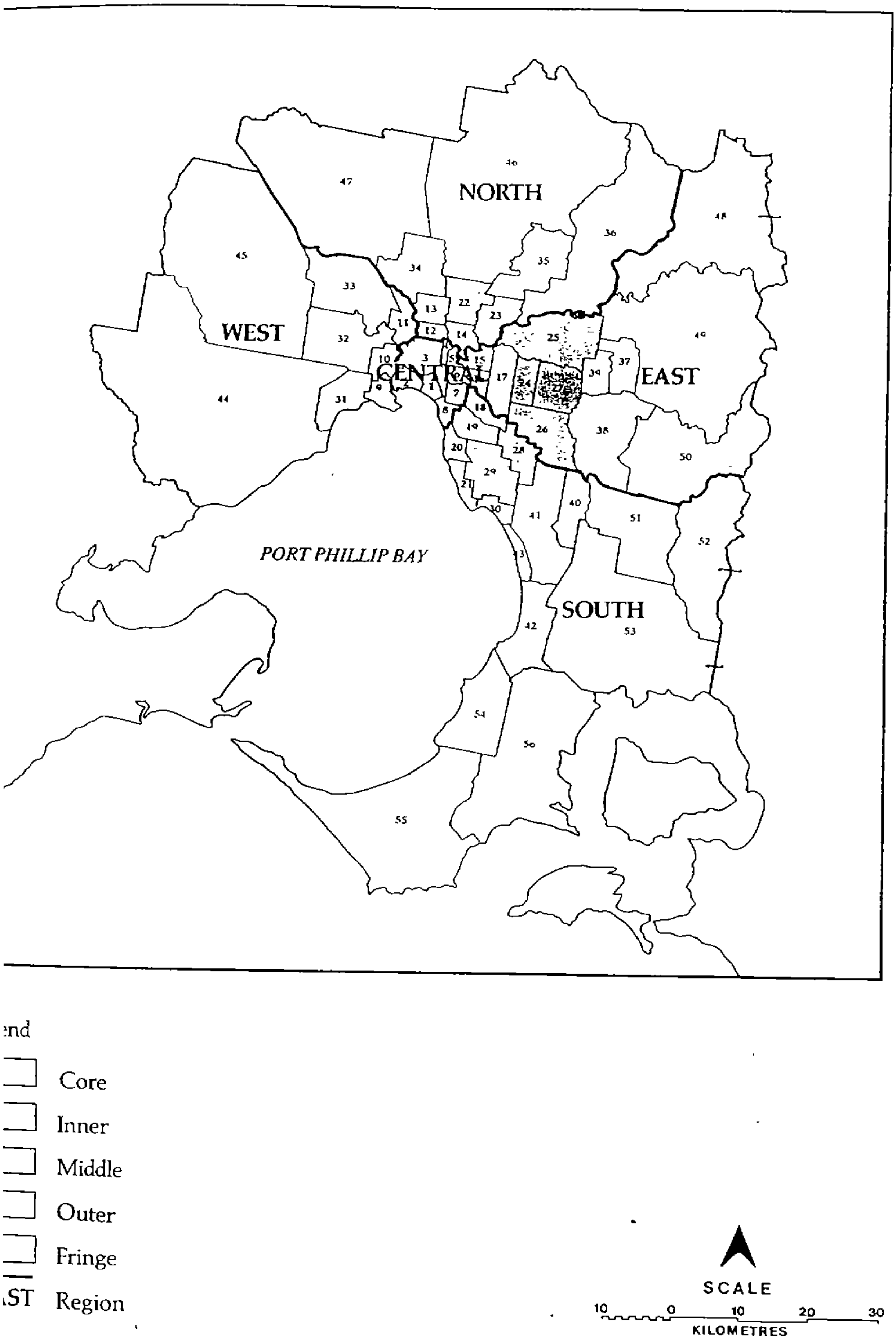


FIG. 1

REGIONS AND RINGS

APPENDIX H

SURVEY QUESTIONNAIRE FOR MELTON

DO YOU CARE ABOUT

- SAVING WATER AND MONEY FROM YOUR WATER BILL
- REDUCING SOCIETY EXPENSES FOR DAM CONSTRUCTION
- PRESERVING THE UNIQUE AUSTRALIAN ENVIRONMENT

<u>You are invited to comment on</u>

WATER SAVING OPTIONS and
DOMESTIC GREYWATER REUSE

Have Your Say

Please return the completed questionnaire to the CIVIC CENTRE of MELTON by the 30th of June or as soon as possible after that date. A postage paid envelope is attached for this purpose.

Surveys can also be returned to the Shire office during office hours or be left in the mailbox adjacent to the front door at other times.

* What is GREYWATER?

GREYWATER IS THE WASTEWATER FROM THE LAUNDRY, BATHROOM AND KITCHEN, BUT DOES NOT INCLUDE TOILET WASTEWATER.

* How can we use it?

In a number of overseas countries with limited water resources GREYWATER has been used particularly for lawn and garden watering and toilet flushing.

A typical GREYWATER reuse system for irrigation purposes involves the use of a collection tank and a subsurface distribution system
The owner of such a system is required to carry out regular maintenance.

* How much could we save?

The typical Victorian house may use about 300 KL of water per year. By reusing GREYWATER for lawn and garden watering this usage could be reduced to about 250 KL per year. If GREYWATER is used for both garden and lawn watering and toilet flushing this figure could be further reduced to about 225 KL per year

* Why public opinion is so important?

Greywater reuse is a subject of extensive research carried out by Victoria University. With the help of experts from Melbourne Water, Department of Health and Community Services and EPA, Victoria University is working on a project to investigate the feasibility for GREYWATER reuse in Victoria.
The Shire of Melton is also strongly interested in the project, and is actively participating by distributing this questionnaire and seeking feedback from local residents.The results of this community consultation will help us with information that only you as consumers can provide.

9. If GREYWATER was available <u>from the bathroom</u> would you use it for WATERING LAWNS or GARDENS?
(please circle one)

	Q9
Yes	1
No	2
Don't know	3

If no, why not ? ______________________________
____
____

If yes, why ? ______________________________
____

10. If GREYWATER was available <u>from the kitchen</u> would you use it for WATERING LAWNS or GARDENS?
(please circle one)

	Q10
Yes	1
No	2
Don't know	3

If no, why not ? ______________________________
____
____

If yes, why ? ______________________________
____

11. Would you be interested in finding out more about HOW TO USE GREYWATER for WATERING LAWNS and GARDENS?
(please circle one)

	Q11
Yes	1
No	2

12. If GREYWATER was available <u>from the laundry</u> would you use it for FLUSHING THE TOILET?
(please circle one)

	Q12
Yes	1
No	2
Don't know	3

If no, why not ? ______________________________
____
____

If yes, why ? ______________________________
____

13. If GREYWATER was available <u>from the bathroom</u> would you use it for FLUSHING THE TOILET? (please circle one)

	Q13
Yes	1
No	2
Don't know	3

If no, why not ? ______________________________
____
____

If yes, why ? ______________________________
____

14. If GREYWATER was available <u>from the kitchen</u> would you use it for FLUSHING THE TOILET? (please circle one)

	Q14
Yes	1
No	2
Don't know	3

If no, why not ? ______________________________
____
____

If yes, why ? ______________________________
____

15. Would you be interested in finding out more about HOW TO USE GREYWATER for FLUSHING THE TOILET?
(please circle one)

	Q15
Yes	1
No	2

SAVINGS OF ABOUT 16% of HOUSEHOLD WATER CONSUMPTION COULD BE ACHIEVED IF A GREYWATER SYSTEM IS USED EITHER FOR WATERING LAWNS AND GARDENS OR FLUSHING THE TOILET. Thus in a number of years the system could pay for itself.

16. What is the longest period you would accept for installation costs to be balanced by savings in water costs?
(please circle one)

	Q16
More than 12 years	1
12 years	2
10 years	3
8 years	4
6 years	5
4 years	6
3 years	7
2 years	8
1 years	9

H 1

SAMPLE CHARACTERISTICS OF MELTON SURVEY

Sample characteristics - Melton survey

	% of Respondents
Region	
Melton	100%
Gender	
Male	51%
Female	46%
Not stated	3%
Age	
Less than 20	0%
20 - 29	10%
30 - 39	30%
40 - 49	38%
50 - 59	8%
60 - 69	5%
70 - 79	7%
80+	0%
Respondents' Origin	
Australia	69%
New Zealand	3%
United Kingdom	18%
Italy	1%
Malta	3%
Other (Greece, India, Holland, Iran, Germany)	3%
Not stated	2%
Origin Mother	
Australia	56%
New Zealand	1%
United Kingdom	17%
Italy	1%
Malta	4%
Other (Greece, India, Holland, Iran, Poland, Germany, Turkey)	7%
Not stated	14%
Origin Father	
Australia	56%
New Zealand	1%
United Kingdom	17%
Italy	2%
Malta	3%
Other (Ukraine, India, Holland, Iran, Poland, Germany, Turkey, Cyprus)	6%
Not stated	14%

	% of Respondents
Tenure	
Owning the home without a mortgage	43%
Paying off a home mortgage	55%
Paying rent	1%
Other	0%
Not stated	1%
Number of People in the Household	
One	5%
Two	21%
Three	18%
Four	33%
Five	16%
Six	6%
Seven	1%
Eight	1%
Number of Children under 3 years	
None	84%
One	11%
Two	3%
Three	1%
Not stated	1%
Employment Status	
Employed	58%
Unemployed	8%
Home duties	17%
Student	0%
Retired	3%
Pensioner	12%
Other	3%
Occupation Type	
Managers & Administrators	7%
Professionals	16%
Para-professionals	11%
Tradesmen	4%
Clerks	16%
Salespersons & Personal service workers	1%
Plant & Machine operators & Drivers	5%
Labourers & Related workers	4%
Other	13%
Not stated	23%

H 2

FULL DEFINITIONS OF THE TERM 'GREYWATER' AS GIVEN BY THE RESPONDENTS

FULL LISTING - DEFINITIONS OF GREYWATER

- Water from laundry and bathroom.
- Recycling of household water.
- Waste water from laundry, etc.
- Waste water from laundry, bathroom and kitchen.
- Reusable waste water.
- I knew what it was, I'd read about it in articles in magazines and newspapers.
- Washing water.
- Using waste water from home to use in garden. I have done it before during 1980/81 drought in Melton.
- Waste water from sink and laundry.
- Waste from kitchen and laundry.
- Recycled waste water supplied by council - piped in.
- Laundry bathroom waste.
- Waste that had been used in the kitchen and/or bathroom and laundry.
- Water used once before in the home.
- Water from the bath, shower, washing water.
- Recycled water.
- Same as explained here.
- Laundry, bathroom and kitchen discharge.
- Dirty water.
- Waste bathroom and laundry water.
- As written.
- Washing machine.
- Laundry water.
- Water from bath and washing.
- Waste water from bath and laundry.
- Laundry and bath water.
- Recycled water from laundry, toilets, etc.
- As stated.
- Waste water from bathroom, laundry and kitchen.
- Recycling of household water.
- I understand that it's water that we can reuse.
- Bath and shower and laundry.
- Laundry, basin and bath water but not toilet water.
- Waste water.
- Recycled water.
- Water from washing machine, shower, etc.
- Reused water.
- Bath. All water except toilet.
- The same as the information.
- Sewerage.
- Waste water from shower, laundry and sink (not sewerage).
- Contaminated water.
- Any household drainage.
- That is water that's used from washing dishes, laundry, bath & shower that's been used.
- Was not clear what it meant.
- Recycling laundry & bath water for garden use.

- Relatives in Queensland reuse greywater.
- Used water.
- Water that you can recycle.
- Recycled water.
- Waste water.
- Overseas news item on TV.

APPENDIX I

RISK EXPOSURE PATHWAYS

I.1

HEALTH RISK
EXPOSURE PATHWAYS

PATHWAYS for RISK ASSESSMENT of GREYWATER APPLICATION

A. Greywater reuse for toilet flushing.

Public health risk

No	Pathway	Description	Most exposed individual
1. a	GW - Human	Cleaning/changing flushing tank filters or toilet.	Person involved in changing the filters.
b	GW - Human	Splash of greywater on the skin.	Members of the family reusing greywater.
c	GW - Human (child)	Toddlers playing with toilet water.	Children of the family reusing greywater.
2.	GW - Air - Human	Inhalation of aerosols from toilet flushing	Members of the family reusing greywater.

PATHWAYS for RISK ASSESSMENT of GREYWATER APPLICATION

Greywater reuse for Irrigation of lawns and gardens.

B. Subsurface irrigation

Public health risk

No	Pathway	Description	Most exposed individual
1. a	GW - Human (direct contact)	Activities for changing and cleaning the filters.	Person involved in changing the filters.
b	GW - Human (indirect contact)	Greywater finding it's way into a swimming pool. (if the swim.pool is at lower than ground level)	
c	GW - Neighbors (Child)	Any possible seepage onto the neighboring property and the possible ill effects on people, plants or soil.	Neighboring property. (especially if the property is down hill)
d	GW - Guests (Child)	Any possible ill effects on people visiting the family and children playing & touching the family pet living there.	Visiting families or relatives.
2.	GW - Soil - Human (Child)	Kids eating soil or digging the garden & than sucking their fingers. Any planting activities in the garden.	Children of the family. (especially under three years of age)
3.	GW - Animal - Human	Accidental ponding of GW and the family pet walking through the puddle, then play with the kids.	Members of the family reusing greywater.
4.	GW - Soil - Plant - Human	Fruit trees irrigated with greywater, and the fruits consumed.(e.g. lemon tree)	Members of the family reusing greywater.
5.	GW - Soil - Animal - Human (Child)	Having a family pet digging the soil and then being stroked by people.(especially kids)	Members of the family reusing greywater.
6.	GW - Soil - Surface water - Child	Any possible ponding of greywater on the surface and the kids playing in the puddle.	Children of the family. (especially under 3 years of age)
7.	GW - Soil - Plant - Animal - Human	Can a disease of a chicken or rabbit being transferred to a human.(with or without consuming it)(eg.Salmonella)	Members of the family reusing greywater.

PATHWAYS for RISK ASSESSMENT of GREYWATER APPLICATION

Greywater reuse for irrigation of lawns and gardens.

C. Surface irrigation

Public health risk

No	Pathway	Description	Most exposed individual
1. a	GW - Human (direct contact)	Activities for changing and cleaning the filters.	Person involved in changing the filters.
b	GW - Human (indirect contact)	Greywater finding it's way into a swimming pool. (if the swim.pool is at lower than ground level)	Children of the family. (especially under three years of age)
c	GW - Neighbors (Child)	Any possible seepage onto the neighboring property and the possible ill effects on people, plants or soil.	Neighboring property. (especially if the property is down hill)
d	GW - Guests (Child)	Any possible ill effects on people visiting the family and children playing & touching the family pet living there.	Visiting families or relatives.
2.	GW - Air - Human	Aerosols in the air. Inhalation of greywater.	Members of the family reusing greywater.
3.	GW - Food - Human	Barbecue in the neighboring property. Ingestion of greywater.	Neighboring property.
4.	GW - Soil - Human (Child)	Kids eating soil or digging the garden & than sucking their fingers. Any planting activities in the garden.	Members of the family reusing greywater.
5.	GW - Surface water - Human (Child)	Any possible ponding of greywater on the surface and the kids playing in the puddle/lying on the grass.	Children of the family. (especially under three years of age)
6.	GW - Animal - Human	Accidental ponding of GW and the family pet walking through the puddle, then play with the kids.	Members of the family reusing greywater.
7.	GW - Plant - Human	Flowers being watered with greywater and then placed in a vase on the table.	Members of the family reusing greywater.
8.	GW - Soil - Plant - Human	Fruit trees irrigated with greywater, and the fruits consumed.(e.g. lemon tree)	Members of the family reusing greywater.
9.	GW - Soil - Animal - Human (Child)	Having a family pet digging the soil and then being stroked by people.(especially kids)	Members of the family reusing greywater.
10.	GW - Soil - Plant - Animal - Human	A disease (eg. Salmonella) of a chicken or rabbit being transferred to a human.(with or without consuming it)	Members of the family reusing greywater.

I.2

ENVIRONMENTAL RISK
EXPOSURE PATHWAYS

PATHWAYS for RISK ASSESSMENT of GREYWATER APPLICATION

Greywater reuse for Irrigation of lawns and gardens.

B. Subsurface irrigation

Environmental risk

No	Pathway	Description	Most exposed element
1	GW - Soil	Any adverse effects on the soil structure and composition.	Soil irrigated with greywater.
2	GW - Soil - Plant	Native trees, fruit trees or plants irrigated with greywater.	Plants on the property irrigated with greywater.
3	GW - Soil - Animal	Having a family pet digging a hole in the soil.	Pets of the family.
4	GW - Soil - Soil biota	Earthworms, slugs, bacteria, fungi living in the soil irrigated with greywater.	Earthworms, slugs, bacteria, fungi living in the soil irrigated with greywater.
5	GW - Soil -Groundwater	Any possible contamination of the groundwater through cracks in the soil.	Ground water table.
6	GW - Soil -Plant - Animal	Having a pet (rabbit or chicken) fed with grass from the lawn.	Pets of the family.
7	GW - Soil - Surface water - Animals	Any possible ponding of greywater on the surface and the pets playing in the puddle.	Pets of the family.

PATHWAYS for RISK ASSESSMENT of GREYWATER APPLICATION

Greywater reuse for irrigation of lawns and gardens.

C. Surface irrigation

Environmental risk

No	Pathway	Description	Most exposed element
1	GW - Animal	Direct spraying onto pets, plants, etc.	Pets of the family.
2	GW - Plant	Trees or plants leaves getting burned by chemical in greywater	Plants on the property irrigated with greywater.
3	GW - Soil	Any adverse effects on the soil structure and composition.	Soil irrigated with greywater.
4	GW - Soil - Animal	Having a family pet digging a hole in the soil.	Pets of the family
5	GW - Soil - Plant	Native trees, fruit trees or plants irrigated with greywater.	Plants on the property irrigated with greywater.
6	GW - Soil - Soil biota	Earthworms, slugs, bacteria, fungi living in the soil irrigated with greywater.	Earthworms, slugs, bacteria, fungi living in the soil irrigated with greywater.
7	GW - Soil -Groundwater	Any possible contamination of the groundwater through cracks in the soil.	Ground water table.
8	GW - Surface water - Animals	Any possible ponding of greywater on the surface and the pets playing in the puddle.	Pets of the family.
9	GW - Soil -Plant - Animal	Having a pet (rabbit or chicken) fed with grass from the lawn.	Pets of the family.

APPENDIX J

J.1

DETAILED DESCRIPTION OF MICROBIOLOGICAL AGENTS OF CONCERN

MICROBIOLOGICAL AGENTS OF CONCERN

(a) Viruses

More than 120 different types of enteric viruses may be found in human wastes and domestic waste water. Rose (1992) described the most common types of enteric viruses which infect humans as well as the wide range of diseases they can cause: diarrhoea, aseptic meningitis, fever, paralysis, conjunctivitis, myocarditis and hepatitis (see Table J.1).

Table J.1 - Characteristics of Enteric Viruses

Human Enteric Viruses			
Virus type	Mortality rates (%)	Morbidity rates (%)	**Illness**
Enteroviruses	0.001		
Poliovirus	0.9	0.1 - 1	Paralysis
Coxsackie A	0.5	50	Meningitis, fever, respiratory disease
Coxsackie B	0.59 - 0.94		Myocarditis, congenital heart disease, rash, fever, meningitis, pleuroodynia, diabetes mellitus
Echovirus	50		Meningitis, encephalitis, rash, fever, gastroenteritis
Norwalk agent (probably a calicivirus)	0.0001	40 -59	Gastroenteritis
Astrovirus			Gastroenteritis
Calicivirus			Gastroenteritis
Snow Mountain agent (probably a calicivirus)			Gastroenteritis
Hepatitis A virus	0.6	75	Infectious hepatitis
Hepatitis E virus			Epidemic infectious hepatitis
Rotavirus	0.01	56 -60	Gastroenteritis
Adenovirus	0.01		Respiratory, eye infections, gastroenteritis

Source: Summarised from Gerba and Rose, 1993 and Rose, 1992.

It is important to note that viruses are not free living organisms. They reproduce and carry on metabolic processes only within the human host, but due to their specific structure may survive for a long time in the environment. Human viruses may transitionally infect dogs and farm animals, but are not believed to cause disease (Gerba and Rose, 1993).

Not all people infected with enteric viruses will become clinically ill. Asymptomatic infections are particularly common with some of the enteroviruses. Morbidity and mortality rates for different viruses are different and strongly dependent on factors such as :

- age of the host,
- immune status of the host,
- type of virus,
- intake dose,
- and route of infection.

For example, the frequency of symptomatic infections for hepatitis A virus is usually less than 5 % for children, but increases greatly with age - up to 75 % in adults. In contrast, for rotavirus the percentage of clinically observed illnesses is greatest in childhood and lowest in adulthood. Altogether for the different enteroviruses the frequency of clinical symptoms may vary in the range from 1% (for poliovirus) to more than 75% (for coxsackie B viruses), and up to 97% during waterborne outbreaks (Rose, 1992).

All enteric viruses are easily transmitted by the faecal-oral route, but infection may occur as well from contaminated water, food, and direct contact with an infected person.

(b) Protozoa

Enteric protozoa are other agents of concern. Giardia and Cryptosporidium are considered to be dominant enteric pathogens infecting the human gastrointestinal tract. These two enteric protozoa are taxonomically different, but share some epidemiological features. Giardia is a flagellate protozoan which reproduces by binary fission, while Cryptosporidium is a coccidian protozoan and undergoes both asexual and sexual reproduction. Both Giardia and Cryptosporidium produce environmental stages known as cysts (12-16μm) and oocysts (4 - 6 μm) respectively (Hutton et al., 1993). They are excreted in the faeces of the infected individual after ingestion by a new host initiates the infection.

Although the faecal-oral route of transmission is considered to be the most typical one, infection may be transmitted by direct contact with an infected individual, as well as from contaminated potable or non-potable water. Waterborne transmission in the U.S. has been estimated to account for 60% of all the giardiasis cases (Rose, 1992).

Giardia and Cryptosporidium are of greater concern because of the prolonged time of survival in the environment. Cysts formed by Giardia and Cryptosporidium may survive for 2 to 6 months in moist conditions (Benenson, 1990). Giardia and Cryptosporidium together with enteric viruses are classified as microorganisms of higher concern than bacteria because they are more resistant to treatment (Regli et al., 1991). Giardia cysts and particularly Cryptosporidium oocysts are extremely resistant to disinfection (eg. with a significant percentage of oocysts apparently surviving 24 hours exposure to 1000 mg/L chlorine (NHMRC/ARMCANZ, 1994)). Furthermore, as few as 10 organisms are required to cause acute diarrhoea (Hutton et al., 1993).

Giardia and Cryptosporidium have been indentified as important causes of waterborne disease, producing a gastrointestinal illness (Rose and Gerba, 1991). The symptoms of giardiasis can include acute and chronic diarrhoea, nausea, fatigue, malabsorption and in severe cases malnutrition and anorexia. An important point however is that infection is frequently asymptomatic and only a small proportion suffer from acute symptoms. Cryptosporidiosis is characterised by acute symptoms (diarrhoea, abdominal pain, vomiting) lasting 5 to 10 days with substantial loss of body fluids. Morbidity rates are about 60 - 80% (Rose, 1992). In immunodeficient persons, the disease may have a prolonged and fulminant clinical course, contributing to death (Benenson, 1990). According to Maynard (1992), diarrhoea (which is a milder enteric illness) still represents around 6% of a general practitioner's workload, or some 5 million consultations per year in Australia, and in the majority of cases the causal pathway is not well defined. There is still a great deal unknown about infectious transmission (Maynard, 1992).

(c) Bacteria

The bacterial pathogens of most concern are Campylobacter and Salmonella. Campylobacter species are Gram-negative spiral rods, with the most common pathogen being Campylobacter jejuni. Other species less commonly causing diarrhoea include Campylobacter coli, Campylobacter laridis and Camplylobacter upsaliensis. About 14 species are pathogenic to humans and animals (eg, C. jejuni, C. coli, C. fetus), while others are considered to be non-pathogenic (C.sputorum, C.concisus). Most members of the thermophilic group of Campylobacters (ie, those that grow at 42°C) cause enteritis in humans. In Australia, Campylobacter are more important than Salmonella as a cause of acute gastroenteritis (NHMRC/ARMCANZ, 1994).

Thermophilic Campylobacter are transmitted by the faecal-oral route. Campylobacter enteritis may be of considerable severity, causing diarrhoea with mucus and/or blood, abdominal pain, fever, dehydration and incapacity. The illness is frequently over within 2 to 5 days and usually lasts no more than 10 days. Campylobacter enteritis may occur in outbreak form (via contaminated water or milk), but most of the notifications appear as sporadic cases. Contaminated food or contact with infected animals (including pets and domestic animals) or their faeces, may account for many cases of infection. Campylobacters, like other bacterial pathogens, survive well at low temperatures, and they can survive for several weeks in cold groundwater (NHMRC/ARMCANZ, 1994).

Salmonella spp. are other human bacterial pathogens which can be transmitted orally by ingesting contaminated water. Faecal contamination of drinking water which is inadequately disinfected is the main source of the water-borne outbreaks of Salmonella. However, most illnesses resulting from Salmonella infection are derived from contaminated foodstuffs, eg. poultry and livestock. Water-borne Salmonella plays only a minor role in causing disease. Salmonella serovar typhi, which is a specific human pathogen, together with Salmonella serovar paratyphi A, and Salmonella serovar paratyphi B are able to invade tissues and cause a septicaemia with high temperature rather than diarrhoea. This is known as enteric fever. Epidemiological and volunteer studies show that the infective dose of Salmonella varies considerably. Factors such as method of intake, individual susceptibility, and virulence of the particular strain determine the dose required to produce an infection.

It is important to note that children under 5 years of age have the highest age - specific incidence rate for some of the most common diseases caused by Campylobacter, as well as for Giardiasis and Salmonellosis.

J.2

QUANTITATIVE RISK ASSESSMENT EXAMPLES

RISK CHARACTERISATION (QRA) (from previous studies).

EXAMPLE 1 (Enferadi et al., 1986)

The study of Enferadi and his team provides numerical values of the public health risk associated with biological toilet systems and greywater treatment. The results indicate the risk of a public health problem occuring associated with the following systems was:

1 chance in 500 000 - for a septic tank/soil absorption system during the life time of the system,

1 chance in 30 000 - for true composting, mouldering, and buried drum toilet with landscaped greywater,

1 chance in 2 300 - for drum toilet waste and greywater on food crops,

1 chance in 7 000 - for true composting when solids are buried and greywater was applied on food crops.

Although only relative these value give an opportunity for comparison between the different systems. The health risk is fourfold higher when greywater is applied on food crops (1:7 000 compared to 1:30 000).

This same study concluded that "system maintenance potentially increases the health risk to individual users", but that "difference in the level of system maintenance would have a limited effect on risk to the community's health, depending on population and system density."

EXAMPLE 2 (Rose, 1992)

Health risk assessment from viruses and parasites in reclaimed water was carried out by Rose (1992). Tests carried out on raw sewage and on secondary treated effluent showed that in raw sewage the levels of viruses were as high as 492000 viral units per liter while in secondary effluent following disinfection , levels were reduced to between 2 and 7150 viral units per liter. It can be concluded that sewage treatment reduces viral counts, but does not eliminate them from sewage effluent. Similar tests for presence of cysts and oocysts of Giardia and Cryptosporidium were carried out. In almost all raw wastewaters, Giardia and Cryptosporidium were found averaging 5800 cysts and 30 oocysts per 100L, respectively. Secondary treatment reduced this by 90% to 99% and no cysts or oocysts were detected in filtered effluent.

Using risk assessment models and the levels of viruses and protozoa detected in wastewater, the risk of infection through exposure to reused waters can be estimated. Assuming 100 mL of accidental ingestion after secondary treatment, for example, the risk of infection would be in the range from 6.1x10^{-3} to 6.8x10^{-2} and 2.0x10^{-5} to 2.6x10^{-4} for rotavirus and echovirus, respectively. Giardia risks would be 2.3x10^{-4} (see Table J.2) It was found that filtration reduced the risk by 100 fold at the minimum of 3.1x10^{-4} or below. To maintain these levels of risks at annual levels the ingestion should not occur more than once per person per year. If the exposure was less than 100 mL then the risk would like-wise decrease.

Table J.2 - Probability of Infection from Accidental Ingestion of 100 mL of Reclaimed Wastewater Containing Various levels of Viruses/cysts

Levels of		Risk in exposed population		
viruses/cysts per 100 L	Exposure per 100 mL	Rotavirus	Echovirus	Giardia
130*	1.3x10^{-1}	6.8x10^{-2}	2.6x10^{-4}	
10*	1x10^{-2}	6.1x10^{-3}	2.0x10^{-5}	
0.5**	5x10^{-4}	3.1x10^{-4}	1.0x10^{-6}	
0.03**	3x10^{-5}	1.9x10^{-5}	6x10^{-8}	
11.4*	1.14x10^{-2}			2.3x10^{-4}
<1**	<1x10^{-3}			<1.9x10^{-5}

* - Secondary treatment, ** - Secondary treatment followed by filtration.

Source: Rose, 1992.

EXAMPLE 3 - **Relative health risks of different pathogens (Gibbs and Ho, 1993)**

The qualitative risk assessment (Gibbs and Ho, 1993) identified five groups of pathogens according to the extent of risk they present. The assessment was based on Western Australia infection rates used in conjunction with estimated excreted loads and persistence in the environment. The available information was used to develop a classification system with low, medium and high corresponding to the criteria outlined in Table J.3. This risk assessment is very general and based on a number of assumptions.

Table J.3 - Criteria Used for Classification

Classification	No. of Cases	Excreted Load	Persistence
Low	less than 100	10^3 and less	1 month and less
Medium	100 to 500	10^4 and 10^5	greater than 1 month to 3 months
High	greater than 500	greater than 10^5	> 3 months

Source: Gibbs and Ho, 1993.

The classifications were combined to rank the pathogens into groups: group 5 pathogens which present the most risk, with the risk decreasing to group 1 - pathogens presenting the least risk (see Tabe J.4). Based on this qualitative risk assessment it was concluded that the pathogens of most concern in Western Australian sludges are enteric viruses, followed by Salmonella, Giardia intestinalis and Trichuris trichiura.

Table J.4 - Relative Health risks of Different Groups of Pathogens

Group	Pathogens	No. of cases in Western Australia in 1991	Excreted Load	Persistence	Infectious Dose
Group 5 (highest risk)	Rotavirus	medium	high	medium	low
	Adenovirus	medium	high	medium	low
	Enterovirus	medium	high	medium	low
	Hepatitis A	medium	high	medium	low
Group 4	Salmonella	high	high	medium	high
	Giardia intestinalis	high	medium	low	low
	Trichuris trichiura	medium	low	high	low
Group 3	Campylobacter	high	high	low	high
	Shigella	medium	high	low	medium
	Cryptosporidium	medium	medium	low	low
	Hookworm ova	medium	low	medium	low
Group 2	Hymenolepis nana	medium	low	low	low
	Entamoeba	low	medium	low	low
	Strongyloides stercoralis	medium	low	low	low
	Enterotoxigenic E.Coli	low	high	medium	high
Group 1 (negligible risk)	Ascaris lumbricoides				

Source: Gibbs and Ho, (1993).

APPENDIX K

CONFERENCE PAPERS DEVELOPED AS A RESULT OF THIS RESEARCH

K 1

AN INVESTIGATION INTO GREYWATER REUSE FOR URBAN RESIDENTIAL PROPERTIES

AN INVESTIGATION INTO GREYWATER REUSE FOR URBAN RESIDENTIAL PROPERTIES

Diana CHRISTOVA-BOAL[1], Bob EDEN[2] and Scott McFARLANE[3]

1. Victoria University of Technology, Ballarat Road, Footscray 3011
2. Water Technology Unit, H&CS, Box 4057 GPO, Melbourne 3001
3. Melbourne Water, 625 Little Collins Street, Melbourne 3000

ABSTRACT

Continuing moves towards full cost recovery for potable water, and the impending privatisation of water supplies in the Melbourne area has enhanced public interest in the reuse of wastewater, and particularly the domestic use of greywater.

Victoria University of Technology, together with support from Melbourne Water and the Department of Health & Community Services, has been investigating the practicalities, costs and social attitudes of using greywater in and around the home.

Four "typical" Melbourne homes were selected and plumbed to utilise greywater for toilet flushing and garden irrigation. Social surveys were conducted by mail and phone to home-owners to determine perceived attitudes towards greywater reuse.

Greywater from baths, showers, laundry troughs and washing machines is being examined for physical, chemical and micro-biological parameters to determine the potential health and environmental risks associated with reuse. Soil tests were also undertaken on gardens to determine any long-term detrimental effects that might occur as a result of using greywater.

This paper describes the greywater testing, results of filtration and filter designs, appropriate disinfectants, and physical findings to date. The two-year project is due for completion early in 1995.

1.0 BACKGROUND

Greywater is defined as all wastewater from the non-toilet plumbing fixtures around the home. From the 1991/92 Melbourne Water Resources Review domestic greywater reuse was identified by the public as an issue of interest. With Melbourne Water's desire to better manage Melbourne's water demand a 2 year research program commenced in March 1993 to determine practical greywater reuse systems which would be safe to use from the perspectives of both public health and the environment. The research program also sets out to survey public risk and social attitudes to greywater reuse. This research is being conducted through Victoria University of Technology (VUT) as a Master's Degree project. Technical support is given by Melbourne Water (MW), the Department of Health and Community Services (H&CS) and Victoria's Environment Protection Authority (EPA).

1.1 WATER CONSERVATION BENEFITS

The estimated water conservation benefits for a typical greywater reusing household in Melbourne (average consumption 250 kL/a) are as follows:

Greywater Reuse:	Saving (kL/a)	% of Total Water Use	% of Total Sewage
garden	52	21	32
toilet	49	20	30
toilet and garden	77	31	47

A social survey recently conducted in Melbourne showed that people were interested in reusing greywater from the bathroom and laundry. The survey respondents indicated a strong preference for using greywater on gardens. However they would only consider a greywater reuse system if there was a short (2-4 years) payback period.

2.0 GREYWATER SOURCES

2.1 KITCHEN

Many previous investigations indicated that kitchen greywater was highly polluting, putrescible and contains many undesirable compounds (eg. cooking oils). Since this water accounts for only about 5% of the 'average' household consumption its use as a greywater source is almost negligible and not recommended.

2.2 BATHROOM, SHOWERS AND HANDBASINS

The combined greywater from these three sources for the 'average' family accounts for about 26% of the total household consumption. Greywater from showers and handbasins normally contains soaps, shampoos, body-fats, hair, soils, and occasionally lint, fabric fibres, skin, urine and faeces. The latter is more prevalent where the family comprises either very young children or the incontinent elderly. In addition greywater may contain household cleaning products and wastes.

2.3 LAUNDRY TROUGHS AND WASHING MACHINES

Typically the 'average' household will use about 15% of its water consumption in clothes washing. Clothes washing detergents and bleaches, plus on occasion oils, paints and solvents should be added to the list of constituents found in the greywater from the bathroom, shower and handbasins. The proportions of constituents will vary according to household habits.

3.0 POTENTIAL FOR THE USE OF GREYWATER

Greywater reuse is potentially feasible for garden watering and toilet flushing.

3.1 GARDENS

Gardens account for around 34% of the total household water budget but this demand is highly seasonal and for Melbourne's temperate climate may only be needed for six months of every year.

3.2 TOILETS

Toilets use around 20% of the total household water but this percentage is reducing as more dual flush and water economising toilets are installed. Wastewater derived from toilets is referred to as blackwater. It is highly faecally contaminated and can only be discharged to an approved sewerage system. Water for toilet flushing is a relatively constant requirement throughout the year.

4.0 THE PROJECT

Four experimental sites were selected to provide a variety of conditions regarding topography, soil characteristics, housing type and size of family. One of the aims in the design of the greywater systems was to determine the volume and constituents of each source of greywater for garden or toilet applications. The combinations of greywater sources and greywater applications at the four sites are shown in Table 1. The H&CS permitted only subsurface irrigation systems to be used to minimise potential health risks associated with greywater reuse. Various methods for irrigation were implemented using leachfield and pressure/drip pipe systems. Different design arrangements with distribution pipe diameters, spacings and depths and a selection of irrigation trench cross sections were trialled.

Table 1 - Combinations of greywater sources and applications

Site number	**Source of greywater**	**Application of greywater**
1	Shower & bath Laundry trough	Toilet flushing & irrigation Irrigation
2	Shower & bath Laundry trough	Irrigation Toilet flushing
3	CWM CWM & bath	Toilet flushing Irrigation
4	CWM Shower	Irrigation Irrigation

*CWM = clothes washing machine

A sampling and testing program was developed to analyse a number of typical physical, chemical and microbiological characteristics of greywater from bathroom and laundry. Findings to date are presented in Table 2. A similar program of tests was prepared for analysing the parameters of the receiving soils. Both the greywater and soil sampling and testing programs are continuing and are expected to be completed by March 1995.

Table 2 - Greywater physical, chemical and microbiological parameters

Parameters	Bathroom water range	Laundry water range	Proposed limits for heavy metals **
pH, units	6.4 - 8.1	9.3 - 10	-
EC 25C, microS/cm	82 -250	190 - 1400	-
Colour, Pt/Co units	60 - 100	50 - 70	-
Turbidity, NTU	60 -240	50 - 210	-
Suspended Solids	48 - 120	88 - 250	-
Nitrate & Nitrite, as N	<0.05 -0.20	0.10 - 0.31	-
Ammonia, as N	<0.1 -15	< 0.1 - 1.9	-
Total Kjeldahl Nitrogen, as N	4.6 - 20	1.0 - 40	-
Phosphorus, total as P	0.11 - 1.8	0.062 - 42	-
BOD, 5 day	76 - 200	48 - 290	-
Azure- A Active Substances	1.2 - 10	30 - 150	-
Oil and Grease	37 - 78	8.0 - 35	-
Total Alkalinity, as CaCO3	24 - 43	83 - 200	-
Calcium (Ca)	3.5 - 7.9	3.9 -12	-
Magnesium (Mg)	1.4 - 2.3	1.1 - 2.9	-
Sodium (Na)	7.4 - 18	49 - 480	-
Potassium (K)	1.5 - 5.2	1.1 - 17	-
Iron (Fe)	0.34 - 1.1	0.29 - 1.0	1.00
Zinc (Zn)	0.2 - 6.3	0.09 - 0.32	2.00
Copper (Cu)	0.06 - 0.12	< 0.05 - 0.27	0.20
Aluminium (Al)	< 1.0	< 1.0 - 21	5.00
Boron (B)	< 0.1	< 0.1 - 0.5	0.75
Sulphur (S)	1.2 - 3.3	9.5 - 40	-
Silicon (Si)	3.2 - 4.1	3.8 - 49	-
Cadmium, as Cd	< 0.01	< 0.01	0.01
Arsenic, as As	0.001	0.001 - 0.007	0.10
Selenium, as Se	< 0.001	< 0.001	0.02
Chloride, as Cl	9.0 - 18	9.0 - 88	-
Total Coliforms/ 100mL	MPN 500 - 2.4×10^{7}	MPN 2.3×10^{3} - 3.3×10^{5}	-
Faecal Coliforms/ 100mL	MPN 170 - 3.3×10^{3}	MPN 110 - 1.09×10^{3}	-
Faecal Streptococci/ 100mL	MPN 79 - >2.4×10^{3}	MPN 23 - >2.4×10^{3}	-

Results are in mg/L unless specified otherwise.

** Taken from NSW Guidelines for Urban and Residential Use of Wastewater . Assuming that soil pH < 5.

The greywater samples were also tested for Salmonella spp., Campylobacter spp., Giardia and Cryptosporidia. None of these microorganisms were detected in any of the samples.

Sodium, phosphorus, aluminium, zinc and copper in some of the samples were at high levels. The main sources of sodium, phosphorus and aluminium were detergents and shampoos. The high levels of zinc and copper were caused by the galvanised steel collection tanks and from the household plumbing.

From the above table it is apparent that the preferred source of greywater for garden irrigation would be water derived from the bathroom, shower and handbasin. Laundry water, on the other hand, with its elevated levels of salt (derived from detergents) would be better suited to toilet flushing. Should the constituents of detergents, soaps, shampoos and other household products change in future, some modifications to these preferred sources may be necessary.

5.0 PROBLEMS AND OPERATIONAL DIFFICULTIES

5.1 DESIGN AND INSTALLATION

Three houses were retrofitted to reuse greywater for garden watering and toilet flushing and one house was designed with a greywater system incorporated prior to construction.

A number of difficulties were encountered when a greywater system was designed and retrofitted to an existing house. These included:

- Insufficient hydraulic head and the consequent need to use a pump,
- Floor level outlets near to ground level - resulting in the collection tanks being installed below ground level and the need for ground anchoring, and
- Long collection, distribution and overflow pipe lines.

Many of these difficulties could be avoided if the greywater reuse system was included in the initial design of a house prior to its construction. All systems must be fail-safe to ensure that greywater is automatically directed to sewer whenever a blockage or system malfunction occurs.

5.2 GARDEN IRRIGATION

Due to the health risks implicit in the use of greywater for gardens, the use of shallow subsurface irrigation techniques is critical to reduce risk to an 'acceptable' level. As indicated in section 2.0 greywater must be considered as dilute sewage since it has all the constituents of a raw sewage. Greywater must be of an adequate quality to prevent build-up of suspended material or biological growths blocking any distribution system. (Biological growths particularly in the irrigation distribution lines can be minimised by suitably disinfecting the greywater).

Subsurface irrigation under investigation currently involves a study of both pumped and gravity distribution lines. The study takes into account soil type, pipe diameter, spacing and emitter characteristics. In general, gravity systems have lower operational costs but achieving a reasonably even distribution of greywater may be difficult in some situations.

5.3 TOILET FLUSHING

Greywater must be of adequate quality to prevent the build-up of undesirable materials in the cistern or its operating components. The water inlet valve must be able to close completely when the cistern design-capacity has been reached. Hair, lint and body fats are particularly liable to become trapped in the inlet, especially since the greywater system will be operating at low pressure (compared with typical water-main pressures).

Incomplete closure of the inlet valve would waste water, either to an external overflow or into the toilet bowl. The same problem arises with hair, lint and fats (including soaps) causing an incomplete closure of the outlet valve which controls the flush to the toilet bowl. At the experimental sites filtration and low pressure ball-cocks were installed to minimise these difficulties.

It is important that any water which is held for longer than usual in the cistern or bowl does not biologically degrade. Biological degradation of fats, soaps and hair usually produces malodorous compounds which are unacceptable, particularly indoors. Greywater in the toilet bowl itself must also be aesthetically acceptable. A coloured disinfectant may overcome both these problems. (Many toilet bowl additives currently on the market are colouring agents only). Greywater must not leave unsightly stains on the sides of the toilet bowl as this tends to increase the house occupier's use of toilet cleaners and reduce the viability of greywater flushing.

5.4 DISINFECTANTS

If greywater is used for toilet flushing there is some health risk associated with splashing when the toilet is used, and aerosols when the toilet is being flushed. The highest perceived risk would be for children and visitors.

There is a need for appropriate disinfectants to treat the greywater before use. Since the characteristics of greywater depend on the products used in the bathroom or laundry (eg. pH, alkalinity, presence of different ions) there is no simple solution in selecting a disinfectant. Some combinations of surfactants can neutralise a disinfectant. Since there is no apparent way to predetermine the characteristics of greywater produced in different households, no specific disinfectants have yet been identified.

Extra long-lasting chlorine tables were used in this study to disinfect the greywater for toilet flushing, but this created problems in the galvanised steel collection and storage tanks with chlorine leaching the zinc from the tank walls. As a result the greywater samples had very high levels of zinc (up to 6.3 mg/100mL).

An optimum disinfectant would be: (a) combination of two or more components - to react in any solution, (b) low cost, (c) easy and inexpensive to dose - prepacked: sachets or blocks and (d) coloured - to provide an indicator of efficacy.

5.5 FILTERS

Removal of suspended matter from greywater is essential for both lawn/garden irrigation and toilet flushing. Filtering greywater can provide acceptable quality for its reuse.

At the experimental sites the removal of the suspended material was achieved by a three-stage filter system:

- Stage 1 - a strainer (pre-filter) in the laundry trough, shower or bath outlet to remove large-sized materials,
- Stage 2 - a mesh filter installed in the collection tanks to collect hair, soap particles, lint and some entrapped body fats, and
- Stage 3 - a fine filter on the supply line to the irrigation pipes or toilet cistern for precipitates and settled materials.

An overview of the filters being tested in this study is presented in Table 3.

The experimental systems were equipped with reusable filters. Regardless of the source of greywater (bathroom or laundry) the filters required servicing at least one a week. Sometimes, depending on the activities of the household (eg. washing pullovers for a football team) the filter system needed servicing twice a week. Each service required a minimum of 15-20 minutes for filter cleaning. Once the filters had been cleaned the filtrate had to be disposed to either the sewer or the garbage bin. Some health risk was almost inevitable for the person who cleaned these filters and simple protective measures needed to be taken (eg. wearing gloves).

These findings highlighted the need for disposable-type filters which would be quick and easy to change and would not pose an unacceptable health risk. Tests were conducted on three different filter materials suitable for disposable-type filters. Very satisfactory results were observed using a nylon sock type filter which provided an expanding surface area as more filtrate was collected.

A geotextile "filtersock" also exhibited very good filtering capability and had the advantage of not promoting as much biological growth as nylon. The third filter made from "cleaning cloth" type material was unsatisfactory as it ruptured after the fourth or fifth filtering cycle.

An ideal disposable filter must: (a) be cheap, (b) have a large surface area (requiring less frequent changing), (c) provide efficient filtering and (d) be incorporated in an in-line filter cartridge.

Automatic backwashing filters (with the backwash water disposed to sewer) of appropriate size may be available in the future. Indications are that such a filter would have a high initial cost but with operating costs comparable with disposable filters.

Table 3 - Experimental filters for greywater reuse.

REUSABLE FILTERS		
Stage	**Type of filter**	**Frequency of cleaning**
Stage 1	"Strainer"	After every second use.
	"Hair Share"	After every second use.
Stage 2	Fly wire mesh filter	Once a week.
	"Hi-FLO" filter screen	Once a week.
	"Leaf canister"	Once a week.
Stage 3	"Amiad" mesh filter	Once a week.
	"Arkal" disc filter	Once a week.
DISPOSABLE FILTERS		
Stage 1 or 2	"Cleaning cloth" filter	After 4 to 5 uses.
	Geotextile "filtersock"	Once a fortnight.
	"Nylon sock" filter	Once a fortnight.

The initial trials with "Amiad" mesh filters and "Arkal" disc filters using 0.1mm mesh or 0.11mm disc spacing clogged almost immediately. More successful performance was achieved using the next larger size of filters (0.2mm mesh and 0.17mm disc spacing).

5.6 TANKS

The incorporation of collection and storage tanks is undesirable in any greywater design. Tanks containing greywater provide an ideal breeding ground for pathogenic microorganisms, mosquitoes and are a source of odours. Tanks need to be vented, childproof and comply with local health and plumbing by-laws.

Physically, tanks require space which is either limited or unavailable (in retrofitted situations) and their optimum siting may interfere with existing services. If the tanks can be located beneath a dwelling there are often difficulties in installation (lack of clearance). Above ground tanks located exterior to the dwelling may have undesirable visual impact, whilst those which are buried must be anchored. All tanks must be accessible for cleaning.

5.7 SOILS AND DETERGENTS

The garden soils at all test sites were analysed for physical and chemical parameters prior to any irrigation with greywater. These soils will be analysed again following the 1994/1995 summer irrigation season to determine the effects of greywater irrigation. In addition to soil analyses, tensiometers were installed to provide an indication of sub-surface moisture content and the potential for sub-surface flows (particularly on sloping topography).

Analyses of greywater, derived from the bathroom and laundry, indicated high levels of sodium, zinc, aluminium and (by inference) carbonate which might be detrimental to soil conditions (Table 2). The high carbonate/alkali content of some laundry-grade water has a significant effect on pH of the water and subsequently on the soil pH. When soil pH exceeds 8 to 8.5 some micronutrient deficiencies occur. High levels of zinc have been found in some of the greywater samples. If such greywater is used for irrigation continuously, zinc might accumulate in soils and cause damage to turf. Soil zinc levels should not exceed 12 ppm to avoid this problem.

Laundry greywater is usually alkaline (pH 9 to 10) because of the types of detergents normally used. At site 2 the household detergent preference produced greywater having a Sodium Absorption Ratio (SAR) greater than 10. A high SAR can be detrimental, in the longer term, to the hydraulic conductivity and physical properties of clay soils and associated plant systems. Most commercially available bathroom/laundry products are currently manufactured using various types and quantities of sodium salts.

Phosphorus from detergents does not pose a problem when disposed to land since it is normally a plant requirement, but clay soils may become phosphate-saturated. There is a potential for leaching to groundwater or run-off to a watercourse. Excess phosphorous leaching to groundwater in sandy soils might be an even more significant problem.

Some detergents contain zeolite (an aluminium compound) as a replacement for phosphates. Greywater tests from site 1 indicated high levels of aluminium which was attributable to this source. Aluminium in zeolite is insoluble in water and therefore is not considered detrimental to plant life.

6.0 COMMENT

Some of the difficulties, solutions and findings to date about using greywater have been outlined in the body of this text. It is anticipated that this particular research project will be complete by mid 1995 and further findings will be presented at that time.**

7 0 DISCLAIMER

The views expressed in this paper are solely those of the authors and do not necessarily represent the official policies of their respective organisations.

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K 2

INSTALLATION AND EVALUATION OF DOMESTIC GREYWATER REUSE SYSTEMS IN MELBOURNE

INSTALLATION AND EVALUATION OF DOMESTIC GREYWATER REUSE SYSTEMS IN MELBOURNE

P. LECHTE, R. SHIPTON AND D. CHRISTOVA-BOAL
VICTORIA UNIVERSITY OF TECHNOLOGY

ABSTRACT:

This paper provides an overview of a research project being undertaken to assess the feasibility of reusing domestic greywater for irrigating lawns/gardens and for flushing toilets, to determine potential health and environmental impacts of such reuse, and to establish guidelines for installing appropriate residential reuse systems. Greywater from bathrooms/laundries at four Melbourne properties with different soil types, slopes, house types and family characteristics was filtered, collected in tanks and distributed by gravity or pumping for subsurface irrigation and/or toilet flushing. Family water use activities, soil parameters and other environmental indicators were monitored, and flows were metered and sampled for microbiological, physical and chemical analyses. Preliminary risk analyses and a social survey aimed at assessing the public's perception of greywater reuse were also carried out. Several conclusions have been drawn regarding technical difficulties and costs involved with various systems, but adequate assessment of environmental and health risks will require further work.

KEY WORDS: Greywater, domestic reuse, health risks, environmental risk, social survey.

1.0 INTRODUCTION

In 1993 Victoria University of Technology with financial support from Melbourne Water began a research project to assess the feasibility of reusing domestic greywater for irrigating lawns/gardens and flushing toilets, to determine potential public health and environmental impacts of such reuse, and to establish guidelines for installing appropriate residential reuse systems. The project has subsequently been guided by a committee comprising representatives of the university, Melbourne Water (MW), the EPA and the Department of Health and Community Services (DHCS), the last of which has also provided significant financial assistance. A number of Melbourne properties with different soil types, slopes, house types and family characteristics were selected for the project. An extensive survey of relevant local and overseas literature, codes and practice was undertaken before design, installation and monitoring of four systems were eventually carried out as indicated in the following sections. A preliminary risk assessment and two social surveys aimed at assessing the public's perception of greywater reuse were also carried out as part of the research This paper provides an overview of the major elements of the project as outlined above, but does not focus on background literature. However it should be noted that reports produced for a parallel project undertaken by Brisbane City Council provide a comprehensive literature review on domestic greywater reuse systems (Brisbane City Council, 1993, 1994).

2.0 REUSE SYSTEM INSTALLATIONS

The selection of properties for installation of reuse systems was carried out to provide as much variation as possible in allotment characteristics (soils, slope, vegetation, irrigable area), housing type (storeys, timber/brick, ground clearance, new/retrofit situation) and family characteristics (number of adults/ teenagers/children/toddlers and associated greywater generation). After systems were designed, and council and other necessary approvals obtained, installation and commissioning were carried out during 1993-94. System characteristics are summarised in table 1.

Table 1 - Summary of Greywater (GW) Reuse System Characteristics

CHARACTERISTICS	SITE 1	SITE 2	SITE 3	SITE 4
1. Location (suburb)	Balwyn	Clifton Hill	Malvern	Strathmore
2. Installation date (month)	December '93	December '93	August '94	October '94
3. Family characteristics				
(a) adults	2	2	2	2
(b) teenagers (13 - 18 yrs)	2	-	-	-
(c) children (3 -12 yrs)	-	2	-	-
(d) babies/toddlers (0 - 2 yrs)	-	-	-	1
4. Typ. GW quan.generated (L/wk)				
(a) bathroom	2450	1420	460	840
(b) laundry	1200	400	210	520
5. Allotment characteristics				
(a) size (m^2)	573	569	216	541
(b) soil type - top soil (150 mm)	silty sandy soil	bl. clayey silty soil	gr./br. silty sand	gr. silty top soil
- subsoil	silty fine/med.sand	bl./gr. silty clay	gr./br. silty sand	gr./br. clayey silt
(c) area irrigated (m^2)	130	160	34	97
(d) slope of area irr. (%)	5 - 7	< 1	< 1	3 - 4
(e) vegetation irrigated	lawn	lawn, some garden	native garden	lawn
6. House details				
(a) construction type/storeys	weatherboard/ 2	weatherboard/ 1	concrete brick/ 1	brick veneer/ 1
(b) approx.floor clearance (m)	0.20 - 1.10	0.25	slab on ground	0.25 - 1.35
(c) number of toilets	3	2	1	1
7. Plumbing & diversion arrang'ts				
(a) new or retrofitted situation	retrofit	retrofit	new	retrofit
(b) tanks (collection/sump(C/S), toil.fl.(TF))	C/S, TF	C/S, TF	TF	-
(c) brief system description	upper fl. b'rm → TF, l'dry →C/S → pumped (drip) and gravity (leachfld) irr'n	b'rm → C/S → pumped (drip) & gravity (leach) irr., l'dry → C/S → pumped → TF	CWM* → TF, b'rm → pits → pump → (leach) irrigation	b'rm (shower) → gravity (leach) irr., CWM* → gravity (leachfld) irr'n
8. Installation costs for project sites($)				
(a) diversion, plumbing, tanks, etc.	2468	2796	1821	1079
(b) irrigation system	3250	3150	1455	1914
(c) metering & instrumentation**	1508	1373	490	426
(d) total	7226	7319	3766	3419

* CWM - clothes washing machine ** - not req'd for normal domestic systems

Greywater from bathrooms and laundries was screened, collected in 140-300 l effective capacity steel or plastic tanks (at sites 1 - 3), filtered and distributed by gravity or pumping for irrigation and (in three cases) toilet flushing. Kitchen greywater was excluded from use because of extreme variability and potentially high concentrations of organic wastes and fat/oil/grease. Based on the literature review and DHCS advice regarding potential health risks, all irrigation systems were subsurface, and comprised both leachfield and pressure/drip arrangements in a number of subzones at each site. A variety of shallow trench cross sections, spacings and outlet types chosen to match soil types (texture, infiltration rate, hydraulic conductivity, etc) were tested, and minimum buffer zones of 1m were adopted adjacent to house and property boundaries. Systems were generally designed to be controlled by manually-operated diversion valves, with unused greywater being directed to the sewer, either directly or via a collection tank. For the pumped irrigation systems at sites 1 and 2, rainwater collection cut-off switches were used to stop pumping when a preset amount of rain had fallen.

3.0 MONITORING PROGRAM

In order to evaluate water usage and potential savings, rain gauges, household water meters and flow meters on lines to irrigation zones, toilet flushing tanks etc. were read at weekly intervals at sites 1 - 3. Site 4 was established more as a prototype than an experimental installation, and was not equipped with flow meters. Residents also kept detailed diaries on a series of pro-forma sheets of all water-consuming activities, soap/detergent usage, and any problems occurring in any part of their systems, eg, odour, scum rings in toilet bowl, filter clogging. Water usage in various parts of systems was then read from meters and inferred from diary entries, and then cross-correlated. In order to make a preliminary evaluation of potential health and environmental impacts of the reuse systems, baseline conditions for a range of parameters in near-surface soils and for vegetative cover were established and then a limited program of greywater sampling and analysis was carried out for each site. Greywater from both bathroom and laundry sources was analysed for a range of microbiological, physical and chemical parameters, with the total number of samples from different sites/sources varying because of the different times of system installation. Although it was recognised that this limited sampling program would not allow a valid statistical analysis, it did provide a set of data which could be compared with other results reported in the literature.

4.0 PRELIMINARY RESULTS AND SYSTEMS EVALUATION

4.1 Greywater Quality and Estimated Water Savings.

Table 2 summarises the range of values found for a number of the more important greywater quality parameters analysed at each site, along with ranges reported in the literature for corresponding parameters. It has not been possible because of space limitations to list all greywater quality, soil and vegetation parameters assessed at the four sites, but these will be reported in more detail at a later stage. Values determined in this project indicate that greywater quality is likely to be highly variable, depending on individual sources, family habits, soaps/ shampoos/ detergents used, and other site-specific determinants, and thus generally confirm the wide range of values reported in the literature. In some cases greywater has many of the characteristics of weak to medium domestic sewage. From a health viewpoint, faecal coliforms in the order of 10^3 per 100 ml are at the low end of the range normally expected in raw sewage, and far exceed guideline concentrations (eg., NSW Recycled Water Coordination Committee, 1993) for water used in domestic surface irrigation. As would be expected, total coliforms and parameters such as BOD, SS, colour, turbidity and in some cases pH are far outside the same guidelines. These findings confirm the preliminary conclusion that any irrigation system used should be subsurface, and indicate a real potential problem with toilet flushing, unless the water can be adequately treated. From an irrigation viewpoint, high pH and sodium concentrations in conjunction with medium to high salinity (EC values) and sodium adsorption ratios, particularly in laundry greywater samples, indicate a potential problem with soil/plant degradation. Some samples showed excessive aluminium and zinc concentrations, with the latter being derived from leaching of a galvanised tank. In one case boron and copper were also a little high in relation to standard wastewater irrigation guidelines (eg, Environment Protection Authority Victoria, 1991). These problems indicate the need for careful selection of detergents, etc., appropriate tank materials, and good irrigation and leaching arrangements if greywater irrigation is to be sustainable.

After a commissioning period, regular greywater reuse commenced at sites 1 and 2 at the start of February '94, but sites 3 and 4 were not established for the '93-'94 summer. Based on extrapolation of measured savings in the period from February to October '94, preliminary estimates have been made for sites 1 and 2 of water savings which would have been achieved in the twelve months from October '93 if greywater had been reused throughout that period. These estimates must obviously be viewed with caution, and will be reconsidered after data is available for the 94-95 summer. At site 1, average annual usage for the three years prior to October '93 was about 377 kl, but in the following twelve months total usage dropped to about 301 kl. Of this amount, approximately 31 kl (10.3%) and 10 kl (3.3%) would have been greywater used for irrigation and toilet flushing respectively, so total savings would have been around 41 kl (14%). At site 2, average annual usage for the three years prior to October '93 was about 142 kl, and was similar at 139 kl in the following twelve months. Of this amount approximately 17 kl (12.2%) and 10 kl (7.2%) would have been greywater used for irrigation and toilet flushing respectively, so total savings would have been around 27 kl (19.4%). It should be noted that Melbourne's '93-'94 summer was wetter than normal, and this was partly reflected in a significant drop in total water usage at site 1, although a similar drop was not observed at site 2. It might be expected that irrigation water savings would be greater in a drier year. It should also be noted (see table 1) that sites 1 and 2 each had only one toilet supplied by greywater, but had three and two toilets respectively in total. A house with only one toilet and with greywater used to flush the toilet would be expected to achieve significantly greater savings on toilet flushing water.

Table 2 - Greywater Quality: physical, chemical and microbiological parameters

Parameters	Project Values		Literature Values (see BCC, 1994)
	Bathroom water	Laundry water	
pH, units	6.4 - 8.1	9.3 - 10	5 - 9.9
EC 25C, microS/cm	82 -250	190 - 1400	330 - 580
Colour, Pt/Co units	60 - 100	50 - 70	-
Turbidity, NTU	60 -240	50 - 210	20 - 140
Suspended Solids	48 - 120	88 - 250	20 - 1500
Nitrate & Nitrite, as N	<0.05 -0.20	0.10 - 0.31	0 - 4.9
Ammonia, as N	<0.1 -15	< 0.1 - 1.9	0.1 - 8.1
Total Kjeldahl Nitrogen, as N	4.6 - 20	1.0 - 40	0.6 - 50
Phosphorus, total as P	0.11 - 1.8	0.062 - 42	0.3 - 35
BOD, 5 day	76 - 200	48 - 290	33 - 620
Azure- A Active Substances	1.2 - 10	30 - 150	-
Oil and Grease	37 - 78	8.0 - 35	-
Total Alkalinity, as CaCO3	24 - 43	83 - 200	125 - 382
Calcium (Ca)	3.5 - 7.9	3.9 -12	4 - 824
Magnesium (Mg)	1.4 - 2.3	1.1 - 2.9	1 - 15
Sodium (Na)	7.4 - 18	49 - 480	32 - 1090
Potassium (K)	1.5 - 5.2	1.1 - 17	4.5 - 13
Iron (Fe)	0.34 - 1.1	0.29 - 1.0	0.79 - 28
Zinc (Zn)	0.2 - 6.3	0.09 - 0.32	0.38
Copper (Cu)	0.06 - 0.12	< 0.05 - 0.27	0.15
Aluminium (Al)	< 1.0	< 1.0 - 21	0.02 - 0.67
Boron (B)	< 0.1	< 0.1 - 0.5	-
Sulphur (S)	1.2 - 3.3	9.5 - 40	-
Silicon (Si)	3.2 - 4.1	3.8 - 49	-
Cadmium (Cd)	< 0.01	< 0.01	< 0.01
Arsenic (As)	0.001	0.001 - 0.007	-
Selenium (Se)	< 0.001	< 0.001	-
Chloride (Cl)	9.0 - 18	9.0 - 88	3.1 - 136
Total Coliforms/ 100mL	MPN 500 - 2.4x10^{7}	MPN 2.3x10^{3} - 3.3x10^{5}	-
Faecal Coliforms/ 100mL	MPN 170 - 3.3x10^{3}	MPN 110 - 1.09x10^{3}	17 - >1.6x10^{5}
Faecal Streptococci/ 100mL	MPN 79 - >2.4x10^{3}	MPN 23 - >2.4x10^{3}	19 - 1.51x10^{3}

Results are in mg/L unless specified otherwise.

4.2 System Problems Encountered.

A number of installation and operational problems were encountered and solutions tested at each of the four sites. Installation problems included the need for adequate screens/filters and customised tappings in collection tanks at specific sites, the need for substantial valving to give reasonable operational control, difficulties with retrofitting plumbing in small ground-clearance situations, and difficulties with arranging gravity-supplied leachfield systems to allow reasonably uniform irrigation. Operational difficulties of most concern to date have related to screen/filter clogging and cleaning, disinfection of greywater in toilet flushing tanks, leaching of zinc from a galvanised steel tank, and adjusting valves to allow uniform irrigation. Root intrusion into subsurface irrigation lines is also considered to be a potential problem, and a range of root inhibitors is being investigated to overcome this problem. It is also considered that such operation and maintenance activities would pose greater problems for a householder (rather than the project officer who has attended to them to date) and would need to be reduced, possibly by better design arrangements, if such systems are to be practically viable in the community at large. Details of a number of these problems have been provided by Christova-Boal, Eden and McFarlane (1994).

4.3 Economic Considerations

System installation costs shown in table 1 may be misleadingly high, particularly for sites 1-3, because it was desired to trial different arrangements and incorporate maximum flexibility/control on the sites because of their experimental nature. On the other hand, a significant amount of necessary site specific design work has not been costed or included in table 1, and if systems were designed/installed on a commercial basis, this would tend to increase costs. Site 4 was established to further test the most promising arrangements deduced from sites 1-3, and although still set up to test different subsurface irrigation methods, can be considered more representative of a "typical" household installation. It should also be noted that site 4 involves neither collection tankage nor pumping, and that greywater is reused only for irrigation. Plumbing and diversion costs, particularly in retrofit situations, are highly variable depending on system complexity, ie, what sources of greywater are tapped, for what purposes they are used, and whether pumps and tanks are involved. The simplest single source - single destination diversion system may cost only a few hundred dollars, whereas multiple source-destination diversion systems may cost well over $2000. Leachfield irrigation arrangements may typically cost $15-20/m^2 if installed by a contractor, but this may be reduced to around $5-8/m^2 if installed by a householder (subject to compliance with necessary regulations).

It might be expected that a slightly simplified version of the arrangement at site 4 could be installed for around $1700 (or say $1400 for a new house installation) if the irrigation system were constructed by the householder. Assuming effective interest rates of 4-8% and a reasonable system lifespan, this represents an equivalent annual cost of about $120-180 p.a. if the cost of disposable filters is also included. Based on water savings estimated to date at the other sites, it is anticipated that annual water savings at site 4 should be in the range 20-30 kl. If the figure of 30 kl is used and costed at $0.65/kl (the current water charge in Melbourne), the annual cost saving for water would be only about $20. The current charge for water would therefore need to be from about $4-6/kl to break even. By considering other systems of greater or lesser complexity than that at site 4 (but all with subsurface irrigation), and the consequent potential for greater or lesser water savings, it is clear that there is at present no economic incentive for householders to install such systems. This conclusion is even more true when regular maintenance tasks (generally matched to the complexity of the system adopted) are taken into account.

5.0 PUBLIC SURVEYS

5.1 General

As part of this project, two social surveys have been conducted to determine (a) the public's perception of greywater reuse and concerns/difficulties of establishing greywater recycling systems for garden watering or toilet flushing, (b) the level of education required for people to operate such systems effectively, (c) the perception of acceptable costs for such systems and (d) customer segments which could be effectively influenced in a greywater system marketing campaign. The first survey comprised 300 phone interviews with randomly selected residents spread across all areas of Melbourne, and was considered to be unbiased. The sample was large enough to give a 95% confidence limit interval of ±6% for the worst case 50% yes/no type response. For the second survey, 990 questionnaires were mailed to randomly selected residents in the town of Melton, which is situated in a low rainfall area 39 kms to the west of Melbourne and comprises 10119 households. The 146 returned questionnaires (~15%) represent a biased sample, but provided much useful information with a 95% confidence limit interval of ± 8% in the worst case. The questionnaires used for both surveys were similar, and requested general household/demographic data, information on residents' conservation/recycling experiences and practices, and specific information on knowledge of and interest in greywater recycling for garden watering or toilet flushing.

5.2 Results

In the Melbourne survey, around 40% of respondents indicated an interest in reusing bathroom or laundry greywater for garden watering, but only about 11% in using this water for toilet flushing. In the Melton survey, corresponding percentages were about 85 and 64 respectively, and general awareness of the concept of greywater reuse was much higher amongst this "interested" group. In both cases there was a significantly greater demand for information on the garden watering option, and the major reasons given for interest were water and cost savings. Aspects of concern to respondents were detergents, development of unhygienic or smelly conditions, and problems with grease/fats (for kitchen greywater, which was also included in the survey). Acceptable costs were generally related to payback periods of 2-4 years. Interest in water conservation and greywater reuse was most evident amongst home owners and retirees, those in the 40-49 year age bracket, and in the professional, manager/administrator and home duties occupational categories.

6.0 RISK ASSESSMENT FOR GREYWATER REUSE

Before any limited or broadscale authorisation for greywater reuse could be given by relevant Public Health and/or Environment Protection Authorities, an assessment must be made of potential risks involved in the various forms of reuse. Reuse of greywater for lawn/garden watering may have both potential public health (disease transmission) and environmental (damage to soil, groundwater, plants, animals, soil biota) risks, whereas reuse for toilet flushing largely involves a potential health risk. Health risk assessment involves the four main steps of hazard identification, dose-response rate determination, exposure assessment and risk characterisation, with each of these steps often being quite difficult to adequately define or quantify. Hazard identification involves defining the agents of concern and the adverse health effects they may cause in humans, dose-response rate relies on good epidemiological data and is complicated by the varying susceptibility of persons at risk, exposure assessment is the estimation (qualitative or quantitative) of the magnitude, frequency, duration, route and extent of exposure to a contaminant, and risk characterisation is the quantification of risk and comparison with other quantifiable risks to determine whether the risk is acceptable. Environmental risk assessment requires a focus on potentially harmful effects on individual environmental elements, eg. groundwater contamination, soil structure breakdown, plant deterioration or death. Analyses are further complicated by the desirability of distinguishing between potential and actual risks.

Hazard identification for greywater reuse is difficult because of the extreme variability in greywater quality, and the wide range of factors affecting this quality including personal hygiene habits/activities, cleaners/detergents used, climate, the health condition of the population at large and the occurrence of infectious diseases. Thus although no Salmonella sp., Campylobacter sp., Giardia or Cryptosporidia have been found in greywater samples taken to date during this project, no quantitative level of risk of their (or other infectious agents') likely presence or numbers in greywater from other households or on a broader scale can be deduced from this information. Generalised infectious doses of selected pathogens are given in the literature (see for example U.S. Environmental Protection Agency, 1992), but in some cases these vary by orders of magnitude depending on individual susceptibility. An attempt has been made in this project to define a range of health risk exposure pathways for toilet flushing and both surface and subsurface irrigation with greywater. Some of these pathways are summarised in table 3. Qualitatively, it seems clear that subsurface irrigation involves less exposure pathways and thus a reduced risk. Similarly, the risk of disease transmission by aerosols during toilet flushing could be reduced by greywater disinfection, but this would involve a householder in more complicated routine maintenance. Because of the difficulties involved in the first three steps of the health risk assessment process, little real progress has been made on quantifying the actual risks involved in reasonably widespread community greywater reuse. This is an area which will require considerable additional research.

Table 3 - Summary of More Important Greywater Health Risk Exposure Pathways.

No	Pathway	Description/Examples
A	Greywater reuse for toilet flushing	
1.	GW - Human	Changing/cleaning flushing tank filters or toilet, splash of greywater on skin, toddlers playing with toilet water.
2.	GW-Air-Human	Inhalation of aerosols from toilet flushing.
B.	Greywater reuse for subsurface irrigation	
1.	GW-Human	Changing/cleaning filters
2.	GW-Soil-Human	Toddlers digging in/eating soil, planting activities in garden
3.	GW-Soil-Plant-Human	Subsurface seepage into (raw) vegetable-growing patch, fruit trees
4.	GW-Soil-Animal-Human	Children/adults playing with dogs/other pets which might dig into soil
5.	GW-Soil-(Surface Water)	Possible saturation to soil surface, surface ponding/runoff, then C1,C3 below
C.	Greywater reuse for surface irrigation: (As for B1-B4, plus pathways below)	
1.	GW-Human	Increased opportunity for direct contact, eg, by playing/lying on grass
2.	GW-Air-Human	Inhalation of aerosols from any form of spray irrigation
3.	GW-Animal-Human	Children/adults playing with pets which might roll on wet grass, etc.

The approach taken to environmental risk minimisation in this project has been largely based on comparing a range of greywater quality parameters with published acceptable values, eg., for wastewater irrigation. Some of the problems indicated in section 4.1, eg, with respect to selection of appropriate detergents and irrigation practices, are being further investigated in the hope that systems involving minimal environmental risk can be developed and recommended.

7.0 CONCLUSIONS

Based on the public surveys carried out in this project, there is significant community interest in reusing bathroom or laundry greywater for garden watering, but less support for the toilet flushing option. Middle-aged home owners and retirees with professional or management backgrounds are generally the most interested group, and both water and cost savings are the main reasons for interest, with preferred pay back periods for reuse systems being 2-4 years.

Greywater from bathroom and laundry is highly variable in quality, and may have many of the characteristics of weak to medium sewage. Unless adequate on-site treatment, which is costly, can be provided, reuse of greywater for toilet flushing or lawn/garden irrigation therefore poses potential health and environmental risks. Health risks caused by aerosols from toilet flushing can be minimised by adequate filtration and disinfection or perhaps automatic toilet lid control. Health risks posed by irrigation can be substantially reduced if only subsurface irrigation is carried out. Minimisation of environmental risk to plants, soils and groundwater depends on good design, correct choice of system materials and soaps/detergents, and on good irrigation management.

Incorporation of the above safeguards poses technical, economic and behavioural difficulties. Technical difficulties include the need for good design of site specific systems, particular problems with retrofitting in many cases, the correct choice of system materials and components, the need for simple but adequate filtration and/or disinfection arrangements, the problem of achieving good irrigation distribution uniformity, and the need for relatively simple controls. All of the above might be overcome but only at substantial cost. Subsurface irrigation systems are likely to cost at least \$5-8/m^2, and as more greywater is required for use, associated plumbing and diversion systems would increase in complexity and cost from say \$300 dollars to over \$2000. In some cases annual operational costs for filter cleaning/replacement and disinfectants would impact severely on potential annual water cost savings. Although in general terms more costly and complex systems would allow greater water savings, the installation of such systems is unlikely to be an attractive proposition to householders on purely economic grounds unless the cost of water were to rise dramatically. Regular maintenance, which itself involves a degree of risk, would be necessary to varying degrees on virtually any system, and good system observation and control would be essential. There must be doubt as to whether many householders would have the necessary long-term commitment to such activities, and this would be a problem for Regulatory Authorities in terms of issuing permits.

8.0 REFERENCES

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