GREYWATER REUSE FOR TOILET FLUSHING IN HIGH-DENSITY URBAN BUILDINGS IN SOUTH AFRICA: A PILOT STUDY

Report to the

WATER RESEARCH COMMISSION

by

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EXECUTIVE SUMMARY

Introduction

Although renewable, water is a finite resource, distributed unevenly in time and space. This distribution is increasingly more severe in arid South African communities where the net fresh water resources reduces annually and increased urbanization and development has led to an overall increase in water demand. A major consumer of high quality water is toilet flushing. Domestic toilet flushing consumes between 20-40% of domestic water demand and between 50-70% of commercial water demand. The replacement of high quality water with greywater to meet toilet flushing is broadly encouraged by national government due to several reasons including the potential to reduce the overburden on traditional drinking water sources by reducing urban drinking water demand and the opportunity to provide reliable non-potable water services in remote locations where municipal drinking water supplies are limited or non-existent. Greywater is wastewater from showers, baths, spas, hand wash basins, laundry tubs, and washing machines. Depending on certain contexts, greywater may or may not include wastewater from dishwashers and kitchen sinks but definitely excludes toilet wastewater.

In contrast to the reasons put forward for greywater reuse, some reasons against reuse include long payback periods, unpleasant odours, and negative perceptions. Despite these reasons against reuse, greywater reuse for toilet flushing (amongst other uses) continues to grow worldwide.

Internationally, greywater reuse for toilet flushing has been implemented (successfully or not) in several places, e.g. Palma Beach hotel, Spain; Florianopolis, Southern Brazil; Institute Agronomique et Veterinaire, Rabat, Morocco; Berlin, Germany; Loughborough University and the Millennium Dome, United Kingdom; Annecy Residential Building, France; the Irvine Ranch Water District, California and Casa del Agua, Tucson, USA; Taiwan; and Ottawa, Canada.

In South Africa, greywater reuse for toilet flushing has not been as popular as greywater irrigation. This is despite results from extensive surveys which recorded domestic respondents' preference for toilet flushing similar to irrigation. This study therefore attempted to answer the question below:

"Given the increasing scarcity of high quality water resources in many South African communities and the need for sustainable supplemental water resources for large quantity but lower quality water requirements (e.g. toilet flushing), how viable are greywater reuse systems for toilet flushing in high density urban buildings?"

In response to the question above, several objectives were framed within context of the triple bottom line attributes of sustainability and these objectives were achieved through undertaking several tasks, i.e.:

- a detailed literature survey, which attempted to garner varied local and international experiences regarding greywater reuse for toilet flushing;
- an extensive review of regulations and guidelines pertaining to greywater reuse and the development of a proposed structure for a national guideline;
- the development of a database of locally available greywater reuse systems for toilet flushing and a framework to guide the evaluation of these systems;
- implementation of a pilot greywater reuse system for toilet flushing in a non-residential (educational) and residential (student residence) building, and monitoring certain parameters over time;
- surveys of perceptions across potential and actual users of the implemented pilot systems over time and awareness exercises; and
- an economical analysis (using payback period) of the pilot systems.

<u>Findings and recommendations</u>

The sections below summarise the key findings and recommendations of this study:

i. Amongst the potential uses for greywater presented to respondents in this study (i.e. toilet flushing and irrigation), toilet flushing was preferred. This was due to the perception of possibly lesser contact with the greywater if used for flushing than if used for irrigation. In essence, the further away the greywater was to dermal contact or ingestion, the better for respondents. Reinforcing this perception was the preference amongst respondents for the pilot systems to be installed in non-residential (public) than residential (private) buildings. It was therefore no surprise to see that the overall assessment of the pilot greywater system after about 7 months of operation received a higher pass mark from respondents at WITS (non-residential) than at UJ (residential);

ii. Prior to the implementation of the pilot greywater reuse systems at the 2 sites, most of the respondents surveyed affirmed that the concept of greywater reuse for toilet flushing was a good idea that could benefit the environment. After implementation of the systems, and the problems and/or discomforts experienced by the respondents (e.g. turbid/foamy greywater in the toilet bowls often forming an unsightly ring and unpleasant odours during flushing at certain times) there was increased concern about hygiene. Surprisingly, this did not negate the earlier affirmation about the concept of greywater reuse, nor did it result in the reduced use of the greywater toilets. The pro-action of the project team in regularly allaying concerns during awareness sessions and speedily rectifying problems is suspected to have played a significant role in sustaining positive perceptions amongst respondents. In essence therefore, a critical component that will sustain beneficiaries' confidence in greywater reuse for toilet flushing (or similar reuse interventions) and the effective functioning of these systems, will be the pro-active and regular community engagement, awareness and maintenance/repair interventions by implementing agencies;

iii. Respondents younger than 21 years were generally more comfortable about greywater reuse than older respondents and therefore should be targeted when considering greywater reuse for toilet flushing (or similar interventions);

iv. In South Africa, there are no national regulations specifically addressing greywater reuse and management. There are however some sections/clauses in broad regulations which address greywater reuse and/or management, albeit to differing degrees of detail. In these sections/clauses, there is no fundamental objection in principle to the use of household greywater for toilet flushing, as long as nuisances, which compromise public health and the pollution status of the environment, are avoided. In fact, in most of the pronouncements made by national governments, there is encouragement to reuse greywater for flushing toilets. What is missing is the absence of national regulations and this has created a chasm between national governments' unequivocal encouragement for greywater reuse for toilet flushing (and irrigation) and the actual implementation of greywater reuse and reuse systems;

v. In addition to the lack of national regulations for greywater reuse and management, is the lack of a definition for greywater as a separate wastewater stream that is distinct from blackwater. The implication of this is that the understanding (and thus, legal position) of greywater is inconsistent amongst the various municipal councils that have by-laws addressing greywater. A national definition, and thus shared understanding of greywater is urgently needed;

vi. A consequence of the lack of national regulations is the lack of national guidelines specifically addressing greywater reuse in South Africa. The proposed structure for a national guideline for greywater reuse for toilet flushing is therefore presented in this report;

vii. It is imperative that prior to the selection of a package plant for greywater reuse, it is evaluated alongside other plants using the proposed framework developed in this study (or similar). This is because there exists a variety of package plants which purport to treat greywater for toilet flushing but for which limited or no data is available to verify the claims. Preferably, a physical evaluation of the plant and its effluent should be carried out. If an independent institution (e.g. the South African Bureau of Standards, SABS or the Joint Acceptance Scheme for Water Services Installation Components, JASWIC) undertook the testing and certification (or non-certification) of these package plants, the evaluation and selection process will be much more effective and implemented systems will function as expected;

viii. As a result of the diverse range of locally available technologies employed for greywater reuse, the quality of treated greywater, and consequently beneficiaries' perceptions, is bound to vary. The technology selected for greywater reuse in this study (i.e. low-technology and low-cost) determined the visual quality of sieved greywater (e.g. turbid/foamy greywater and unpleasant odours) and consequently, influenced beneficiaries' perceptions;

ix. The low-technology, low-cost greywater reuse systems implemented produced several pros and cons.

The pros were: (a) the systems were easy to modify to suit site conditions; and (b) the systems required no specialised skill to conduct weekly maintenance.

The cons which had a major impact on beneficiaries' perceptions were: (a) the greywater system, which did not remove scum, produced visually unpleasing (turbid/foamy) greywater especially at UJ and this was a particular concern for beneficiaries; (b) sieved greywater retained in the tanks for more than 48 hours and/or depleted chlorine, resulted in septic greywater which produced unpleasant smells during flushing; (c) an erroneous pipe connection at UJ resulted in greywater from the 1st floor bath and shower flowing into the ground floor bath and shower and this was a major cause for concern and discomfort for residents; (d) preliminary microbiological tests of the greywater produced by the initial implemented greywater system showed high microbiological counts, and thus the system was modified to include 2 inline chlorinators which provided increased disinfection but resulted in increased operational costs; (e) the small volume of the tank at WITS (~200 litres) in order to reduce the retention time of the greywater often resulted in the tank emptying out during peak (teaching) periods when the frequency of toilet flushing was high. As a result, the back-up municipal potable water supply was often used, thus negating the potable water savings which were to be achieved by implementing the greywater system;

x. In order to avoid the difficulties and consequently, additional costs associated with retrofitting greywater reuse systems for toilet flushing into existing buildings, it is preferable that reuse be incorporated into the designs for new buildings. To achieve this, there will be need to create awareness amongst various stake-holders.

xi. At WITS, there was on average, a total potable water savings of about 6% during off-peak teaching periods and 10% during peak teaching periods due to greywater reuse for toilet flushing in 2 of the 12 toilets. At UJ, there was on average, a 25% saving in total potable water used for toilet flushing during the academic term. From these results, WITS (non-residential), due to larger total potable water volumes, achieved larger potable water savings (and consequently costs) than UJ (residential);

xii. Payback at WITS was achieved 17 years after implementation while at UJ, payback was not achieved within the 20 year design life for the infrastructure. Therefore, on the basis of users paying the full costs of the reuse systems and a preferred payback period of 8 years, the systems at WITS and UJ were economically unviable;

xiii. In many of the communities where payback has been within the preferred durations (8-14 years), governments have been known to provide subsidies. In order therefore to achieve a payback period of 8 years for the reuse systems, initial costs at WITS will have to reduce to about 30% of its 2009 value while at UJ, an 8 year payback could only be realised when users paid only 76.5% of the recurrent costs.

Recommendations in brief

In brief, twelve key recommendations from this study in relation to greywater reuse for toilet flushing were:

i. Develop (or adopt) and enforce regulations and/or guidelines for greywater reuse;

ii. Incorporate greywater reuse for toilet flushing into the design of new buildings;

iii. Do not take the technology for granted. Select a greywater treatment technology only after a broad scrutiny and clear understanding (on the part of both the implementing agency and beneficiaries) of available technologies, how they function, operation and maintenance requirements, and the expected greywater output quality. There is no "*one size fits all*" greywater reuse technology.

iv. If possible, only select greywater treatment technologies that have received local certification by, e.g. SABS or JASWIC;

v. Insist on a purchase and prolonged (e.g. 12 month) service agreement with the supplier/manufacturer of the greywater system;

vi. Budget for regular operation and maintenance, modification, and replacement costs when installing especially low-technology and low-cost greywater treatment systems;

vii. Aim to achieve payback within 8 years. Payback periods of more than 8 years will be unattractive to potential beneficiaries and decision makers;

viii. Ensure greywater is collected from the correct sources within the building and that sufficient quantities of greywater for the intended use(s) can be collected;

ix. Aim for greywater quality that is visually similar to municipal potable water. If not possible, ensure there is regular monitoring and assurance of treated greywater quality and the monitoring of users' perceptions towards the quality;

x. Ensure there is regular engagement and awareness with beneficiaries before and after implementation;

xi. Target young people; and

xii. Target non-residential buildings.

Conclusion

The broad concepts of greywater reuse for toilet flushing, and potential beneficiaries' attitudes towards adopting greywater reuse for toilet flushing as one way of preserving/improving the environment, are laudable. However, the experiences garnered from this study show that implementing greywater reuse for toilet flushing in South African high density urban buildings already supplied with municipal potable water, must be approached carefully. Implementation of greywater reuse systems for toilet flushing should only proceed after a rigorous evaluation and conclusion on several critical issues including: the availability of regulations or guidelines to which the reuse system would be accountable; consideration (on the part of both the implementing agency and beneficiaries) of the trade-offs between implementing low-technology, low-cost, high maintenance but minimum skill required, and low greywater quality reuse systems versus other greywater reuse system permutations; employing accredited greywater reuse systems; targeting the most appropriate end users, i.e. young people and non-residential buildings; achieving economic viability based on a maximum payback period of 8 years; and the need for regular beneficiary awareness and engagement. A cursory evaluation of the above issues would likely result in the failure of such systems.

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GLOSSARY

Blackwater	Wastewater collected from the bathroom and kitchen and therefore consists of faeces, foods, fats, soaps and urine.
Dual system	Two separate pipelines that supply a building with two qualities of water for drinking and non-drinking purposes.
Effluent	Water that flows out of treatment plants.
E.P. / P.E.	Defined as “equivalent person” typically consuming 200 litres/p/day
Greywater	Wastewater from showers, baths, spas, hand wash basins, laundry tubs, and washing machines. Depending on certain contexts, greywater may or may not include wastewater from dishwashers and kitchen sinks but definitely excludes toilet wastewater.
Non-potable water	Water that is not suitable for drinking.
Potable water	Water that is considered safe for human consumption.
Recycling	See Reuse.
Reuse	An umbrella term for the process of treating non-potable water for potable and/or non-potable use
Wastewater	Water carrying contaminants. Note that wastewater to one user may be a desirable supply or resource to the same or another user at a different location for a different purpose.

1. INTRODUCTION

1.1. Background to the study and motivation

Although renewable, water is a finite resource, distributed unevenly in time and space. This distribution is increasingly more severe in arid communities where the net fresh water resources available reduces annually and increased urbanization and development has led to an overall increase in water demand. This water demand has traditionally been met with water from the best available sources. However, over the years, it has become evident that high quality water sources in many provinces (e.g. Western Cape, Northern Cape and Limpopo) are inadequate to meet demands and, that not all uses require the same water quality. Some water uses can be supplied with water of an inferior quality, which frees the high quality sources for higher quality uses. This is nothing new in the history of mankind since by 226 A.D., Rome already had eleven aqueducts and each one had its own quality of water and specific use (Duncan, 2002).

The largest percentage (62%) of South Africa's water demand occurs in the irrigation sector (DWAF, 2004c) with the highest proportion of this demand being private irrigation (59%). By volume, irrigation is also one of the major inefficient water users in South Africa (Stevens and Stimie, 2005). Another major consumer of high quality water is toilet flushing. Domestic toilet flushing consumes between 20-40% of domestic water demand (DWAF, 2007) and between 50-70% of commercial water demand. Any savings in the above sectors will certainly make a significant difference in drinking water allocation for other uses and users.

The replacement of scarce drinking water with less quality water (e.g. greywater) to meet some non-potable water demands such as flushing of toilets, fire fighting and lawn irrigation is encouraged in several places due to one or more of the reasons below:

i. the potential to reduce the overburden on traditional drinking water sources by reducing urban drinking water demand by between 30-70% (Radcliffe, 2003);

ii. the opportunity to provide reliable non-potable water services in remote locations where municipal drinking water supplies are limited or non-existent;
iii. mitigating the rising costs of drinking water treatment by reducing the quantity of chemicals required to treat drinking water and in the reduction of sludge which arises during the treatment of drinking water;
iv. the potential to reduce sewage discharges to water bodies; and
v. exploiting the nutritional benefits of using suitably treated non-potable water in irrigation.

Greywater is broadly referred to as wastewater from showers, baths, spas, hand wash basins, laundry tubs, and washing machines. Depending on certain contexts, greywater may or may not include wastewater from dishwashers and kitchen sinks but definitely excludes toilet wastewater. Blackwater, which refers to toilet wastewater and greywater, is a distinct wastewater stream in quality to greywater. As a result, greywater which at generation is a better quality resource than blackwater, can be beneficially and appropriately employed for certain non-potable water requirements (such as toilet flushing). To reduce contaminants in greywater, several communities (e.g. Australia and USA) exclude kitchen and related wastewaters which typically contain significant microbial loads, foods, fats, oils and grease.

Internationally, greywater reuse for toilet flushing has been successfully implemented in several places, e.g. Palma Beach hotel, Spain (March *et al.*, 2004); Florianopolis, Southern Brazil (Ghisi and Ferreira, 2007); Institute Agronomique et Veterinaire, Rabat, Morocco (El Hamouri *et al.*, 2007); Berlin, Germany (Nolde, 1999); Loughborough University (Surendran and Wheatley, 1998) and the Millennium Dome (Hills *et al.*, 2001) United Kingdom; Annecy Residential Building, France (Lazarova, 2001); the Irvine Ranch Water District, California (Lewinger and Young, 1988) and Casa del Agua, Tucson (Karpiscak *et al.*, 2001) USA; Taiwan (Chin-Jung *et al.*, 2005); and Ottawa, Canada (Oasis Design, 2006). In contrast, some of the failures, negatives and controversies surrounding greywater reuse systems include long pay-back periods, outbreak of water-borne diseases due to greywater ingestion, clogging or fouling of filters, unpleasant odours, negative perceptions, and/or sediment/microbial accumulation in the storage tank. Despite the latter, one or more of the drivers for greywater reuse listed above have continued to motivate growing greywater reuse for several purposes including toilet flushing.

Because of the potential risks to public health due to the possible ingestion of contaminated greywater, greywater reuse in South Africa is viewed with caution and not commonly practised. The most common greywater reuse sites in South Africa have been experimental domestic irrigation and non-domestic irrigation and this reuse has been driven by the heightened awareness of the nutritional benefits of applying suitably treated greywater to the irrigation of plants and the need to efficiently manage greywater disposal in especially non-sewered areas (Rhodda *et al*., 2010 and Carden *et al*., 2007). Some of the innovative irrigation methods designed for greywater reuse include the Wagon Wheel Irrigation System developed by the Institute for Deciduous fruit, Vines and Wine (Infruitec-Nietvoorbij) at the Agricultural Research Council (ARC), which has been installed at a number of sites in South Africa (Albertse, 2000). The tower garden is another interesting concept (derived from a project in Kenya), which consists of vegetables growing around the sides of a column of soil surrounding a central stone-packed drain (Crosby, 2004). Greywater is poured on top of the stones and filters slowly through the soil column. These systems were primarily designed for low-cost, small-scale irrigation with greywater, but have also been applied commercially in some high-income sewered areas (Alcock, 2002). Khosa (2003) describes an on-farm study using the 'Drum and Drip' micro-irrigation system (an adapted low-cost irrigation system for use on small holdings) in two settlements in Limpopo province.

Greywater has also been employed for irrigating crops a formal housing community (Wyebank near Hillcrest) and an informal housing community (Mandela Park) that did not have any drainage systems in place. Other examples include the collection, sieving, disinfection and reuse of greywater (bathroom and kitchen wastewater) from about 110 sewered and non-sewered households in Carnarvon in the Northern Cape for lawn and vegetable garden irrigation (Ilemobade *et al*., 2009a); and the direct application of greywater from washing machines for irrigating lawns and kitchen greywater via a below surface rock-filled trench to also irrigate lawns at the Hull street housing complex in Kimberley in the Northern Cape (Ilemobade *et al*., 2009a).

Several of the above systems were discontinued (e.g. Wyebank and Mandela Park) due to possible health implications, e.g. the consuming of crops irrigated with contaminated greywater, children or pets playing in and ingesting contaminated greywater used to irrigate fields/lawns, and the potential contamination of ground water.

In South Africa, greywater reuse for toilet flushing has not been as popular as irrigation. This is despite results from extensive surveys conducted by Ilemobade *et al.* (2009a and 2009b) which record domestic respondents' preference for non-potable water reuse for toilet flushing similar to irrigation. Some sites that have however employed greywater reuse for toilet flushing include (i) the Creche within the Old Mutual building in Pinelands, City of Cape Town where greywater from hand wash basins is collected, sieved, disinfected and used to flush 30 toilets (Water Rhapsody Conservation Systems, 2011) and a building in the City of Cape Town which houses 7 apartments and uses a highly technical system to biologically purify, store and reuse greywater (from bath tubs, hand wash basins and showers) for toilet flushing (Kieslich, 2009). If correctly implemented and managed, greywater reuse for toilet flushing may likely mitigate several of the reasons why greywater reuse for irrigation has been found to be unsuitable.

A dual water reticulation system comprises two sub-systems – a conventional system that meets potable end uses and a separate system that meets non-potable end uses within a building. In this report, the separate system comprises the components that collect, treat, store and supply greywater for toilet flushing. Dual grey and drinking water reticulation systems (henceforth, dual systems) are particularly promising for application in high-density urban buildings (HDUBs) located in arid South African environments. This is because HDUBs:

i. are typically generate significant volumes of greywater per unit area as compared to stand alone dwellings;
ii. are typically cost less in terms of rent/mortgage than stand alone houses and therefore attract low to middle income earners who are looking for value for money. Hence, the installation of a dual system may likely provide cost savings which may be an attractive incentive for residents;

iii. are typically multi-storey buildings with centralised service areas and hence, the installation of the greywater reuse system will likely be easier for plumbers looking to connect several households within a building than as comparison to several stand alone households spread over large area; and
iv. are reasonably access-controlled and centrally managed and hence, potential risks to public health can be mitigated.

In terms of national and municipal regulation and guidelines for implementing dual systems and greywater reuse for toilet flushing, South Africa is deficient. The local instances of greywater reuse cited above have depended primarily on growing local experience and/or international regulation/guidelines. This gap therefore provides impetus for research.

Based on the above, the question currently driving the need for a South African investigation into the reuse of greywater for toilet flushing is:

"given the increasing scarcity of high quality water resources in many South African communities and the need for sustainable supplemental water resources for large quantity but lower quality water requirements (e.g. toilet flushing), how viable are greywater reuse systems for toilet flushing in high density urban buildings?"

This project aims to provide a response to this question.

1.2. Project objectives

In addressing the above question, the objectives of this study were framed within context of the triple bottom line attributes of sustainability, i.e. economic, social and environment (Figure 1). The economic attribute incorporated technical criteria, the social attribute incorporated regulatory criteria and the environment attribute (which focused on greywater quality) was addressed only within context of the desktop studies and not in the pilot study.

Figure 1. The triple bottom line attributes of sustainability

Hence, the objectives of this study were:

i. To review knowledge and experience in greywater reuse and reuse systems specifically for toilet flushing;
ii. To interrogate regulations and guidelines pertaining to greywater reuse for toilet flushing in South Africa and to propose a structure for a national guideline;
iii. To collate a database of locally available greywater reuse systems suitable for toilet flushing and to develop a robust framework for evaluating these systems for local implementation;
iv. To monitor perceptions of potential and actual beneficiaries towards the implementation of greywater reuse systems primarily for toilet flushing;
v. To implement and monitor a pilot greywater reuse system for toilet flushing at 2 distinct water users, i.e. a residential and educational building; and
vi. To undertake an economical analysis of the pilot greywater reuse systems;

1.3. Methodologies employed to achieve project objectives

Literature surveys

Literature surveys were carried out to document the varied characteristics of greywater; successful and failed/controversial greywater reuse systems for toilet flushing; greywater treatment criteria, technologies and locally available systems; regulations and guidelines regarding greywater reuse internationally and locally; and a diversity of social, institutional, economical, technical, environmental, and public health issues that have arisen with the use of greywater reuse systems. The literature surveys laid the foundation for the succeeding methods employed in the study.

<u>Surveys of locally available greywater reuse systems for toilet flushing and development of the selection framework</u>

In the literature survey, the qualities of greywater suitable for toilet flushing and typical greywater treatment technologies were investigated. This review was undertaken to determine the variety of greywater reuse technologies manufactured locally or imported. To this end, several related Water Research Commission reports, relevant databases and literature were investigated and advertised manufacturers, retailers and importers of greywater and wastewater treatment technologies were contacted and questionnaires administered to determine the specifications of their greywater/wastewater systems and typical effluent output. Based on the data collated, a framework was developed, using robust criteria and benchmarks, to assist in the selection of the most appropriate greywater reuse system for the selected pilot sites. This framework may be employed to guide future decision-making regarding the selection of appropriate reuse technology(ies) to be implemented for different purposes.

<u>Perception surveys</u>

Perception surveys, using 3 sets of questionnaires, were administered to potential and actual beneficiaries of the implemented greywater reuse systems for toilet flushing. The questionnaires monitored critical perceptive factors known in literature to influence non-potable water reuse amongst a diversity of respondents. The questionnaires were administered to respondents within the universities of the Witwatersrand, Johannesburg and Cape Town over the period 2008-2010. After the first set of questionnaires were administered to potential respondents in the 3 institutions in 2008 and 2009, the pilot study locations were selected (i.e. an academic building at the university of the Witwatersrand and a student residence at the University of Johannesburg). Subsequent to the implementation of the greywater reuse systems at the selected sites, the second and third sets of questionnaires were administered to beneficiaries while concurrently monitoring perceptions.

Implementation and monitoring of 2 pilot greywater reuse systems for toilet flushing

A pilot greywater system for toilet flushing was implemented for 2 distinct end users – an educational building (the School of Civil and Environmental Engineering) at the University of the Witwatersrand, (WITS) and a residential building at the Student Town residence of the University of Johannesburg, Kingsway campus (UJ). This section of the study involved the following:

i. Monitoring, prior to installation of the greywater reuse system and afterwards, toilet flushing and bulk potable water demands at the 2 buildings. This exercise was undertaken to determine the quantities of greywater which would be required to flush toilets and therefore, the potential potable water savings and sewage volume reductions that may be achieved from greywater reuse for toilet flushing;
ii. Administering perception surveys and awareness sessions with beneficiaries in the 2 buildings in order to monitor evolving perceptions; This exercise was undertaken to involve beneficiaries in the project prior to and after implementation; inform beneficiaries of their responsibilities towards the functionality and sustainability of the system; and receive feedback (in the form of comments, suggestions, complaints, etc.) which assisted in the modification of subsequent questionnaires and the modification of the greywater reuse system to suit user requirements;
iii. Retrofitting the existing buildings' plumbing components and installing the selected greywater reuse systems to flush 2 toilets within each building;
iv. Monitoring the electricity consumption of the pumps;
v. Weekly maintenance of the greywater reuse system (i.e. cleaning the filters, chlorine disinfection capsules and greywater tank sides; replenishing cistern blocks which provide colouring and chlorine tablets; and inspecting the system to ensure there are no leaks, breaks or missing components) to ensure it optimally functions;
vi. Training relevant personnel on how to operate and maintain the greywater reuse system;

Economical analysis of the implemented pilot greywater reuse systems

Subsequent to implementation and monitoring, a desktop exercise was carried out to economically analyse the implemented greywater reuse systems. Since the length of payback on reuse projects stands out in the literature as a significant contributor to potential beneficiaries' and decision-makers' interest in the technology and thus overall viability, the payback period is computed for the 2 greywater reuse systems.

1.4. Layout of this report

The 1st chapter of this report presents the background and motivation and consequently, objectives of this study. A summary of the methodologies employed to achieve the objectives are also presented in this chapter. The 2nd and 3rd chapters document local and international experience regarding greywater, greywater reuse and reuse systems. Chapter 4 reviews international and local regulations and guidelines governing greywater reuse and reuse systems while Chapter 5 presents a broad review of existing greywater treatment technologies and then develops the framework for selecting an appropriate greywater reuse system amongst a diversity of locally available options. The sites which were selected and the implementation of the pilot greywater systems are discussed in Chapter 6. The methodology and highlights from the perception surveys, awareness and education sessions are presented in Chapter 7. Chapter 8 presents the technical highlights and economic analysis of the pilot systems while Chapter 9 presents the summary of findings, recommendations and conclusions of this study.

2. LITERATURE REVIEW

2.1. Domestic water consumption

Water consumption depends on several factors (e.g. the degree of aridity, income, level of development, level of services, household occupancy and culture) and is typically measured as litres per person per day (l/p/d). Water consumption tends to increase with increasing income, decreasing household occupancy and increased level of development. In the UK, a water consumption range of 102 to 212 l/p/d was reported between 1991 and 1998 (Table 1). This compares well with the values of 115-260 l/p/d (Griggs *et al*., 1997) presented for the rest of Europe about the same time but is lower in comparison to the 450 l/p/d published for Zurich, Switzerland (Stanner and Bordeau, 1995). The water consumption figures for the USA about 2 decades before, appears to be within the range published in Table 1 for the UK. In 1998, a water consumption figure as high as 1136 l/p/d (which is likely to have included garden irrigation) was reported for some arid areas in the US.

A breakdown of typical domestic water usage in various countries (Table 1) demonstrates that the proportions of water used for different purposes in household are similar. Daily toilet flush water per capita is roughly a third of total domestic water consumption and slightly larger than the combination of bath, shower and hand wash basin water consumption. Butler *et al.* (1995) estimates that the toilet consumes about 40% of the total instantaneous flow during the day and up to 90% at night. One implication of this figures is that domestic greywater generated from the bath, shower and washbasin can roughly satisfy toilet flush water demand. However, since greywater from the bath, shower and wash basin is typically generated over a short duration of each day and toilet flushing typically occurs over a prolonged period over each day, there is need to store greywater to meet the flushing demand.

Table 1. Domestic water consumption in l/p/d for different end uses in various countries
(Laine, 2001)

Reference	Butler (1991,1993)	Surendran and Wheatley (1998)	Mikkelsen *et al.* (1999)	Van der Hoek *et al.* (1999)	Laak (1974)	Ligman *et al.* (1974)	Siegrist *et al.* (1976)
Country	**UK**	**UK**	**Denmark**	**The Netherlands**	**USA**	**USA**	**USA**
Toilet	31	61.2	40	30.5	75	76	36
Kitchen	13	29.7	20	10.5	14	13	18
Wash basin	13	25.5	-	5.4	8	-	-
Bath and shower	28	34.4	45	59.7	32	47	38
Washing machine	17	25.6	10	23.1	28	38	41
Other	-	35.9	45	15.4	-	6	
Total (l/p/d)	102	212.3	160	144.6	157	180	133

2.2. What is Greywater?

Residential wastewater (i.e. blackwater) is a mixture of household wastewater from the following sources – bathroom hand wash basins, bathtubs, showers, toilets, kitchen sinks, washing machines, laundry tubs and dish washers. Blackwater is characterized by high concentrations of organic contaminants, disease and non-disease causing microorganisms and chemicals. This wastewater may be disaggregated into two sub-categories of greywater (i.e. light greywater and dark greywater) based on organic strength or the levels of contaminants contained in the water:

i. Light greywater typically consists of wastewater from bathroom hand basins, bathtubs, showers, and laundry. Light greywater generally has lower concentrations of contaminants than blackwater and dark greywater.
ii. Dark greywater is a combination of light greywater and wastewater from kitchen sinks, dishwashers, or other sinks involving food preparation. Food waste, grease, oils and cleaning products contribute significantly to increased contaminant loading and disease-causing microorganisms when combined with light greywater.

2.3. Greywater generation

The volume and pattern of greywater generated in a household varies and is influenced by factors such as total potable water consumption, water supply level of service, number of household members, age distribution of household members, lifestyles, and water use pattern. Greywater volume in low-income areas of South Africa with water scarcity and rudimentary forms of water supply (e.g. community taps or wells) can be as low as single-digit volumes per person per day in households where surface water bodies (e.g. rivers or lakes) are used for personal hygiene. On the other hand, households in middle- to high-income areas with piped water reticulation may generate significant volumes per person per day. It is estimated that on average, typical greywater generation in South African households with piped water reticulation may likely range between 45-80 l/p/d (approximately 50% of total water consumption). Table 2 shows greywater generated from different end uses in households which have piped water reticulation in different countries. On average, light greywater comprises between 70%-85% (69-96 l/p/d) of total greywater generated in most of the countries that have disaggregated figures for different end uses.

Table 2. Domestic greywater generation in l/p/d in selected countries.

	Busser (2006)	Friedler (2004)	Helvetas (2005)	www.greenhouse.gov.au	Martin (2005)	Wheatley and Surendran (2008)		Shrestha (1999)	Faruqui and Al-Jayyousi (2002)
Country	**Vietnam**	**Israel**	**Switzerland**	**Australia**	**Malaysia**	**UK**		**Nepal**	**Jordan**
						University hall	**Domestic household**		
Water source	**In-house taps**	**In-house taps**	**In-house taps**	**In-house taps**	**In-house taps**	**In-house taps**		**In-house taps**	**In-house taps**
Kitchen	15-20	30	28	17	-	-	-	-	-
Bath & shower	30-60	55	52	62	-	46	34	-	-
Laundry	15-30	13	30	34	-	14	26	-	-
Wash basin	-	-	-	-	-	44	24		
Total	80-110	98	110	113	225	104	84	72	30-50

Wheatley and Surendran (2008) show that a morning greywater generated peak flow is typically followed by two major peak flows – one about noon and the other about 19h00 in the evening. A minimum flow of less than 1 l/p/hour occurs between 02h00 and 05h00, corresponding to occupants' sleeping hours. Butler (1993) documents that blackwater from different end uses, flows more frequently in households with more occupants than in those with less occupants. At weekends, the morning blackwater peak flows are more extended and smaller than during the week, and typically appear after a delay of 1 to 2 hours. Butler *et al.* (1995) estimates that the greywater generated from the bath and shower end uses, constitutes up to 66% of the total instantaneous discharge in the early morning between 04h00 and 08h00 and in the evenings between 18h00 and 22h00.

2.4. Characteristics of Greywater

The characteristics of domestic greywater vary over time and space. Three factors significantly affect greywater composition: water supply quality, the condition of the components conveying greywater from point of discharge, and the water related activities in the house (Eriksson *et al.* 2002). Table 3 indicates the likely constituents of water from various household sources.

Table 3. Common constituents of domestic greywater
(CSBE, 2003)

Graywater Source	Possible Contents
Automatic Clothes Washer	suspended solids (dirt, lint), organic material, oil and grease, sodium, nitrates and phosphates (from detergent), increased salinity and pH, bleach, heat
Automatic Dishwasher	organic material and suspended solids (from food), bacteria, increased pH and salinity, fat, oil and grease, detergent material, heat
Bathtub and Shower	bacteria, hair, organic material and suspended solids (skin, particles, lint), oil and grease, soap and detergent residue, heat
Sinks, including Kitchen	bacteria, organic matter and suspended solids (food particles), fat, oil and grease, soap and detergent residue, heat
Swimming Pool	chlorine, organic material, suspended solids

Greywater quality will vary based on the end uses of water. For example, cooking habits as well as the amount and type of soaps and detergents will significantly determine the level of contamination in greywater. The heterogeneity of greywater therefore complicates both the treatment and the assessment of the risk of reuse (Rose *et al.*, 1991). Tables 4 and 5 show the heterogeneous characteristics of greywater in both developed and developing countries where greywater samples were analysed. These figures do not reflect country averages, bur relate to specific cases with specific settings.

Table 4. Characteristics of domestic greywater in some developed countries

	Lazarova (2001)	**Smith *et al.* (2001)**	**Surendran and Wheatley (1998)**		**Wheatley and Surendran (2008)**	**Rose *et al.* (1991)**	**Laine (2001)**	**Christova-Boal *et al* (1996)**
Country	**France**	**UK**	**UK**	**UK**	**UK**			
Greywater type	DGW	LGW	LGW	DGW	LGW	LGW	LGW	LGW
BOD_5 (mg/l)	275-580	33	216-252	472-536	81.2-110.4	-	129-155	76-200
COD (mg/l)	471-915	95	424-433	725-936	-	-	367-587	-
SS (mg/l)	71-215	36	40-76	68	37-53.7	-	58-153	48-120
NH_3-N (mg/l)	0.6-18.8	-	0.5-1.6	4.6-10.7	1.6-3.8	0.15-3.2	-	<0.1-15
TKN (mg/l)	3.9-22.8	4	-	-	-	0.6-5.2	6.6-10.4	4.6-20
TP (mg/l)	5-26.7	-	1.6-45.5	15.6-101	-	4-35	-	0.11-1.8
TC (CFU/100 ml)	1.8×10^{6}-1.8×10^{8}	2.4×10^{3} - $>2.4 \times 10^{6}$	5×10^{4}-6×10^{6}	7×10^{5}	-	6.1×10^{9}	6.8×10^{3} - 9.4×10^{3}	500-2.4×10^{7}
FC(CFU/100 ml)	3.0×10^{5}-1.6×10^{8}	-	32-600	728	-	1.8×10^{4}-7.9×10^{6}	-	170-8.3×10^{3}
E.coli (CFU/100 ml)	7.6×10^{5}-2.04×10^{7}	0-$>2.4 \times 10^{6}$	-	-	1.2×10^{3}		10-1.5×10^{3}	-

LGW = Light greywater; DGW = Dark greywater

Table 5. Characteristics of domestic greywater in some developing countries

	Dallas *et al.* (2004)	Burnat and Mahmoud (2005)	Friedler (2004)	Gross *et al.* (2006)	Shrestha *et al.* (2001)	Martin (2005)	Al-Jayyousi (2003), Faruqui and Al-Jayyousi (2002) & Bino (2004)
Country	**Costa Rica**	**Palestine**	**Israel**	**Israel**	**Nepal**	**Malay-sia**	**Jordan**
Greywater type	DGW	DGW	DGW	-	-	DGW	DGW
BOD_5 (mg/l)	167	590	477	280-688	200	129	275-2287
COD (mg/l)	-	1270	822	702-984	411	212	-
TSS (mg/l)	-	1396	330	85-285	98	76	316
NH_4-N (mg/l)	-	3.8	1.6	0.1-0.5	13.3	13	-
TN (mg/l)	-	-	-	25-45	-	37	-
TP (mg/l)	-	-	-	17-27	-	2.4	-
Boron (mg/l)	-	-	-	1.4-1.7	-	-	-
FC(CFU/100 ml)	1.5-4.6×10^8	3.1×10^4	2.5×10^6	5.0×10^5	-	-	1.0×10^7
Oil&Grease (mg/l)	-	-	193	-	-	190	7-230

LGW = Light greywater; DGW = Dark greywater

Greywater qualities from sewered and non-sewered communities in South Africa have been published by several authors, e.g. Alcock (2002), Kallerfelt and Nordberg (2004) (cited in Carden *et al*., 2007); the Pollution Research Group of the University of Kwazulu-Natal (Jackson *et al*., 2006); Stephenson *et al.* (2006); Engelbrecht and Murphy, 2006; Carden *et al.* (2007), and Rhodda *et al*. (2010). Engelbrecht and Murphy (2006) undertook an analysis of dish water, bath water and source water from a selection of 18 respondents/households in Stellenbosch. The respondents were selected based on their residential location within Stellenbosch, economic and social status. A summary of the analysis of samples received from these respondents are presented in Table 6.

Table 6. Analysis of dark-(dish) and light-(bath) greywater, and source water in Stellenbosch, South Africa
(Engelbrecht and Murphy, 2006)

Parameter		Dishwater min - max	STD	AVG	Bathwater min - max	STD	AVG	Source water min - max
K	mg/L	2.5 - 28	8	9	0.58 - 30	9	5	0.23 - 0.74
Na	mg/L	25 - 655	175	121	6.6 - 192	66	50	4.9 - 11
Ca	mg/L	4.4 - 20	6	13	3.5 - 21	6	11	6.2 - 20
Mg	mg/L	0.5 - 4.9	1	2	0.15 - 1.8	0.5	0.8	0.56 - 2.3
NH_4 (N)	mg/L	0.3 - 3	1	1	<0.1 - 57	16	6	<0.1
SO_4	mg/L	2.7 - 483	135	58	2.9 - 51	14	15	4 - 18
Cl	mg/L	17 - 144	41	60	6.8 - 127	35	28	7.9 - 18
Alkalinity	mg/L	10 - 572	158	94	14 - 453	138	103	12 - 32
NO_3 (N)	mg/L	<0.1 - 0.35	0.1	0.2	<0.1 - 0.6	0.2	0.1	<0.1
Ortho P	mg/L	0.27 - 9.3	3	2	<0.1 - 11	3	1.5	<0.1
B	mg/L	<0.1 - 9.5	3	1	<0.1 - 0.16	0.04	0.1	-
DOC	mg/L	51 - 571	170	246	4.3 - 330	93	52	<1 - 1
EC	mS/m	19 - 265	69	58	8 - 145	39	33	7.1 - 15.2
pH	units	5.5 - 9.5	1	7	6.7 - 9.9	0.9	8	7.6 - 9.0
Hardness	mg/L	13 - 57	16	39	11 - 59	16	31	19 - 54
SAR	units	1.7 - 38	11	8	0.86 - 21	6	5	0.3 - 0.8
COD	mg/L	713 - 7821	2352	3244	70 - 8619	2527	1491	-
Kjeldahl N	mg/L	15 - 62	15	38	1.1 - 224	63	36	-
Total P	mg/L	0.87 - 131	37	14	<0.1 - 14	4	2	-
SS	mg/L	36 - 1173	341	377	0 - 1553	449	270	-
TDS	mg/L	212 - 2990	815	1110	78 - 1622	510	389	-
FOG	mg/L	<10 - 2741	826	654	<10 - 1656	495	363	-
HPC	mL	30 - 2.0 x 10^7	-	-	2350 - 2.2 x 10^7	-	-	0 - 320
FC	100 mL	0 - 1.0 x 10^8	-	-	0 - 296000	-	-	0
E. coli	100 mL	0 - 1.0 x 10^8	-	-	0 - 20000	-	-	0

From the Table above, there are significant distinctions and notably large ranges between dark greywater being more polluted than light greywater. Hence, the justification in Australia and the USA to reuse only light greywater. As mentioned earlier, light greywater is contaminated with oils, animal fats, chemical detergents and food particles and hence, promotes and supports the growth of micro-organisms. Chemical detergents used for dish washing may be very alkaline and fats can solidify causing blockages in the pipe reticulation and natural drainage systems of soils if used for irrigation. Whilst light greywater do not normally contain human waste, it may contain similar micro-organisms as dark greywater. It is however safe to say that light greywater contains much lower numbers of these organisms and is considered safe to use if done responsibly and within a prescribed period from collection. In terms of chemical parameters, greywater generally has higher concentrations of chlorine, sodium and potassium with variable levels of nitrogen and phosphorous. Greywater is also generally alkaline and has a high sodium adsorption ratio.

The sections below discuss the three broad categories by which water quality is typically analysed:

2.4.1. Physical characteristics

Physical parameters of relevance are temperature, colour, turbidity and suspended solids. Greywater temperature is often higher than that of the water supply and varies within a range of 18-30^{o}C. These comparably higher temperatures are attributed to the use of warm water for personal hygiene and cooking. These temperatures fall within the temperature range for biological treatment processes since aerobic and anaerobic digestion occurs within an optimal range of 25-35^{o}C (Crites and Tchobanoglous, 1998). The high temperatures on the other hand, encourage bacterial growth and decreased $CaCO_3$ solubility, causing precipitation in storage tanks or piping reticulation systems. Suspended solids in greywater range from 0-1553 mg/l with developed countries recording lesser amounts than that recorded in Stellenbosch, likely due to the quality of the source waters. Also, the highest concentrations of suspended solids are typically found in dark greywater.

2.4.2. Chemical characteristics

The chemical parameters of relevance are pH, alkalinity, electrical conductivity, sodium adsorption ratio (SAR), biological and chemical oxygen demand (BOD_5, COD), nutrient content (nitrogen, phosphorous), and heavy metals, disinfectants, bleach, surfactants or organic pollutants in detergents.

pH indicates whether a liquid is acidic or basic. For easier treatment for irrigation purposes, greywater, which strongly depends on the pH of its source water, should be in the range of 6.5-8.4 (USEPA and USAID, 2004). However, Christova-Boal *et al.* (1996) observed pH values of 9.3-10 in laundry greywater, partly as a result of the sodium hydroxide-based soaps and bleach used.

Greywater also contains salts indicated as electrical conductivity (EC). EC measures salinity of all the ions dissolved in greywater including negatively charged ions (e.g. Cl-, NO_3-) and positively charged ions (e.g.Ca^{++}, Na^{+}). The most common salt is sodium chloride – table salt. Other important sources of salts are sodium-based soaps, nitrates and phosphates present in detergents and washing powders. Salinity of greywater is normally not problematic but can become a hazard when greywater is reused for irrigation. In laundry wastewater, sodium concentrations can be as high as 530 mg/l (Friedler, 2004) (similar to the upper limits observed in the Stellenbosch samples), with SAR exceeding 100 for some powder detergents (Petterson and Ashbolt, 2001). Sodium is of special concern when applied to loamy soils poor in calcite or calcium/magnesium as a high SAR may result in the degradation of well structured soils, thus limiting aeration and water permeability. This high sodium problem in soils can best be avoided by using low sodium products, such as liquid laundry detergents. While European and North American countries recommend irrigation water with SAR < 15 for sensitive plants (FAO, 1985), Patterson (1997) observed hydraulic conductivity problems in Australian soils irrigated with a SAR as low as 3 in wastewater.

Biological and chemical oxygen demand (BOD, COD) are parameters used to measure the organic pollution in water. COD describes the amount of oxygen required to oxidise all organic matter found in greywater. BOD describes biological oxidation through bacteria within a certain time span (normally 5 days, BOD_5). Discharging greywater with high BOD and COD concentrations into surface water results in oxygen depletion, which is then no longer available for aquatic life. BOD and COD concentrations in greywater strongly depend on the amount of water and products used in the household (especially detergents, soaps, oils and fats). Where water consumption is relatively low, BOD and COD concentrations are high. In Table 5, Dallas *et al.* (2004) observed an average BOD_5 of 167 mg/l in dark greywater in Costa Rica with a total water consumption of 107 l/p/d. In Palestine, where dark greywater is also generated and the total consumption is 40 l/p/d, average BOD was as high as 590 mg/l and exceeded 2,000 mg/l in isolated cases (Burnat and Mahmoud, 2005).The COD/BOD ratio is also a good indicator of greywater biodegradability. A COD/BOD ratio below 2-2.5 indicates easily degradable greywater. While greywater is generally considered easily biodegradable with BOD accounting for up to 90% of the ultimate oxygen demand (Del Porto and Steinfeld, 2000), different studies have also indicated low greywater biodegradability with COD/BOD ratios of 2.9-3.6 (Al-Jayyousi, 2003; Jefferson *et al.*, 2000). This is attributed to the fact that biodegradability of greywater depends primarily on the type of synthetic surfactants used in detergents and on the amount of oil and fat present. While Western countries have banned and replaced non-biodegradable (and thus, troublesome) surfactants with biodegradable detergents (Tchobanoglous, 1991), such biodegradable resistant products may still be used (e.g. in powdered laundry detergents) in low and middle-income countries. Greywater data collected in low and middle-income countries indicate COD/BOD ratios within a range of 1.6-2.9. Values close to the upper limit typically proceed from laundry and kitchen wastewater.

Greywater normally contains low levels of nutrients compared to toilet wastewater. Nonetheless, nutrients such as nitrogen and phosphorous are important parameters given their fertilising value for plants, their relevance for natural treatment processes and their potential negative impact on the aquatic environment. The high phosphorous contents often observed in greywater can lead to problems such as algae growth in receiving waters. Dishwashing and laundry detergents are the main sources of phosphorous in greywater. Average phosphorous concentrations are typically found within a range of 4-14 mg/l in regions where non-phosphorous detergents are used (Eriksson *et al.*, 2002). However, they can be as high as 45-280 mg/l in households where phosphorous detergents are utilised, as observed for dark greywater in the UK (Surendran and Wheatley, 1998) and Stellenbosch (Engelbrecht and Murphy, 2006). Levels of nitrogen in greywater are relatively low with kitchen wastewater being the main source of nitrogen in dark greywater. Nitrogen in greywater originates from ammonia and ammonia-containing cleansing products as well as from proteins in meats, vegetables, protein-containing shampoos, and other household products (Del Porto and Steinfeld, 2000). In some instances, even the water supply can be an important source of ammonium nitrogen. This was observed in Hanoi (Vietnam) where NH_4-N concentrations as high as 25 mg/l were measured, originating from mineralisation of peat, an abundant organic material in Hanoi's groundwater aquifers (Duong *et al.*, 2003).

Dark greywater is certain to contain significant amounts of fat such as vegetable oil, and cooking and oil grease (O&G) originating mainly from kitchen sinks and dishwashers. The O&G content of kitchen greywater strongly depends on the cooking and disposal habits of households. No recommended range of values for O&G was determined in the literature, however values as high as 230 mg/l were observed in Jordan for mixed greywater (Al-Jayyousi, 2003) (Table 5), while Crites and Tchobanglous (1998) recorded O&G concentrations ranging between 1,000 and 2,000 mg/l in restaurant wastewater. As soon as greywater cools down, grease and fat congeal and can cause mats on the surface of settling tanks, on the interior of pipes and other surfaces.

Surfactants are the main components of household cleaning products. Laundry and automatic dishwashing detergents are the main sources of surfactants in greywater. Other sources include personal cleansing products and household cleaners. The amount of surfactants present in greywater is strongly dependent on the type and amount of detergent used. Surfactants, also called surface-active agents, are organic chemicals that alter the properties of water. They consist of a hydrophilic head and a hydrophobic tail. By lowering the surface tension of water, they allow the cleaning solution to wet a surface (e.g. clothes, dishes, etc.) more rapidly. They also emulsify oily stains and keep them dispersed and suspended so that they do not settle back on the surface. The most common surfactants used in household cleansing chemicals are LAS (*linear alkylbenzene sulfonate*), AES (*alcohol ether sulphate*) and AE (*alcohol ethoxylate*). While in most Western countries, non-biodegradable surfactants were banned in the 1960s, these environmentally problematic organic chemicals are still used in many developing countries, e.g. Pakistan (Siddiq, 2005), Jordan (Bino, 2004) and South Africa. Studies conducted by Friedler (2004) and Shafran *et al.* (2005) revealed surfactant concentrations in greywater ranging between 1 and 60 mg/l, and averaging 17-40 mg/l. The highest concentrations were observed in laundry, shower and kitchen sink greywater.

Other pollutants that could occur in greywater include heavy metals and Xenobiotic organic compounds (XOCs). XOCs constitute a heterogeneous group of compounds that originate from the chemical products used in households such as detergents, soaps and perfumes. Information about the presence and levels of XOC's is scarce and it has been recommended that further research be conducted in this regard if greywater is to be used for irrigation or groundwater infiltration, as these contaminants may be toxic to plants and could pollute the groundwater respectively (Eriksson *et al.*, 2002).

2.4.3. Microbiological characteristics

Greywater may pose a public health risk given its contamination with pathogens, e.g. viruses, bacteria, protozoa, and intestinal parasites. For light greywater, these pathogens are primarily faecal in origin (e.g. hand washing after toilet use, washing of babies after defecation, and diaper washing) while for dark greywater, these pathogens originate from both faecal and food (e.g. washing of vegetables and raw meat) contamination. Faecal contamination of greywater typically depends on the age distribution of household members, i.e. the higher faecal contamination of greywater is typically experienced where babies and young children are present in a household.

The often hesitance by the pubic and decision-makers to reuse greywater stems from the potential for human exposure which will lead to illness. Enteric viruses, which are known to be the most critical group of pathogens, can cause illness even at low doses and cannot be detected by routine microbial analysis. They also represent the microbial component that is most difficult to process: it can be assumed that a process effective in removing enteric viruses will be similarly effective for all other pathogens (Asano, 1998). It is normal, however, to base standards on the more readily quantifiable indicator organisms of faecal or total coliforms since the main issue when reusing greywater is the potential risk to human health. These indicator species demonstrate a potential for disease transmission, rather than an actual risk of illness, but are more familiar bacteriological quality determinands than viruses and are more easily measured. On the other hand, no proven correlation exists between concentrations of indicator species and actual pathogen levels, and some pathogens are known to be more resistant to treatment than the indicator species (Asano, 1998). This has resulted in the more conservative approach being adopted in the USA, Japan and Australia where greywater reuse is an established operation. In the USA specifically, the USEPA guideline for water recycling (USEPA, 1992) promotes non-detectable concentrations of faecal coliform for urban reuse combined with a specification for a minimum level of treatment required (Jefferson *et al*., 1999).

Greywater, which can contain at least 10^5/100 ml of potentially pathogenic microorganisms, typically changes in quality over time. Research has shown that counts of total coliform and faecal coliform increased from 10^0-$l0^5$/100 ml to above 10^5/100 ml within 48 hours in stored greywater from various sources (Al-Jayyousi, 2003). Easily bio-degradable organic compounds, which are typically found in dark greywater, also favour the growth of microorganisms (Ottoson and Stenstrom, 2003).

3. CASES STUDIES OF IMPLEMENTED GREYWATER SYSTEMS

3.1. Successful case studies

3.1.1. Palma Beach Hotel, Spain

(March *et al.*, 2004)

Palma Beach Hotel is a three-star hotel that has 81 rooms (63 of which include a kitchen) located on 9 floors. It is mostly occupied by foreign visitors (most of them from Scandinavia) who come to Spain for summer holidays. Usually, customers stay at the hotel for either 1 or 2 weeks.

A simple greywater recycling system was introduced for toilet flushing with the aim of conserving the available potable water. The treatment involved filtration using a nylon sock type filter (0.3 mm mesh size and 1 m^2 filtration surface), sedimentation, and disinfection with sodium hypochlorite. The treated greywater was initially stored in a ground level tank (4.5 m^3) and from there was pumped using an automatic pump to a terrace tank, which could also be fed with drinking water, if necessary. From the terrace tank, the toilet cisterns in the rooms were fed by gravity. The average toilet cistern is 6 litres and average consumption on site during the study was 36 l/person/day.

While undertaking an economic analysis of the system, a 14 year payback period was computed. The payback period was based on the seasonal characteristics of the tourist industry with the system operating over an average of 7 months a year with an average hotel occupancy of 85%.

In terms of educating users and determining perceptions, an informative pamphlet was left in all the rooms. The pamphlet included a short introduction on the importance of water management, a description of the greywater reuse project, identification of the institutions involved, input for residents' personal data (nationality, age, gender, duration of stay at the hotel) and several questions requesting residents' perceptions regarding the reuse system (i.e. opinion on the system and the quality of water in the toilet cistern). Data from residents indicated a general satisfaction with the system. Unpleasant odours was mentioned by one of the hotel's customers who also gave a "fair" overall impression of his holiday period. No complaints about the system were reported to the hotel administration. The system has been proven to be sustainable in terms of energy consumption, land requirements and waste production. The system also showed durability (by operating for 1 year without any significant problems) and robustness (fluctuations in greywater composition did not affect the maintenance program). With adequate information given to users the social acceptance of the system was generally positive.

3.1.2. Florianopolis, Southern Brazil

(Ghisi and Ferreira, 2007)

The study was conducted to evaluate the potential for potable water savings by using rainwater and greywater in a residential building located in Florianopolis, southern Brazil. The building is a four-storey residential building composed of three blocks housing 16 three bedroom flats.

In order to estimate potable water end-uses within the building, data was collected by interviewing residents (between December 2003 and February 2004), measuring water flow rates and obtaining water consumption figures from the local water utility. Residents provided information on frequency of use of plumbing fixtures and durations of water use over working days and weekends. A weighted average water use was calculated along with frequency of use and duration of water use per resident. From these calculations, figures were obtained per resident, flat, block and the entire building.

An economic analysis was performed to evaluate the cost effectiveness of using rainwater and greywater either separately or jointly. Results show that the average potential for potable water savings (using non-potable water for toilet flushing, clothes washing and cleaning) ranged from 39.2% to 42.7%. By using rainwater alone, potable water savings ranged from 14.7% to 17.7%. When greywater was used alone, potable water savings were higher, ranging from 28.7% to 34.8%. As for the combined use of rainwater and greywater, actual potable water savings ranged from 36.7% to 42.0%. One of the conclusions that were deduced from this project was that the three non-potable water supply options investigated in the study were cost effective as the payback periods for each were less than 8 years. In comparison to rainwater, the greywater option proved more cost effective.

3.1.3. Institute Agronomique et Veterinaire, Rabat, Morocco

(El Hamouri *et al.*, 2007)

This pilot study was conducted on the campus of the Institute Agronomique et Veterinaire (IAV), Rabat, Morocco which is located next to the Club of the Association Culturelle et Sportive de l'Agriculture (ACSA). Wastewater generated in the showers and the toilets of the ACSA club gym is segregated thus allowing the collection of 8 m^3/d of greywater. A reservoir outside the gym collects greywater which was then pumped through a 50-mm diameter pipe over a distance of 504 m to the wastewater treatment facility located inside the IAV Campus.

Greywater is then treated in a two step gravel/sand filtration unit. Step 1 consists of a planted horizontal-flow gravel filter, while step 2 is a vertical-flow multilayer sand filter.

The horizontal-flow gravel filter is constructed of reinforced concrete and has the following characteristics: length = 2.25 m, width = 2.0 m, and cross sectional area = 1.6 m^2. After passing through the filters, greywater is disinfected in an Ultra-Violet Tspa. The treated and UV disinfected greywater is then stored in a black, polyethylene reservoir and conveyed, using a 50-mm diameter pipe, over a distance of 460 metres to the building housing the Department of Rural Engineering (DRE). The four toilets on the ground floor of this building are connected to the greywater supply pipe. A dual piping system was adopted in the DRE building toilets to avoid any cross connections between potable and recycled greywater. Hence, the toilet cisterns have access to potable water when greywater is not available (Figure 2). For comparison purposes, 4 other toilets, located on the first floor of the DRE building, were flushed with potable water.

Figure 2. Dual piping supplies (grey and potable water) into a toilet cistern

The performance of the two-step unit was satisfactory. The effluents' average turbidity was reduced from about 28 to 2 NTU. Removal rates of COD and BOD_5 were 75% and 80% respectively. Half of the nitrogen was nitrified during the filtration process, the removal rate of phosphorus was almost 50%, while anionic surfactants were removed at a rate of 97%. On the other hand, the gravel/sand filter performance in Faecal Coliform removal was low and did not exceed one log unit.

3.1.4. Berlin, Germany
(Nolde, 1999)

Nolde (1999) presented two sites reusing greywater for toilet flushing in multi-storey buildings in Germany. In the first building (a 400-bed hotel), the greywater treatment plant, which was located in a 15 m^2 basement, collected greywater from showers, bathtubs and hand-wash basins. Biological treatment which initially consisted of a two-stage rotating bio-contractor (RBC) was later replaced with a four-stage RBC.

The greywater treatment plant in the 2nd building consisted of a two-stage fluidized-bed reactor which collected and treated greywater from the shower and bathtub of a two-person household. The system had a total volume of 165 litres (the volume for the stage 1 reactor was 105 litres and for the stage 2 reactor, 60 litres) and is placed above the toilet in the bathroom. A cube shaped polyurethane material is used as biofilm carrier in both stages.

A set of tests were undertaken to determine the quality of treated greywater from both treatment plants. Mixed samples of the 1st plant and random samples of the 2nd plant were taken over a period of 24 hours, immediately stored without preservation at 4°C and processed within 24 hours. Influent samples were taken from the sedimentation tank of the 1st plant or bathtub of the 2nd plant where greywater was initially collected, and effluent samples were taken from the clear well or service water tank. Testing for feacal and total coliform followed in triplicate serial dilutions and was quantified using the Most Probable Number (MPN) method. Results from the 1st plant showed that the effluents' BOD_7 concentration was always below the 5 mg/l control limit. In terms of the total bacterial count, the water samples produced counts lower than the minimum microbiological standards of 100 CFU/ml and 1000 CFU/ml. These values indicated that the faecal coliform and faecal streptococci were below the detection limit of 0.03 bacterm/l. Also, results from the 2nd plant showed that reasonable water quality may be achieved with a smaller greywater system.

Based on the results from the two sites, Nolde (1999) suggested an optimal greywater treatment train shown in Figure 3.

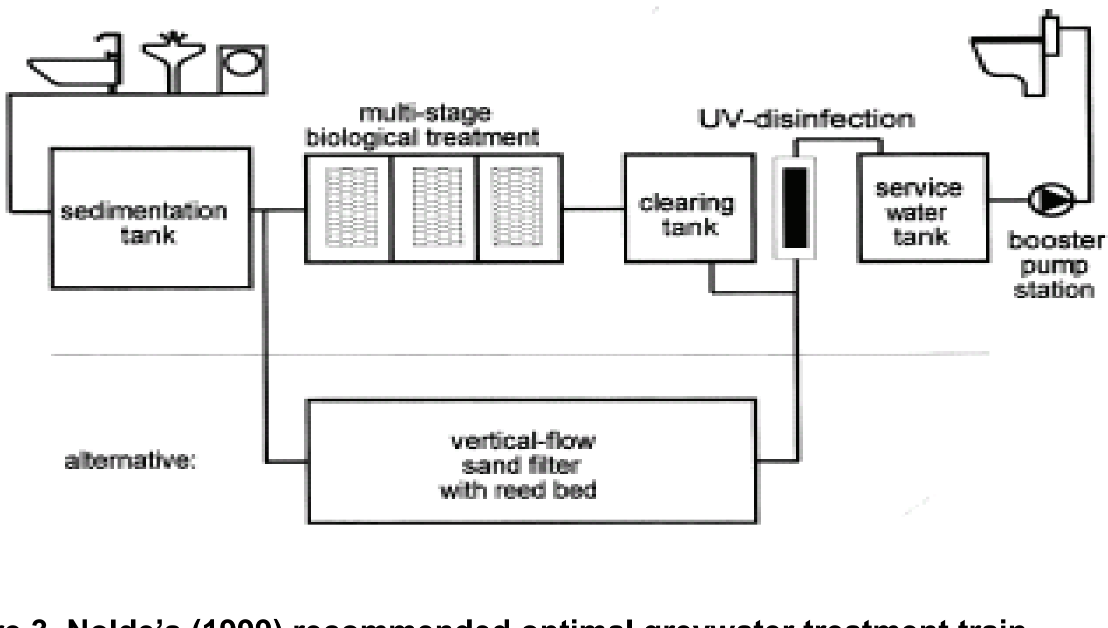

Figure 3. Nolde's (1999) recommended optimal greywater treatment train

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3.1.5. Nicosia, Cyprus

(Kambanellas, 2007)

Cyprus has a population of around 700,000 people but is visited by over 2.5 million tourists a year. As a result, the different water resources in the area are almost fully utilised. A greywater reuse scheme was started in 1997 as part of an initiative to conserve water at the household level.

During the experimental study, measurements were taken and it was determined that only 50% of the total potable water supply needed to be of drinking water quality. A plan was then developed to use treated greywater to reduce the drinking water demand. The first greywater systems were installed in 1997, and 7 additional units were installed by the end of 1998. The experimental studies were carried out in a hotel, a stadium and five houses (Kambanellas, 2007).

At the hotel, the mean per capital drinking water demand was about 40 litres per day. The bathing water was used for irrigating gardens. At the stadium, the water used by players for bathing amounted to 70% of the drinking water consumed. This greywater was then used to water the lawns. For the five households (Figure 4), the mean per capital drinking water consumption amounted to 122 litres per day, from which dark greywater was about 33%. The dark greywater generated was used for toilet flushing.

The cost of a household plant with capacity to treat 1 m^3/day was approximately CDN $2000 – the government currently pays over half of the money as a subsidy. The drinking water savings were between 35 and 40% of total potable water supply.

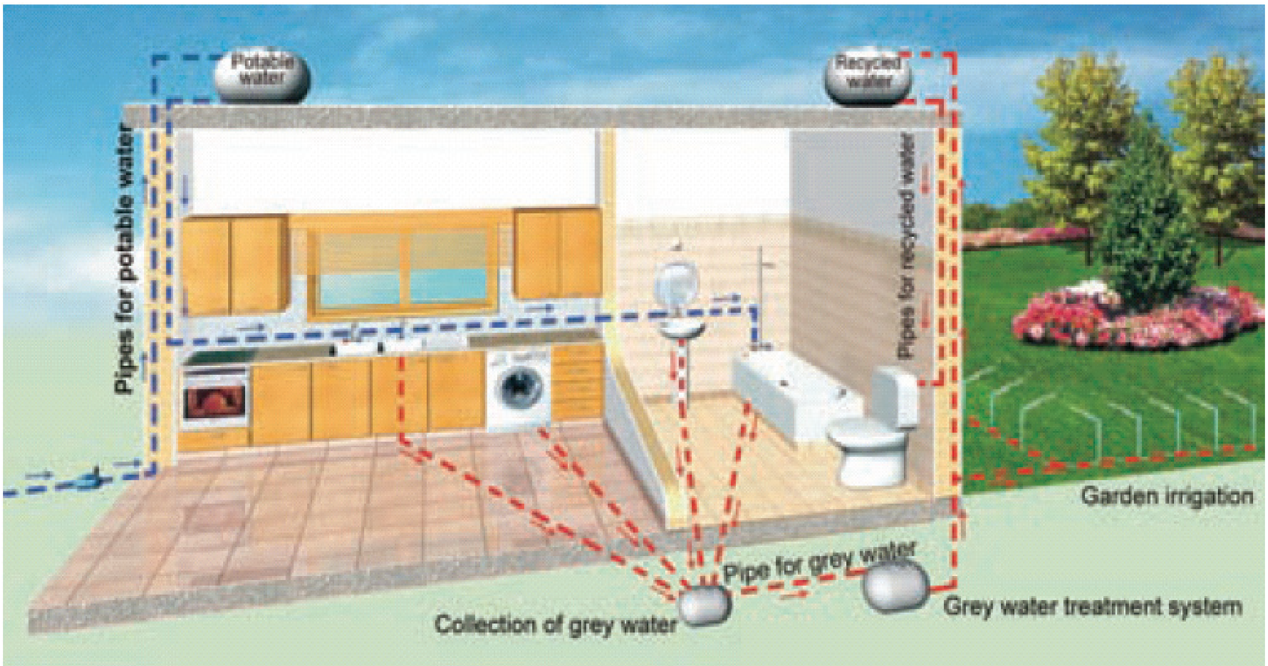


Figure 4. Dark greywater reuse at the household level in Nicosia, Cyprus

3.1.6. Loughborough University, United Kingdom

(Surendran and Wheatley, 1998)

A model and prototype greywater treatment system for university residences were constructed at Loughborough University (Surendran and Wheatley, 1998). The model, used in the lab had a capacity of 75 litres and consisted of four stages, i.e. (i) balancing flow and buffering peak mass loads (ii) solid separation and digestion (iii) aerated bio-filter to remove organics, and (iv) deep bed slow filtration to generate near potable quality. It operated for 200 days without any maintenance or disinfection. Prior to the lab experiment, a survey was conducted to determine people's perceptions and it revealed that as many as 96% of customers would accept greywater use for toilet flushing. The dissenting 4% expressed concern about the purity and safety of recycled greywater and this prevented their acceptance. During lab experimentation, the cost of the prototype plant arose as the major concern.

The prototype, which was based on the lab model, was built to flush toilets used by 33 students with greywater and rainwater. Greywater for flushing 4 toilets was collected from 16 wash basins, 2 baths, 2 showers and about $^{2}/_{3}$rd of the water discharged from a washing machine. The treatment processes comprise 4 of the 5 stages listed below while the fifth stage was optional.

Stage 1:	1400-litre balancing tank with a filter.
Stage 2:	anaerobic solids treatment tank with large pore size.
Stage 3:	aerated bioreactor with large pore size foam and beads. The aeration used 2.4 l/min of coarse air bubbles.
Stage 4:	active slow filter with small pore size reticulated foam. The tertiary treatment phase was a deep slow filter that used 100 mm of 20 ppi foam over 700 mm of 45 ppi foam cartridges. The system operated for approximately a year without problems.
Stage 5 (optional):	activated carbon stage (for potable water quality).

Treated water was collected into two storage tanks; a low-level tank (700 litres) attached to the treatment plant and a high level tank 500 litres) connected to the 4 toilets. The low-level tank was equipped with a timer to initiate pumping of treated greywater to the high-level tank. Excess water was returned to the low-level tank via a return pipe. A standby mains water supply was connected to the high level tank to ensure adequate water supply when the amount of treated greywater was insufficient for reuse. Water usage and some water quality determinants were regularly monitored by means of flow meters and on-line monitors.

Twelve months of operation demonstrated that the treated water met the mandatory limits of both EC and UK bathing water quality criteria in terms of turbidity, BOD_5 and faecal coliform. Odour problems or sludge blockages were not experienced (Surendran and Wheatley, 1998). The unit was evaluated to have a payback period of 8-9 years and a life-span of 20 years.

3.1.7. Annecy Residential Building, France

(Lazarova, 2001)

A full-scale greywater recycling scheme was set-up in a residential building with 64 apartments in Annecy, France (Lazarova, 2001). Forty of these apartments (approximately 120 users) reuse greywater. Light and dark greywater is collected from washing machines, baths, showers, wash basins, kitchen sinks and dishwashers and treated using a membrane bioreactor (MBR) which undertakes biological treatment followed by ultra-filtration. The collected greywater accounts for approximately 50-70% of the total water use within the 40 apartments. Excess recycled greywater water is discharged into the sewer or used for landscape irrigation.

Water quality analysis showed that the dark greywater contained high concentrations of organic matter, comparable to conventional urban wastewater but with a higher fraction of biodegradable and soluble organics. It contained less suspended solids and nitrogen but more phosphorus. Bacterial content was also high – up to 6-7 log units of total coliform, faecal coliform, streptococci and *E. coli*. Consequently, MBR treatment appeared to be a highly appropriate technical solution for the combined shades of recycled greywater, because it produced a high quality effluent (fully disinfected) and was operationally reliable. However, it remains one of the most expensive *treatment* alternatives for water reuse, particularly in small installations (<75 m^3/d) such as was employed in this installation. The annualised capital and operational cost was estimated at €3/m^3 (Lazarova, 2001). This cost dropped to €1.7 /m^3 for greywater treatment plants of up to 300 m^3/d capacity which can serve installations serving more than 500 inhabitants.

3.1.8. The Millennium Dome, London, United Kingdom
(Hills *et al.*, 2001)

The largest in-building recycling scheme in the UK, known as the "Water cycle", was developed by Thames Water at the Millennium Dome (Hills *et al.*, 2001). To reduce the potable water requirement at the Dome, the recycling scheme treated greywater, rainwater and ground water from site to flush all of the toilets and urinals on site (646 toilets and 191 urinals). The recycling plant had a capacity of 500 m^3/d and served 6.5 million visitors in the year 2000.

Rainwater, which is the least polluted of the 3 water sources, from the Dome's roof is collected in specially designed hoppers which direct the roof run-off into the surface water drainage system and treats it through a reed-bed system. The effluent from the reed-bed is of a very high quality. Greywater from washbasins inside the Dome is treated using a biologically aerated filter (BAF), followed by membrane filtration. The BAF provides a compact and reliable treatment system for the reduction of BOD, SS and microbiological contaminants from the greywater. Rising groundwater from an aquifer beneath the Dome makes up the required flushing volume.

Preliminary tests revealed that the groundwater under the Dome is heavily contaminated and brackish, so Granular Activated Carbon (GAC) and membrane filtration were used to remove the organic contaminants and salt from the ground water. Ultra-filtration membranes remove particulate matter and bacteria from the influent. Microbial analysis showed 100% removal of both total coliform and *E. Coli*. The reverse osmosis plant worked efficiently throughout the year with no cleaning of the membranes necessary due to the efficiency of the ultra-filtration pre-treatment (Smith *et al*., 2001).

Overall, the scheme provided recycled water for 55% of the Dome's water requirements during the year 2000. Greywater only made up 10% of the recycled water requirement. This was because water was collected only from the washbasins (i.e. not from kitchens, showers, etc.) and as water efficient taps were also used, volumes of greywater collected were low. The major source of recycled water was from groundwater (71%) with rainwater contributing 19% (Hills *et al*., 2001). A survey carried out on a sample of visitors to the Dome showed positive results about the recycled water used for toilet flushing (Hills *et al*., 2001).

3.1.9. Irvine Ranch Water District, California, USA

(Lewinger and Young, 1988)

The Irvine Ranch Water District, IRWD in California is a full service water and sewer agency serving approximately 120 square miles and a population of about 138,000 people (year 2000). In the mid-1960s, the IRWD maintained a dual system which provided reclaimed water for irrigation uses (Lewinger and Young, 1988 and Young *et al*., 1994). The reclaimed water was expected to contain less than 2.2 coliform per 100 ml and was thus classified as Type 1 or Class A of Title 22 of the California Administrative Code.

In 1987, with the planned development of high rise offices in the area, IRWD began to investigate the feasibility of using reclaimed water in commercial buildings for non-potable uses (Lewinger and Young, 1988). It was further estimated that 70-90% of the total water used could be reclaimed water if employed for toilet and urinal flushing and landscape irrigation (Young *et al*., 1994). A significant proportion of the unused recycled water went to cooling tower operations.

In 1991, Irvine was the first district in the USA to obtain health department permits for the use of greywater in interior spaces such as for toilet flushing (Young *et al*., 1994). As a result, Irvine was the first city to use its reclaimed water for toilet-flushing on a large scale (Young *et al*., 1994). Initially, greywater was used in two high-rise buildings but by the late 1990s, the scheme was extended to two more 20-strorey, high-rise and two low-rise buildings with five additional high-rise towers awaiting dual service.

A 66 000 m^3/d reclamation plant was constructed to provide treated greywater (Young *et al*., 1994). Greywater was treated by biological oxidation, in-line chemical coagulation and dual media filtration followed by disinfection. It was ensured that all the processes met the requirements of the State of California Department of Health Services Wastewater Reclamation Criteria (Lewinger and Young, 1998).

Results from the operation showed potable water demand drop in the high-rise developments by 75%. For new buildings over seven storeys, the additional cost of providing a dual system added only 9% to the cost of plumbing (IRWD, 2006). The life-cycle cost of supplying greywater to at least half of the high-rise towers in the districts was less than purchasing and distributing potable water over a 50 year period (Lewinger and Young, 1988).

3.1.10. Casa del Agua, Tucson, Arizona, USA

(Karpiscak *et al*., 2001)

Casa del Agua is a Tucson residence that was retrofitted in 1985 with water-conserving fixtures and reuse technologies, and landscaped with drought tolerant plants. It is an occupied residence that is also an educational project designed to facilitate research and to test domestic water use and conservation strategies, and is open to the public during scheduled hours. Modifications included retrofitting existing landscapes and enlarging the rooftop to collect and harvest rainwater; separating blackwater and greywater drains; installing meters, low water-use appliances and fixtures; and an approximately 22 litre underground sump for rainwater and greywater collection. A public information centre was also developed. The construction cost of the greywater treatment and distribution system was about US$1500.

A filter was fitted over the greywater drain where it enters the sump to remove lint and hair before the water was pumped to other components of the recycling system. The sump filled to a level that activated a float switch and then greywater was pumped through an underground drip irrigation system to the landscape or for use in toilet flushing

Over the 13-plus years of actual operation, research results have indicated that large reductions in water use are possible using water-saving devices and/or harvesting and reusing rainwater and greywater respectively. Casa achieved a 47% reduction in municipal potable water use compared to a typical Tucson residence. Overall, water use comprised of harvested rainwater (10%), recycled greywater (20%), and municipal potable water (70%).

3.1.11. Japan

Greywater reuse is also practiced in Japan on a scale that ranges from the simple residential use of untreated greywater for toilet flushing to complex systems in office blocks. The simple residential use of untreated greywater for toilet flushing is illustrated in Figure 5. This technology is popular in Japan and installed in many Japanese homes, as well as in commercial areas. This system incorporates a hand basin at the top of the cistern, with a tap for hand washing. The tap automatically and simultaneously operates with each toilet/urinal flush refilling the toilet cistern while permitting the washing of hands. While this system is very simple, it nevertheless promotes the conservation of water for residential use. In applications where the greywater has been captured from other household sources for toilet flushing, unpleasant odors and discoloration of the toilet bowl were reported (CSBE, 2003). The Japanese government does not provide incentives for household residents to implement greywater systems in their own living spaces. Nevertheless, many people choose to implement them in urban areas because water costs are very high.

Figure 5. A simple untreated greywater reuse system in Tokyo

On the other hand, the Japanese government is making an effort to implement greywater technology in more extensive urban commercial uses. In the capital city, Tokyo, greywater reuse is mandatory for buildings with an area over 30,000 m^2 or with potential reuse of 100 m^3/day. In order to offset the costs associated with construction, the Japanese Ministry of Construction provides subsidies of up to 50 percent of the capital costs. The government also assists in connecting commercial greywater systems to the public sewerage system. Therefore, while residential greywater use is minor in Japan, commercial greywater use is very extensive (Chung and White, 2010).

3.1.12. Taiwan

(Chin-Jung *et al.*, 2005)

A pilot-scale, compact and inexpensive electro-coagulation process with a capacity of 28 m^3/day was developed at the National Taiwan University, Taipei. The pilot-scale system was intended at using domestic greywater for human non-contact requirements (including toilet flushing). The total cost of the on-site domestic greywater reuse system was U.S. $0.27/$m^3$ – below the potable water rate and the cost of a regional dual water system. Moreover, the treatment facility required an area of just 8 m^2. Experimental results from this system supported the feasibility of installing further on-site greywater reuse systems in high-rise buildings.

3.1.13. Vehicle washing in some South African cities

(Ewasha, 2011)

Several vehicle wash services in Durban (e.g. La Mercy Airport), Port Elizabeth, George, Johannesburg (e.g. Jet Park) and Cape Town (e.g. at the airport) employ a system for reusing water previously used for washing (Figure 6). The system collects the used vehicle wash water and pumps it through a series of bioreactors which use a natural, biological process to clean the water of impurities such as soap, grease and dirt. No chemicals or filters are used. Once the treatment process has been completed, the water is returned to the wash bay ready for re-use in the washing of the vehicles. Any loss in used water, due to factors such as evaporation or spray mist, is replenished using stored rainwater before using the municipal water supply. It is claimed that municipal potable water usage using this system has been reduced by up to 90% with a commensurate reduction in the amount of wash bay runoff being discharged.

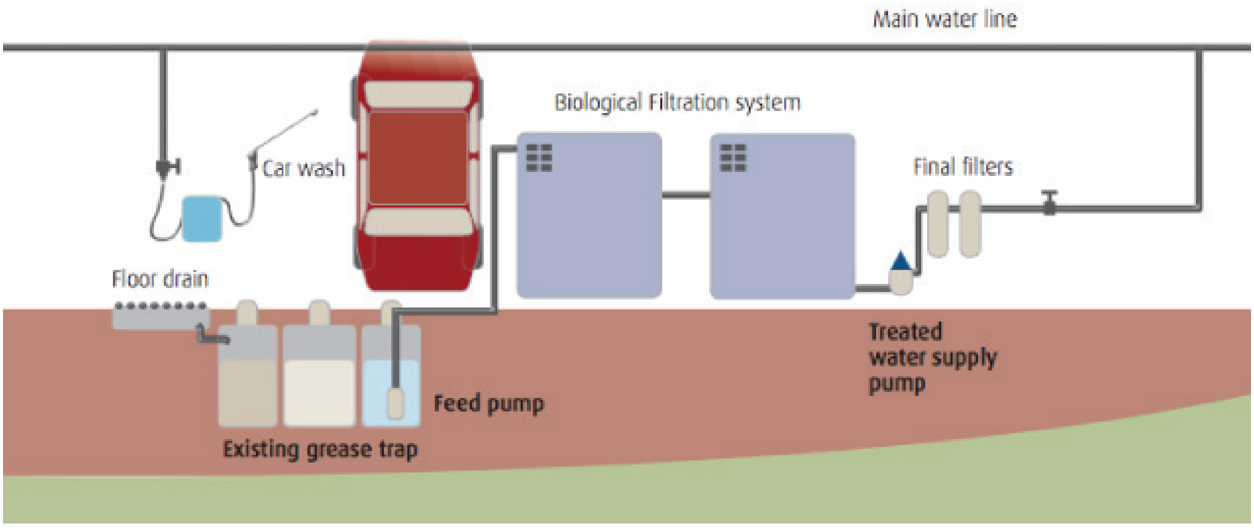


Figure 6. (Above) A schematic of the Ewasha greywater reuse technology. (Below) One of the vehicle wash services in Durban

3.1.14. Green's Cool Early Learning Centre, Pinelands, South Africa
(Water Rhapsody Conservation Systems, 2011)

In 2008, a R25 million corporate daycare centre – the Green's Cool Early Learning Centre, was built for financial services group, Old Mutual. The centre with floor area of 21442 m² can accommodate up to 75 babies and 300 pre-school children of Old Mutual's employees who work within sight and walking distance of the company's Pinelands head office in the City of Cape Town. Several environmental friendly technologies were implemented in the facility including the installation of a system which reuses greywater from washbasins to flush the centre's toilets (Figure 7). After collection of greywater, the reuse system employs a simple coarse filter and chlorination system for treatment. Thereafter, the treated greywater is stored in submerged tanks housing pumps which convey the greywater from the tanks to the toilet bowls when the pumps are activated within the toilet cubicle.

Figure 7. (Left) One of the centre's toilets reusing greywater for flushing. (Right) Several submerged filters and tanks that house the pumps that convey greywater to the toilet bowls

<u>3.1.15. Featherbrook Estate, Gauteng, South Africa</u>

(Aquacycle, 2009)

In one of the residential units within the Featherbrook Estate on Gauteng's West Rand, there is a greywater reuse system that recycles light greywater for non-potable water requirements such as toilet flushing, garden irrigation and car washing. The system which is developed in Europe is called *Pontos AquaCycle®* (Figure 8).

The first treatment stage of the greywater treatment unit is pre-filtration. Pre-filtration involves the separation of larger particles such as hair and textile fragments from the greywater stream. These sediments are then washed into the sewer. The next process is a 2-fold biological treatment process where in the main and secondary treatment chambers, sediments in the greywater are decomposed by bio-cultures. The organic sediments which are produced during this process are regularly sucked out from the chambers and diverted into the sewer. The resultant greywater is then pumped to the next station in three hour intervals. A UV lamp disinfects the greywater as it flows into the storage chamber and should the supply in the storage unit drop below a certain level, municipal potable water will automatically be fed into this chamber to ensure there is enough supply for flushing toilets. The system is built as closed up compartments and the treatment processes are not typically visible to the by-stander. This system is also automated with on-board software.

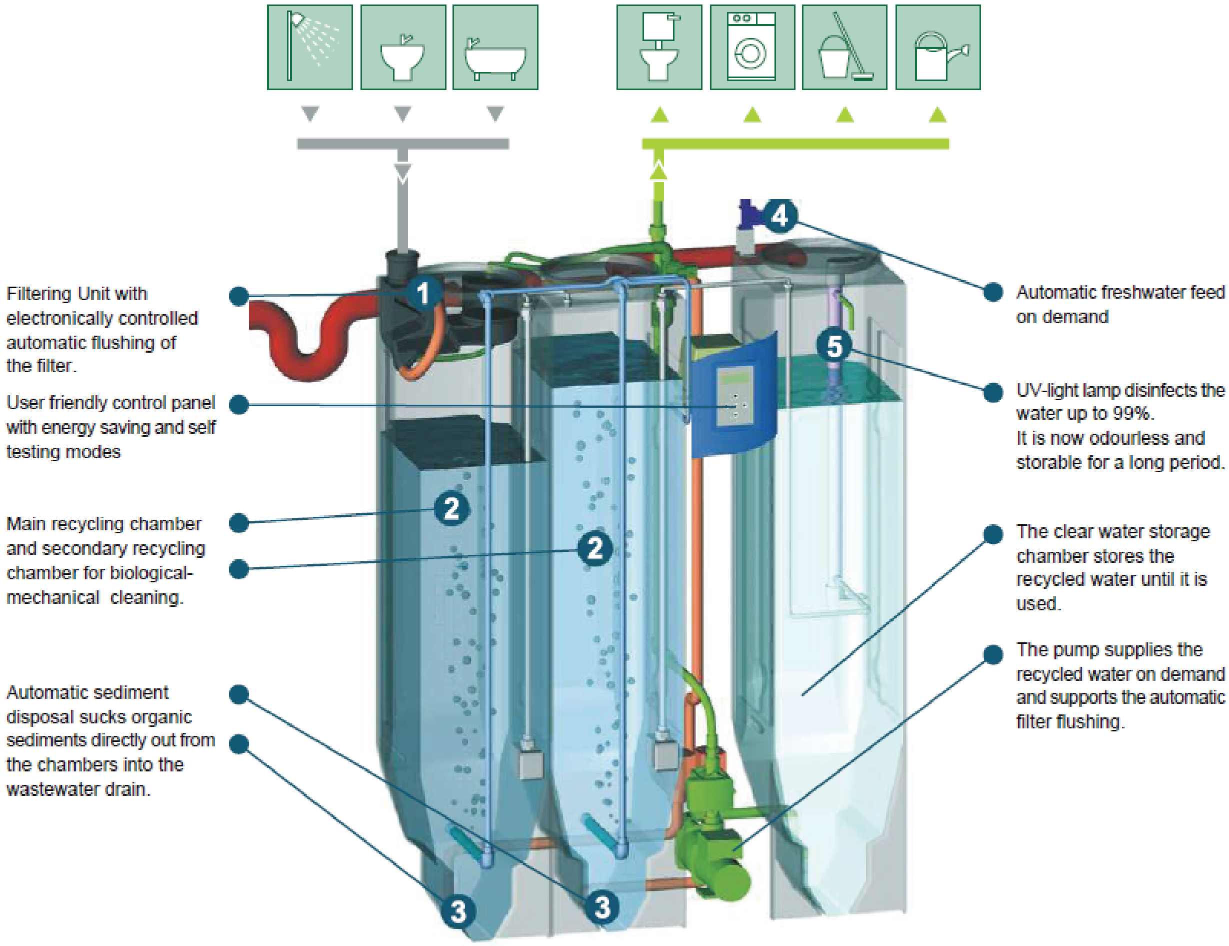


Figure 8. The Pontos greywater treatment system

3.2. Controversial/failed case studies

<u>3.2.1. Victoria University of Technology, Melbourne, Australia</u>

(Christova-Boal *et al*., 1996)

A social survey conducted in Melbourne showed that people were interested in reusing greywater from the bathroom and laundry and had a strong preference to use the effluent for garden irrigation. However, most of these people would only consider a greywater reuse system if the payback period was between 2-4 years. In response, a sampling and testing programme (to analyze some physical, chemical and microbiological characteristics of bathroom and laundry greywater) was undertaken.

Four experimental sites were selected. Three houses were retrofitted to reuse greywater for garden watering and toilet flushing while one house was newly built with a greywater system incorporated in the building plans. At the experimental sites, removal of suspended materials was achieved using a three-stage filter system:

- Stage 1 – a strainer (pre-filter) in the laundry, shower or bath drain 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.

A number of difficulties were encountered when the greywater systems were retrofitted. One of which was that the greywater sources were located very close to the ground level, thus making gravity flow of the greywater into the collection tanks difficult. Collection tanks thus had to be installed below ground level.

Lessons learnt

i. Inclusion of the greywater system in the construction of buildings is imperative in order to optimise costs and to implement efficient and sustainable systems. Retrofitting of the greywater system naturally creates problems as it tends to obstruct or occupy spaces not originally design for it. Cost has been highlighted as one of the major barriers to a wider uptake of greywater recycling systems (Mustow *et al*., 1997). The costs associated with greywater recycling in different locations are difficult to compare as they depend on the quality of the recycled water and the use to which it may be put. They also depend on which costs are considered in the life cycle analysis carried out, i.e. capital, operational and externalities (e.g. greenhouse gas production)

ii. Long pay-back periods tend to infer non-profitability, and thus tend to dampen public and decision-makers' interests in greywater reuse. In the survey conducted by Christova-Boal *et al*. (1996), most respondents preferred a payback period of between 2-4 years.
iii. The operating costs of treating the greywater were considered high because a significant amount of money was spent on disposable filters.
iv. The analyses of bathroom and laundry greywater showed high levels of sodium, zinc, aluminium and, by inference, carbonate which are detrimental to soil conditions. The initial trials using 0.1 mm mesh filters and 0.11 mm disc spacings did not work as the filters got clogged almost immediately. Satisfactory performance was achieved using the next larger size of filters (i.e. 0.2 mm mesh filters and 0.17 mm disc spacing).
v. Tanks containing greywater generally provided an ideal breeding ground for pathogenic microorganisms and mosquitoes, and were a source of odour. Hence, tanks need to be regularly maintained, disinfected, ventilated, child-proof and comply with local health and plumbing by-laws. Physically, tanks require space which may either be limited or unavailable (in retrofitted situations), and their optimum location on site may interfere with existing services. Above-ground tanks located exterior to the dwelling may have undesirable visual impacts and hence tanks may be located beneath a dwelling or below ground surface. In addition to the above, tanks must be accessible for cleaning.

3.2.2. Linacre College, Oxford, United Kingdom

Linacre College houses the first domestic water recycling scheme in the UK. A student residence housing 23 occupants was built in 1995 using "environmental friendly" or recycled materials in order to cut down on energy and water demand. One of the conservation aspects was the reuse of greywater for toilet flushing. A survey conducted prior to the project showed that 40% of the occupants were concerned about the potential odour and smell of the treated water but would consent to the plan if these were eliminated.

The first scheme comprised a bag filter and a depth filter. Due to severe problems, however, the plant operated for only two days. Subsequently, Anglian water services Ltd, Huntingdon, undertook a series of process selection trails (Murrer and Wards, 1997) to identify a suitable system for the scheme, and a number of sand filters and membranes were tested. A trail house with a selected process was identified and used in investigating the cause of the earlier problems. This led to the second stage of the Linacre scheme where the greywater was treated using a depth filter and a membrane. Greywater from baths, showers and hand basins was collected in a tank and filtered through a 4 inch diameter sand filter (Murrer and Ward, 1997). This was followed by further filtration using a hollow fibre ultra-filtration membrane with pore size of 0.01μm. The filtered effluent was collected into a tank located in the loft of the house. The effluent in the tank may be topped up with potable water supply from the mains when necessary in order to supply enough water for toilet flushing. The effluent was then disinfected with chlorine prior to use. Some of the effluent from the ultra-filtration membrane was used to backwash the sand filter. A 5 log reduction in bacteria was attained through this treatment train and viruses were not detected in the effluent.

After a few months of operation, the system suffered some operational difficulties. Operation and maintenance costs were found to be high due to excessive membrane fouling resulting in low flux (Ward, 2000). Raw greywater was partially digested under anaerobic conditions in the lengthy collection network resulting in poor permeate quality and odour problems from the network. Consequently, a further process modification was done and this time a biological system (Ward, 2000) was incorporated. The process scheme now comprises a bioreactor followed by a sand filter, an activated carbon column and chemical disinfection. Further development of the membrane cleaning procedure was undertaken to reduce membrane fouling from fats and other organic material in the greywater treatment system. The system has been effectively working since then.

<u>Lessons Learnt</u>

i. Perception surveys of the consumers and the local authority was very important before the implementation of the reuse system.
ii. Public enlightenment campaigns incorporating the concerns raised, helped to

educate consumers on the benefits of the reuse system. Positive community attitudes towards recycled water use have been identified as a key component of the success of a water reuse project (Po *et al*., 2003).

iii. Prior to the choosing of water reuse treatment equipment, project managers should talk extensively to manufactures about the technical issues and processes involved. This is to ensure that the components are compatible and can synergistically work as a system. The challenges of using smaller membrane sizes resulting in membrane fouling, poor permeate quality, and odour problems may have been avoided in the above scheme.

iv. Realistic timelines should also be negotiated and understood by the engineers, architects, project managers, residents and municipal staff.

<u>3.2.3. Water Dynamics systems, various locations in UK</u>

(Sayers, 1998)

A two-year project was carried out by Environmental Agency (EA) to assess the feasibility of single household greywater systems. Water consumption, cost savings, water quality, and user perceptions of the reuse system were evaluated. Ten houses were retrofitted with Water Dynamics' recycling systems, in order to recycle greywater from hand basins, baths and showers for toilet flushing. Water meter readings, along with greywater samples from the storage units and the toilet cisterns were taken on monthly basis for analyses.

After the first year of operation, cost savings from 5.2-30.6% were realised for the 10 houses. In the second year, savings of 5.3-35.9% where realised with the number of houses involved in the study dropping to 8 (Sayers, 1998). Acceptable water quality in terms of pH (6-8) and phosphorus (around 1 mg/l) were realised. Ammonia averaged <8 mg/l, but on occasions, rose to 40 mg/l thus resulting in odour problems (Sayers, 1998). The following operational concerns were raised during the study:

- The need for frequent cleaning of the filters due to blocking;
- Pump failures occurred often times and hence, the potable water supply was used for toilet flushing during those times;
- Chlorine dosing using a bromine-based disinfectant led to some odour;

- Staining of toilet bowls led to the more frequent use of cleaning products;
- There was a building-up of sediments in the toilet cistern;

Improvement to the system design, such as the location of the disinfectant and alarms (in case of blockages or low levels of disinfectant) were suggested by the residents. Residents generally found the appearance of the treated greywater to be visually acceptable though the retrofitted greywater reuse infrastructure was visually unattractive. Payback periods were calculated based on a range of water and sewerage charges and household occupancy and excluding running and replacement costs. The most economical payback period was 13 years in case of a 4 person household and the most uneconomic at 138 years in case of a single person household.

Lessons Learnt

i. The accuracy of modelling experiments was critical in determining actual greywater generation and toilet flushing flows. An accurate estimation of these flows would have prevented a significant number of the breakdowns experienced during operation;

ii. Continual monitoring and education of residents on the greywater units was critical to sustainability. In many instances, residents “forgot” about the systems and hence problems occurred;

iii. The economical aspect (specifically payback period in this project) of implementing a greywater reuse project is critical in evaluating the viability of greywater reuse.

3.2.4. Quayside Village Vancouver, British Columbia, Canada

Quayside village (QV) is a co-housing community located in the City of North Vancouver British Columbia. As a multi-agency supported demonstration project, Quayside’s greywater system had to be reviewed and discussed with a number of agencies. Government municipal staff expressed concern about possible liability for water-related sickness. For this reason, a conservative greywater reuse system with several backup features was permitted, with treated greywater to be used for toilet flushing. The reuse system included the following components (Figure 9):

- A septic tank to remove coarse solids and grease/oil;
- A biofilter with recirculation back to the septic tank inlet;
- A slow sand filter to remove solids;
- Ozone generator and contact tank which was subsequently replaced by chlorination;
- A slow sand filter for automated back-washing, and
- A storage tank.

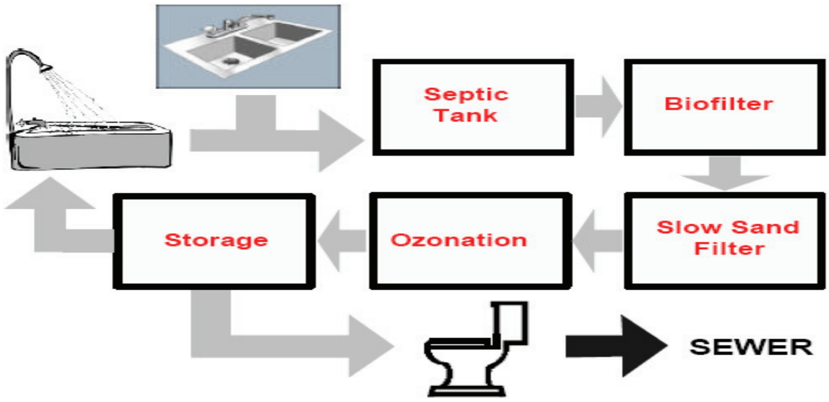


Figure 9. Quayside Village greywater reuse System

Although the system operated for over three years, there were a number of equipment failures that interfered with the system being able to meet the regulatory requirement of six continuous months of operation. One of the key problems initially identified was the reliance on ozone as the sole means of disinfection, compounded by the lack of adequate ventilation for the ozone gas residue.

The following remedial measures were then implemented:

- The ozone generator contact tank was removed and replaced with a chlorination system. This eliminated the problem with the ozone gas residue and provided a chlorine residual to control the re-growth of bacteria
- The cloth fabric which was intended to assist in removing colloidal particles was removed from the septic tank. This was because the structure supporting the fabric in the tank collapsed and blocked the outlet.

Lessons Learnt

System design and function should be resolved with the relevant authorities before reuse equipment are purchased and the system installed. This is because municipalities would generally require a conservative system that will be robust enough to prevent risks to public health and safety.

3.2.5. Toronto Healthy House, Ontario, Canada

The Toronto Healthy House project resulted from a Canada wide Health Housing Design Competition. Two residences located next to one another were not connected to the municipal potable water supply and sewage infrastructure, and were situated on small stands (approximately 6 m by 22 m in area). The dwellings relied on harvesting rainwater for potable water requirements, and reuse water for all other domestic water needs (i.e. toilet flushing, laundry, bath/showers and irrigation). Blackwater and greywater were collected and treated for reuse. The treatment process consisted of the following components which are similar to the Quayside Village greywater reuse system discussed above:

- A 3 000 litre septic tank which was divided into two unequal (2/3,1/3) compartments. The first compartment was designed to remove coarse solids and grease, while the second was equipped with hanging filter cloths intended to remove colloidal solids;
- Biofilter with recirculation back to the septic tank inlet;
- Roughing filter to remove coarse biosolids;
- Slow sand filter to remove fine particles (both the roughing and slow sand filters are automatically back-washed;
- In line ozone injection, followed by a contact tank;
- Storage tank.

Any wastewater that is in excess of the reuse requirement of the household is discharged to a gravel bed situated in the front yard of the building.

A three component filter (roughing filter, slow sand filter and activated carbon filter) was originally installed but was decommissioned and replaced with a separate roughing filter and slow sand filter due to problems experienced with filter clogging. Online data for both the potable and reuse system was collected by an independent agency from November 2000. Parameters monitored included microbiological (Total Coliforms, *E. coli* and background bacteria) and chemical (nitrate, BOD, TSS, TDS, sodium, chlorides, phosphates and ammonia). Although some reuse water qualities (i.e. BOD, TSS and turbidity) consistently met the relevant standards, the Total Coliform criteria were not met during certain times and heterotrophic plate counts were often elevated, indicating bacterial regrowth in the reuse storage tank and distribution system. Regrowth can include "opportunistic pathogens" such as strains of *pseudomonas aeruginosa,* and *Acinetobacter spp.*. The potential for regrowth is of particular concern where the water is being sprayed and potentially inhaled as will occur when using treated greywater for showers/baths and toilet flushing. Strains of *Klebsiella pneumoniae* and *Legionella pneumophila* if inhaled as aerosols can cause severe illness. Water temperatures of 30 to 50^{o}C are favourable for the growth of *Legionella pneumophila*. Another concern with the existing treatment system was that ozone was being released into the residence posing a health hazard to the occupants.

The following remedial measures were recommended to improve system performance and address the problems observed with the Toronto Health House reuse water system:

- An ozone sensor and alarm to be installed, and consideration given to modifying the ventilation of the equipment space to ensure the ozone is destroyed and the gas is ventilated outside of the building.
- That either a secondary chlorination or ultraviolet disinfection be added to both the potable and reuse water treatment systems to inhibit bacterial regrowth within the storage and distribution systems. The provincial health agency preferred to have a minimum 1 mg /l chlorine residual maintained within the distribution system.

<u>Lessons learnt</u>

Careful consideration must be given to ensure that ozone residue is allowed access to proper ventilation, and that consideration is given to controlling regrowth of bacteria within the storage and distribution systems. One method of achieving this is to maintain an adequate residual chloride level within the treated water storage tank.

3.2.6. The Conservation Co-operative Apartment Building, Ontario

Conservation co-operative is a 4 storey, 84 unit apartment building located in the Sandy hill district of the City of Ottawa. The tenants are committed to providing "green" alternatives within an environmentally friendly building thus reducing the consumption of energy, water and waste to levels significantly lower than conventional households. Constructed in 1995, the project incorporates water conserving plumbing fixtures that have resulted in a normalized water use per apartment of 390l/day compared to a typical apartment's water consumption of 530l/day in the Ottawa area. Bathrooms in 8 of the 84 apartments were constructed with dual plumbing systems. The plumbing systems allowed the bathrooms to operate using both municipal potable water and reuse greywater for toilet flushing. The primary source of greywater is the bathtubs.

Discussions were held with the Ministry and City officials to develop treatment criteria. The criteria for the design of the treatment systems were established and accepted by the Regional Health Department on the understanding that this was an experimental system for water reuse strictly for toilet flushing. The average daily water use was 640 l/day for toilet flushing, 1300 l for baths/showers and 700 l/day for other uses (there were no laundry facilities in individual apartments).

The greywater reuse system was completed and commissioned for use in August of 1999. It consisted of the following components:

i. Basket screens (1 mm mesh) to trap hair, lint and other large particles. Sodium hypochlorite packs were placed in the screening baskets to control odours and filter fouling;
ii. Equalization tanks (440 l) to remove floatable oils ,scum and settleable solids, as well as provide initial disinfection. Accumulated solid scum was automatically discharged into the sewer after each treatment cycle was complete;

iii. A pump to transfer effluent from the equalization tanks and through a multi-media pressure filter;
iv. Upflow multi-media pressure automatic-backwash filter to remove particulate material. These types of filters are more commonly used in potable water treatment systems and do not remove BOD;
v. Ozone is added to the filtered water prior to discharge into the treated water tank;
vi. A treated water tank (600 l);
vii. A distribution pump that is activated by a drop in pressure (i.e. toilet flushing) within the distribution system.

By late September 1999, the filter media had to be replaced, and by mid-October, one of the system pumps had failed and the system was down for two weeks until the pump was replaced. A valve and pump failure in November shut the system down until early December 1999. By March 2000, the treatment system was shut down and the toilets to the eight units were once again connected to the municipal potable water mains. This action was taken in response to extensive complaints from the residents of the 8 apartment units regarding problems with odour and rapid scum accumulation in the toilets, and an accident in which ozone release from the treatment facility caused injury to the maintenance supervisor.

An independent review of the treatment system noted the greywater had a significant biochemical oxygen demand (BOD_5) of 130 mg /l that had not been taken into consideration in the treatment process design. As a result, no biological treatment had been provided for and the filtered greywater rapidly became anaerobic, producing black, foul-smelling reuse water that was being reused for flushing the toilets. Furthermore, the toilets for the 8 apartments were subjected to significant water-hammer effects as a result of the transfer pump and temporary nature of the pilot installation, resulting in loud banging noises and vibrations that were extremely disconcerting to the residents.

The following remedial measures were recommended to improve system performance and address the problems observed:

- Add a biological treatment component to reduce the BOD concentration to less than 10 mg/l;
- Add a pressure tank to the distribution system to improve water supply to the toilets;
- Remove the ozone system and replace it with either a second chlorination or ultraviolet disinfection system.

Lessons learnt

The project demonstrated that significant operating and maintenance problems can be experienced with greywater reuse if (i) wastewater characterization is not considered in the design, and (ii) appropriate components are not incorporated in the treatment system to remove BOD. Greywater must be treated if it is to be stored for any significant period of time, or if it is to be distributed through plumbing for any indoor application.

3.2.7. The Limpopo Parliamentary Village, Polokwane, South Africa

Dingilizwe (2010).

The Limpopo Parliamentary Village in Bendor Park, Polokwane is situated on an 18 hectare plot. It comprises forty-four 3 and 4 bedroom housing units and other social amenities including a social club, tennis courts and volleyball courts. The village's wastewater disposal system was designed such that all the greywater (including kitchen water) is recycled. The greywater is initially conveyed to a tank from where it is then pumped to the irrigation system that serves the gardens and open spaces. The recycled water undergoes only sedimentation and oil separation which take place within the tank. Rainwater is also harvested from roofs and conveyed to the tank.

Since commissioning, residents have complained of unpleasant odours emanating from the system and the recycled greywater which is used to irrigate the gardens. A preliminary investigation was carried out in May 2010 to address these complaints and some of the findings of the investigation included:

i. The tank volume was about 50 m^3 thus resulting in an average greywater retention time of about 64 hours. Considering the minimal treatment carried out on the greywater, the prolonged retention time encouraged deterioration of the greywater quality;
ii. The above point was compounded by the fact that the tank was closed and thus, promoted anaerobic conditions which are conducive to pathogenic growth and consequently, higher BOD;
iii. A sprinkler system was employed for irrigation. This was inappropriate considering the potential of inhaling contaminated greywater molecules that become airborne. This was also one of the likely causes of the smells that the residents complained about. Sub-surface or drip irrigation technologies would have provided a better and safer technology for irrigation;

These findings have been presented to the relevant Water Supply Provider/authority.

3.3. Pertinent issues from the case studies

- Government subsidies have proven positive in encouraging individuals, communities or institutions to embrace greywater reuse systems (Kambanellas, 2007 and Chung and White, 2010) as subsidies typically lower the cost of greywater reuse and often times cause them to be lower than potable water.
- Long pay-back periods tend to infer non-profitability, and thus tend to dampen public and decision-makers' interests in greywater reuse. The case studies reviewed indicate that on average, greywater systems had a payback period of between 8-14 years (Sayers, 1998; Surendran and Wheatley, 1998; March *et al.*, 2004; and Ghisi and Ferreira, 2007) with preference for between 2-4 years amongst potential respondents in Melbourne, Australia (Christova-Boal *et al.*, 1996).
- Large housing developments have provided more tangible economic benefits than smaller ones as a result of economies-of-scale
- The most economical applications for many greywater systems were in combination with rainwater.
- The recycling of greywater needs to be done in such a way as to avoid the

building up of impurities. The use of a final, polishing filter in the treatment plant would then seem to be an essential component of the treatment plant.

- The technologies used to treat greywater for reuse must be effective in dealing with organic material, solids and pathogens. The different greywater recycling schemes reported to date, have however achieved very different performances. Simple technologies and sand filters have been shown to have only a limited effect on greywater, whereas membranes have been reported to provide good solids removal but cannot efficiently tackle the organic component. Micro-organism removal was achieved in schemes that included a disinfection stage or membrane bioreactor.
- Disinfection of greywater for utilization in flushing toilets and urinals was stressed in order to eliminate pathogenic organisms which have potential to impact negatively on public health if ingested.

4. INTERNATIONAL AND LOCAL REVIEW OF REGULATIONS AND GUIDELINES REGARDING GREYWATER REUSE

4.1. Introduction

It has been noted that the major barrier to the adoption of water reuse as a strategy is the lack of regulations and/or guidelines for plumbing requirements for non-potable water systems and reuse water quality (CMHC, 1997). Regulations for water reuse are based on the necessity to protect human health and the environment and are thus enacted and enforceable by government agencies while guidelines are not enforceable, but are a compilation of best practice and can be used in the development of a reuse program (USEPA and USAID, 2004).

In respect of protecting human health, regulations/guidelines generally attempt to reduce the risks to public health due to greywater exposure, which may occur either via inhalation, direct skin contact or ingestion of microorganisms (bacteria, protozoa and viruses) and chemicals in household greywater. Exposure via ingestion can be responsible for severe gastrointestinal illness. This is of particular concern for susceptible individuals, such as infants, the elderly, and those that have compromised immune systems, for whom the effects may be more severe, chronic (e.g., kidney damage), or even fatal. Microbiological hazards have been identified as the greatest source of risk to human health from the use of reclaimed water (WGHRW, 2007). Effective treatment can produce reclaimed water that is virtually free of disease-causing microorganisms. There are no negative health impacts expected from chemicals in household reclaimed water used only for toilet and urinal flushing.

In respect of protecting the environment, regulations/guidelines guard against the short- and long-term deleterious impacts on activities such as irrigation and effluent discharge into natural water courses.

Regulations and guidelines relating to greywater reuse vary from one country to another and these are briefly appraised in the following sections:

4.2. Review of regulations and/or guidelines regarding greywater reuse in other countries

4.2.1. USA

There are no federal regulations directly governing water reuse practices in the USA. Water reuse regulations and guidelines have, however, been developed by many individual states. As of November 2002, 25 states had adopted regulations regarding the reuse of reclaimed water, 16 states had guidelines or design standards, and 9 states had no regulations or guidelines. In states with no specific regulations or guidelines on water reuse, programs may still be permitted on a case-by-case basis (USEPA and USAID, 2004).

States that have water reuse regulations or guidelines have set standards for reclaimed water quality and/or specified minimum treatment requirements. Generally, where unrestricted public exposure (such as toilet flushing) is likely in the reuse application, wastewater must be treated to a high degree prior to its application. Where exposure is not likely, however, a lower level of treatment is usually accepted. The most common parameters for which water quality limits are imposed are biochemical oxygen demand (BOD), total suspended solids (TSS), and total or faecal coliform counts (USEPA and USAID, 2004).

States with regulations or guidelines pertaining to the use of reclaimed water for toilet flushing (i.e. unrestricted urban reuse) are Arizona, California, Florida, Hawaii, Massachusetts, New Jersey, North Carolina, Texas, Utah, and Washington. Table 7 presents greywater treatment and quality requirements for these different states.

Table 7. Greywater quality and treatment requirements for different states for unrestricted urban reuse (USEPA and USAID, 2004)

	Arizona	California	Florida	Hawaii	Nevada	Texas	Washington
Treatment	Secondary treatment, filtration, and disinfection	Oxidized, coagulated, filtered, and disinfected	Secondary treatment, filtration, and high-level disinfection	Oxidized, filtered, and disinfected	Secondary treatment and disinfection	NS [(1)]	Oxidized, coagulated, filtered, and disinfected
BOD_5	NS	NS	20 mg/l $CBOD_5$	NS	30 mg/l	5 mg/l	30 mg/l
TSS	NS	NS	5.0 mg/l	NS	NS	NS	30 mg/l
Turbidity	2 NTU (Avg)	2 NTU (Avg)	NS	2 NTU (Max)	NS	3 NTU	2 NTU (Avg)
	5 NTU (Max)	5 NTU (Max)					5 NTU (Max)
Coliform	Fecal	Total	Fecal	Fecal	Fecal	Fecal	Total
	None detectable (Avg)	2.2/100 ml (Avg)	75% of samples below detection	2.2/100 ml (Avg)	2.2/100 ml (Avg)	20/100 ml (Avg)	2.2/100 ml (Avg)
	23/100 ml (Max)	23/100 ml (Max in 30 days)	25/100 ml (Max)	23/100 ml (Max in 30 days)	23/100 ml (Max)	75/100 ml (Max)	23/100 ml (Max)

[(1)] NS – Not specified by state regulations

4.2.2. Australia

The EPHC *et al*., (2006) guidelines is one of the most recent guidelines on greywater reuse to be published in Australia. This is against the back drop of different guidelines which have been published by Australia's different regions in the past. A nationally consistent approach to the management of health and environmental risks from water recycling requires high-level national guidance on risk assessment and management. Such guidance is provided in the EPHC *et al*. (2006) guidelines in the form of a risk management framework for beneficial and sustainable management of water recycling systems. Although these guidelines are not mandatory and have no formal legal status, their adoption provides a shared national objective, and at the same time allows flexibility of response to different circumstances at regional and local levels. All states and territories are therefore encouraged to adopt the framework in the document. However, application of the framework may vary across jurisdictions, depending on the arrangements for water and wastewater management.

As mentioned above, a central feature of the EPHC *et al*. (2006) guidelines is a generic risk management framework that can be applied to any system recycling water from treated sewage, greywater and stormwater. The risk management framework is used to develop a 'risk management plan' that describes the nature of a recycled water system and how it should be operated and managed. An excerpt from the EPHC *et al*. (2006) guidelines on the risk management approach to water quality and use is presented below:

"A risk management approach involves identifying and managing risks in a proactive way, rather than simply reacting when problems arise. In applying this approach to water recycling, the first step is to look systematically at all the hazards in the recycled water that could potentially affect human or environmental health (i.e. *what might happen and how?*). Once the hazards are identified, the risk from each hazard is assessed by estimating the likelihood that the event will happen and the consequences if it did. That is, the risk assessment asks '*How likely is it that something will happen*?' and '*How serious will it be if it does happen?*', and thus provides a means to identify those hazards that represent significant risks for the proposed end use. The next step is to identify preventive measures to control such hazards, and to establish monitoring programs, to ensure that the preventive measures operate effectively. The final step is to verify that the management system consistently provides recycled water of a quality that is fit for the intended use (i.e. 'fit for purpose')."

The framework for management of recycled water quality incorporates 12 elements. Although listed as discrete components, these elements are interrelated, and each supports the effectiveness of the others. Because most problems associated with recycled water schemes are attributable to a combination of factors, the 12 elements need to be addressed together to assure a safe and sustainable recycled water supply. The 12 elements are organised within four general areas, as illustrated in Figure 29, and listed below:

- *Commitment to responsible use and management of recycled water*. This requires the development of a commitment to responsible use of recycled water and to application of a preventive risk management approach to support this use.

The commitment requires active participation of senior managers, and a supportive organisational philosophy within agencies responsible for operating and managing recycled water schemes;

- *System analysis and management*. This requires an understanding of the entire recycled water system, the hazards and events that can compromise recycled water quality, and the preventive measures and operational control necessary for assuring safe and reliable use of recycled water;
- *Supporting requirements*. These include basic elements of good practice, such as employee training, community involvement, research and development, validation of process efficacy, and systems for documentation and reporting;
- *Review*. This includes evaluation and audit processes to ensure that the management system is functioning satisfactorily. It also provides a basis for review and continuous improvement.

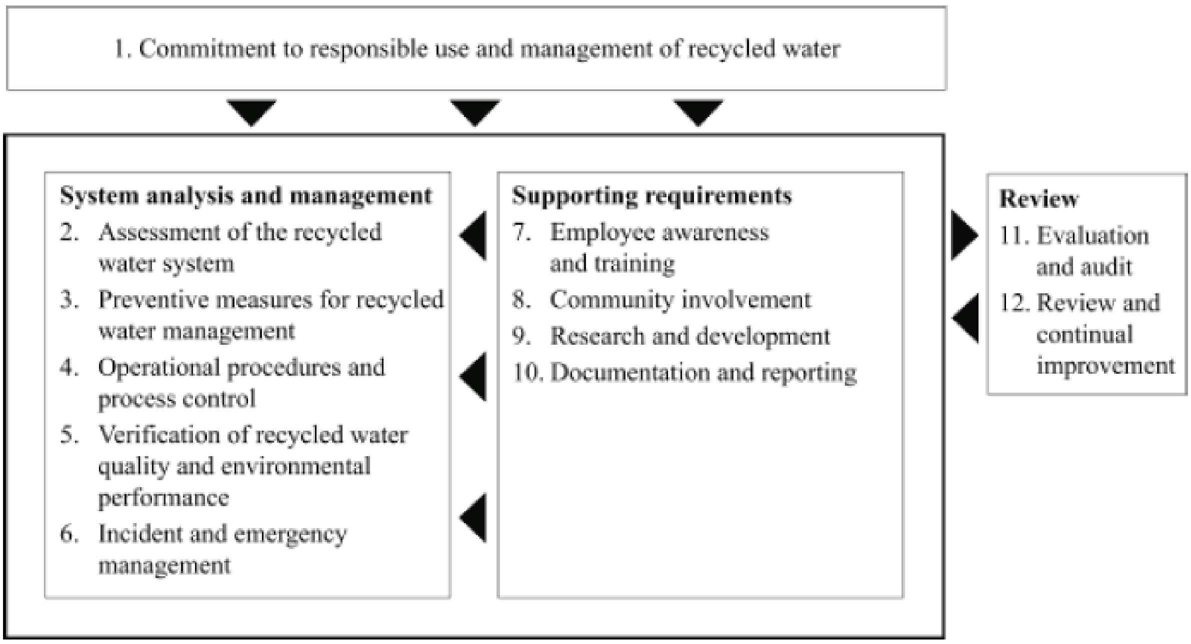


Figure 29. Elements of the framework for management of recycled water quality and use (EPHC *et al*. 2006)

The guidelines provide specific guidance for:

i. large-scale greywater to be used for (a) residential garden watering, car washing, toilet flushing and clothes washing, (b) irrigation for urban recreational and open space; agriculture and horticulture, (c) fire protection and fire fighting systems, and (d) industrial uses, including cooling water (from a human health perspective); and

ii. greywater treated on-site for use in residential garden watering, car washing, toilet flushing and clothes washing.

Table 8 presents an extract of treatment processes and on-site controls for toilet flushing water quality

Table 8. An extract of treatment processes and on-site controls for toilet flushing water quality

Log reduction targets (V, P, B)[a]	Indicative treatment process	Log reductions achievable by treatment (V, P, B)	On-site preventive measures	Expo-sure reduct-ion[b]	Water quality objectives[c]
Use — Dual reticulation, toilet flushing, washing machines, garden use					
6.5 5.0 5.0	Advanced treatment required, such as: • secondary, coagulation, filtration and disinfection • secondary, membrane filtration, UV light	6.5 5.0 5.0	Strengthened cross-connection controls required including ongoing education of householders and plumbers		• To be determined on case-by-case basis depending on technologies • Could include turbidity criteria for filtration, disinfectant Ct or dose (UV) • *E. coli* <1 per 100 mL

4.2.3. Japan

Japanese local and national governments have initiated numerous municipal and industrial wastewater reuse projects since 1970. Estimates of water reused in urban dwellings for toilet flushing ranges from 33 to 37%. An increasing need to incorporate water reuse into traditional water supply practice led to revision of some of the existing regulations and guidelines in the 1990s. For example, in Tokyo, greywater recycling is mandatory for buildings with a floor area greater than 30 000 m^2 or with a potential reuse of greater than 100 m^3/d. Japanese guidelines for domestic reuse of greywater are similar to many other standards in terms of BOD and some physical parameters (e.g. pH and turbidity) (an extract is shown in the Table below) (Surendran and Wheatley, 1998).

Table 9. Japanese mandatory standards for greywater reuse
(Surendran and Wheatley, 1998)

Total coliforms (cfu/ 100 ml)	***E. coli* (cfu/100 ml)**	**Faecal coliforms (cfu/100 ml)**	**BOD (mg/l)**	**Turbidity (NTU)**	**CL^2 residual (mg/l)**	**pH**
10	10	10 for any sample	10	5	-	6-9

4.2.4. European Union

The European Union (EU) drafted a directive to assimilate all existing European regulations on water (Bontoux, 1998). The major problem encountered in the assimilation was finding a uniform solution for all the EU member countries which differ geographically, climatically as well as in availability of water sources. Although greywater recycling for toilet flushing and fire fighting are emerging applications in France and Spain, these countries have developed a regulatory framework around agricultural reuse – which remains the major greywater reuse application. In 2000, the Spanish government issued a draft of guidelines which include non-potable urban reuse such as toilet flushing (see Table below). In Germany, greywater reuse is not widely employed due to the inherent health risks. However, research towards greywater treatment for in-building reuse has gained interest and has resulted in the installation of some operating system on various sites. Guidelines for treated greywater were introduced at a local level in Berlin (Nolde, 1999), with the key water quality parameters shown in Table 10.

Table 10. Standards for wastewater reuse quality in the European Union
(Surendran and Wheatley, 1998; Nolde, 1999)

	Total coliforms (cfu/ 100 ml)	*E. coli* (cfu/100 ml)	SS (mg/l)	Faecal coliforms (cfu/100 ml)	BOD (mg/l)	Turbidity (NTU)	CL^2 residual (mg/l)	pH
Spain	-	0	10	-	-	2	-	-
EC[a] bathing water standard	1000(m) 500(g)	-	-	1000(m) 500(g)	-	-	-	6-9
Germany (g)	100(g)	-	-	10-500(g)	5(g)[b] 20(g)[c]	1-2(m) 20	-	6-9
WHO[d] lawn irrigation	-	-	-	1000(m) 500(g)	-	-	-	-

(g) = guideline; (m) = mandatory; [a] = European Community; [b] = BOD_7; [c] = BOD_5; [d] = World Health Organization;

4.2.5. The United Kingdom

To meet the needs of the increasing number of recycling systems available in the UK, the Building Services Research and Information Association (BSRIA) proposed guidelines (Mustow *et al*. 1997) for greywater, stored rainwater and combined greywater and rainwater reuse systems. The BSRIA guidelines adopted the same guidelines for bacteriological quality as the USEPA (see Table below). The BSRIA guidelines have since been reviewed. In 1999, new water supply regulations (WRAS, 1999) were introduced. These regulations recognized greywater and rainwater as beneficial resources, made the identification of pipe work compulsory and rendered illegal cross-connections between potable and non-potable supply pipes.

Table 11. UK quality standards for domestic greywater reuse
(Surendran and Wheatley, 1998)

	Total coliforms (cfu/ 100 ml)	Faecal coliforms (cfu/100 ml)	BOD (mg/l)	Turbidity (NTU)	CL^2 residual (mg/l)	pH
UK bathing water standard[a]	1000(m) 500(g)	1000(m) 500(g)	-	2 m(g) 1 m(m)	-	6-9
UK (BSRIA)[f]	-	14 for any sample 0 for 90% samples	-	-	-	-

[a] = Bathing water standards suggested as appropriate for domestic water recycling;
[f] = toilet flushing

4.2.6. Canada

Due to the risks to human health or the environment and the low cost for water in Canada, pursuit of water reclamation has been slow. British Columbia was the first Canadian province to have enacted a reclaimed water standard for a variety of applications (Government of British Columbia, 1999). The Atlantic Canada Standards and Guidelines Manual for the Collection, Treatment and Disposal of Sanitary Sewage include a chapter on reclaimed water use, with a focus on irrigation (Environment Canada, 2006). Other provinces have typically used a case-by-case approach to proposed water reclamation projects. In the absence of guidelines, some jurisdictions have used (or are using) demonstration or test sites to explore water reclamation (CMHC, 1997).

In 2006, the CSA International developed Standard B128.01-06/B128.2-06 (CSA, 2006) to address plumbing requirements for non-potable water systems for residential or commercial toilet and urinal flushing. In 2007, the WGHRW (2007) published a second, draft consultative document to address the lack of standards for plumbing requirements for non-potable water systems and to contribute to the development of a consistent, national approach for the safe and sustainable use of household reclaimed water. This document (similar to the EPHC *et al*. (2006) guidelines for Australia) adopted a risk-based approach in order to ensure appropriate quality and management of reused water that is protective of public health over the long-term. The WGHRW document recommends possible elements of a management framework that are applicable to on-site or decentralized treatment of household water for reuse in residential or commercial toilet and urinal flushing. If the recommended management framework including the treatment technologies are adopted, the WGHRW document estimates that the following reclaimed water qualities (to be used in toilet and urinal flushing) will be realized (Table 12):

Table 12. Canadian guideline for reclaimed water to be used in toilet and urinal flushing (WGHRW, 2007)

Parameter	Units	Water quality parameters	
		Median[b]	Maximum
BOD_5	mg/L	≤10	≤20
TSS[c]	mg/L	≤10	≤20
Turbidity[c]	NTU	**≤2 (alternative to TSS)**	**≤5 (alternative to TSS)**
Escherichia coli	CFU/100 mL	Not detected	≤200
Thermotolerant coliforms	CFU/100 mL	Not detected	≤200
Total Chlorine residual[d]	mg/L	≥0.5	

[a] Unless otherwise noted, recommended quality limits apply to the reclaimed water at the point of discharge from the treatment facility or treatment unit. BOD_5 = five-day biochemical oxygen demand; TSS = total suspended solids; NTU = nephelometric turbidity unit; CFU = colony-forming unit.
[b] Median of at least five samples collected over a 30-day period.
[c] Measured prior to disinfection point.
[d] Measured at the point where the treated effluent leaves the reservoir or storage.

4.2.7. Kuwait

Irrigation accounts for approximately 60% of Kuwait's water use, while approximately 37% is withdrawn for domestic use. Irrigation water is primarily supplied from groundwater (61%) and reclaimed water (34%). While the use of reclaimed water for landscape irrigation is growing in urban areas, the main reuse application is agricultural irrigation (4,470 hectares in 1997), representing 25% of the total irrigated area. Reclaimed water is only allowed for the irrigation of vegetables eaten cooked (e.g. potatoes and cauliflower), industrial crops, forage crops (alfalfa and barley), and irrigation of highway landscapes. Table 13 details the effluent quality standards established by the Kuwait Ministry of Public Works for reclaimed water (USEPA and USAID, 2004).

Table 13. Reclaimed water standards in Kuwait

Parameter	Irrigation of Fodder and Food Crops Not Eaten Raw, Forestland	Irrigation of Food Crops Eaten Raw
Level of Treatment	Advanced	Advanced
SS (mg/L)	10	10
BOD (mg/L)	10	10
COD (mg/L)	40	40
Chlorine Residual (mg/L), After 12 hours at 20° C	1	1
Coliform Bacteria (count/100 ml)	10,000	100

4.3. Review of regulations and by-laws regarding greywater reuse in South Africa

4.3.1. National regulations regarding greywater reuse

In South Africa, there are no national regulations specifically addressing greywater reuse and management (DWAF, 2006a; Ilemobade *et al*., 2009a; Rodda *et al*., 2010). The regulations listed below (i-iv) however have clauses/sections that specifically address the treatment, disposal or reuse of waste/greywater. In these regulations, there is no fundamental objection in principle to the use of household greywater for non-potable uses, e.g. yard irrigation and toilet flushing. In terms of common law, the Health Act (No. 63 of 1977), and the National Water Act (No. 36 of 1998), normal precautions with regard to nuisances are however required (Murphy, 2006). Nuisances are defined inter alia as fly/mosquito breeding, objectionable odours, the surface ponding of wastewater, and the entry of polluted water onto a neighbouring property (Murphy, 2006). In these regulations, Water Services Institutions are mandated to provide effective approval and monitoring mechanisms for waste/greywater reuse within their jurisdictions and to provide suitable and safe environments for the treatment and reuse of greywater.

i. Government Gazette No. 9225, Regulation 991: Requirements for the purification of wastewater or effluent (EAF, 1984);

ii. the revision of the Water Services Act of 1997 relating to greywater and treated effluent (DWAF, 2001) (see Figure 30). The revision to the Act specifies the function of Water Service Institutions as far as the disposal and use of greywater is concerned and the responsibility of users in ensuring appropriate use of the resource;

GOVERNMENT GAZETTE (DWAF, 2001)

Regulation Gazette No. 7079
Vol. 432 Pretoria. 8 June 2001. No. 22355

GOVERNMENT NOTICE
No. R. 509
DEPARTMENT OF WATER AFFAIRS AND FORESTRY

WATER SERVICES ACT, 1997
REGULATIONS RELATING TO COMPULSORY NATIONAL STANDARDS
AND MEASURES TO CONSERVE WATER

The Minister of Water Affairs and Forestry has under sections 91() and 73(I) (j) of the Water Services Act, 1997 (Act No. 108 of 1997), made the Regulations in the Schedule.

Disposal of grey water
7. A water services institution may impose limitations on the use of grey water if the use thereof may negatively affect health, the environment or available water resources.
Use of effluent
8. (1) A water services institution must ensure that the use of effluent for any purpose does not pose a health risk before approving that use.
(2) Any tap or point of access through which effluent or non-potable water can be accessed, must be clearly marked with a durable notice indicating that the effluent or non-potable water is not suitable for potable purpose.
(3) A notice contemplated in sub regulation (2) must be in more than one official language and must include the PV5 symbolic sign for non-potable water as described in SABS 11 86: Symbolic Safety Signs: Part 1 : Standards, Signs and General Requirements.

Figure 30. An excerpt of the Water Services Act of 1997 relating to greywater disposal and use

iii. the revision of the National Water Act of 1998, 37(1) (DWAF, 2004a) relating to the irrigation of any land with waste or water containing waste generated through any industrial activity or by a water works. The Act makes no specific reference to greywater, but refers to “disposal of waste or water containing waste”. This may be considered to apply also to greywater (Rodda *et al*., 2010). The authorization permitted in terms of the revision does not require a wastewater irrigator, who is owner or legal occupier of the irrigated land, or who has legal access to the land, to apply for a license in terms of the National Water Act provided that the irrigation complies with the limits and conditions set out in the revised authorization (Murphy, 2006), users register such use with a responsible authority, and the general authorisation applies for a maximum of five years

(DWAF, 2004a). For biodegradable industrial wastewater (maximum of 50 m^3 per day) used for irrigation for instance, the applicable authorization is covered under the requirement (Section 2.7(iii)) that the irrigator is allowed to irrigate provided that (Murphy, 2006):

- electrical conductivity does not exceed 200 milliSiemens per metre (mS/m);
- pH is not less than 6 or more than 9 pH units;
- Chemical Oxygen Demand does not exceed 5 000 mg/l after removal of algae;
- Faecal coliform do not exceed 100 000 per 100 ml;
- Sodium Adsorption Ratio (SAR) does not exceed 5;
- the irrigation of wastewater does not impact on a water resource or any other person's water use, property or land; and is not detrimental to the health and safety of the public in the vicinity of the activity; and
- the irrigated site is located above the 100 year flood line, or alternatively, more than 100 metres from the edge of a water resource or a borehole which is utilised for potable water or stock watering, whichever is further; and on land that is not, or does not, overlie a major aquifer.

Although greywater is not mentioned among the types of wastewater considered above, this is probably the closest that existing legislation comes to providing guidance for quality of greywater intended for irrigation use (Rodda *et al*., 2010).

iv. The National Water Resources Strategy (DWAF, 2004c). This document simply refers to the regulations under the Water Services Act of 1997 (Figure 30).

In summary and according to Rodda *et al*. (2010) "*existing legislation does not specifically exclude use of greywater….. but there are inconsistencies which arise from the absence of a clear definition of greywater as a subset of domestic wastewater which differs in character and hazards from blackwater. These need to be resolved to clarify the legal position of use of greywater* …".

In response to the limited national regulations regarding greywater reuse, some by-laws have been developed in municipalities were grey reuse is being practiced in one form or another. By-laws refer to regulations promulgated by a municipality and thus enforceable within the jurisdiction of the municipality.

4.3.2. Municipal regulations regarding greywater reuse

For many municipalities in South Africa, the use of greywater for a variety of domestic and non-domestic purposes is often addressed in dedicated sections/clauses of their water supply, sanitation or effluent specific by-laws. In many of these by-laws, the use of greywater is attended to on a case-by-case basis and often delegated to a certain municipality executive. The emphasis in the related sections/clauses of these by-laws is to ensure appropriate use, assign responsibility, prevent nuisances, reduce pollution to the environment and reduce risks to public health. Three of such by-laws are briefly discussed below:

a. **The City of Cape Town Treated Effluent By-Law (2010)**

In July 2010, the City of Cape Town promulgated its Treated Effluent By-Law (CoCT, 2010) (see excerpt in Figure 31). The City of Cape Town remains the only municipality in South Africa with a by-law specifically addressing treated effluent. The by-law aims to control and regulate treated effluent in the City of Cape Town, and to provide for matters connected therewith. Treated effluent is broadly defined as "*wastewater which has been treated*" at one of the city's wastewater treatment plants. To this end, the by-law does not directly address greywater which differs in character and hazards from treated effluent. The by-law is however briefly discussed here as treated effluent may be considered for toilet flushing. The by-law empowers the Director, Water and Sanitation, to approve, on a case-by-case basis, the diverse uses (including toilet flushing) to which treated effluent may be employed. In summary, the by-law sets out the following: (i) use and responsibilities of each party involved (i.e. the City and consumers) (ii) provisions relating to the supply of treated effluent, (iii) general treated effluent installation requirements, (iv) water quality, (v) health and hygiene, (vi) plans approval procedure, (vii) persons permitted to do installation and other work, and (viii) good use practices. The treated effluent quality is benchmarked against the DNHPD (1978) guidelines which essentially specifies tertiary treatment with nil to 1000 *E. coli*/100 ml of treated effluent for toilet flushing.

30 July 2010 Province of Western Cape: Provincial Gazette 6772 1267

CITY OF CAPE TOWN

CITY OF CAPE TOWN: TREATED EFFLUENT BY-LAW

To control and regulate treated effluent in the City of Cape Town; and to provide for matters connected therewith.

Figure 31. An excerpt of the City of Cape Town Treated Effluent By-Law (CoCT, 2010)

b. **The Durban Metro Water Supply By-laws (2008)**

The Durban Metro (2008) Water Supply By-laws states that no person shall use or permit the use of water obtained from a source other than the (*potable*) water supply system, except with the prior consent of the Authorised Officer and in accordance with such conditions as it may impose for (i) domestic, commercial or industrial purposes or (ii) filling of swimming pools. The by-law employs the term *non-potable* which caters for the diversity of non-conventional water resources including greywater. Some of the clauses relevant to greywater in this by-law include:

- The supply of non-potable water shall be entirely at the risk of the consumer, both as to condition and use, who shall be liable for any consequential damage or loss arising to himself or others caused directly or indirectly there from, including the consequences of any bona fide fault of the Councillor or malfunction of a treatment plant;
- If non-potable water supplied by the municipality is used for irrigation purposes, the consumer shall ensure that it is applied uniformly over the irrigated areas and in such a way as to prevent ponding;
- The consumer shall, at his own expense, take such steps as may be necessary to prevent any run-off of surplus non-potable water from irrigated areas;
- On premises on which non-potable water is used, the consumer shall ensure that every terminal water fitting and every appliance which supplies or uses such water is clearly marked with a weatherproof notice indicating the water there from is unsuitable for domestic purposes.

c. **The Moses Kotane Local Municipality Water and Sanitation By-laws (2008)**

The Moses Kotane Local Municipality Water and Sanitation By-Laws (2008) Section 78 (1) understands greywater to be wastewater excluding "*water derived from any* *kitchen, excluding clothes washing machines, or from toilet discharges*" and as such, states the following as regards greywater use:

- Section 60. All commercial vehicle washing facilities shall be constructed and operated in such a manner that 50% of the water used by such facility is recycled for reuse in the facility;
- Section 61. Any device which entails the recycling or reuse of water shall not make use of water derived from any kitchen, excluding clothes washing machines, or from toilet discharges;
- Section 67. (1) No person shall use or permit the use of water obtained from a source other than the water supply system, except rainwater tanks which are not connected to the water installation, except with the prior consent of Municipality and in accordance with such conditions as it may impose, for domestic, commercial or industrial purposes.

  (2) Any person desiring the consent referred to in subsection 67(1) shall provide the Municipality with satisfactory evidence to the effect that the water referred to in that subsection complies, whether as a result of treatment or otherwise, with the requirements of SABS Specification 241-1984: Water for Domestic Supplies, published in the Government Gazette under General Notice 2828 dated 20 December 1985, or that the use of such water does not or will not constitute a danger to health.

4.4. Review of guidelines regarding greywater reuse in South Africa

Guidelines represent a compilation of best practice. There are no national guidelines specifically addressing greywater reuse in South Africa except the brief mention of greywater reuse for various uses (e.g. irrigation and toilet flushing) in the Guidelines for Compulsory National Standards and Norms and Standards for Water Services Tariffs (DWAF, 2002) (briefly discussed below). On the other hand, several greywater reuse guidelines (or clauses in guidelines) have been developed by municipalities, groups, and individuals (e.g. Wood *et al*., 2001; Murphy, 2006, Carden *et al*., 2007 and Rodda *et al*., 2010) involved in greywater reuse of one form or another. Many of these guidelines have emerged from Water Research Commission funded studies on greywater management and use, and provide guidance for minimising the adverse impact of greywater on human users and the environment, and for the planning and operation of greywater facilities (especially irrigation). Brief discussions on some of these guidelines are presented below:

4.4.1. Guidelines for compulsory national standards and norms and standards for water services tariffs (DWAF, 2002).

This document provides a framework within which local government can provide efficient, affordable, economical and sustainable access to water supply and sanitation. These regulations support the principles enshrined in the Constitution and the Water Services Act (1997) and help to give substance to the right of access to a basic level of service. Although, the regulations go a long way towards assisting municipalities provide basic services in a sustainable manner, they respect the executive authority of local government. Thus, the regulations provide a broad framework, by emphasising the principles of sound management, but the discretion on how this is implemented rests with local government. The guidelines advocate for the appropriate and safe use of greywater (which is defined as *"wastewater resulting from the use of water for domestic purposes, but does not include human excreta"*) for end-uses such as toilet flushing, urinal flushing and irrigation. The relevant Water Services Institution must however oversee and control the different phases of the project in order to protect the health of the public or to prevent any pollution to the environment.

4.4.2. The City of Cape Town Greywater Guidelines (CoCT, 2005)

The City of Cape Town (CoCT, 2005) developed greywater guidelines primarily to guide how and where to dispose of greywater so as to avoid pollution in the City's informal settlements which benefit from municipal water supply. In this guideline, greywater is referred to as "*wastewater from the washing of laundry, personal bathing and cooking activities*". Three disposal points, in order of preference, were recommended, i.e. sewer (preferred), soil (via a soakaway facility) and stormwater/surface drainage system (this option is only to be considered when the first two options are impossible). Innovative methods of greywater disposal, e.g. the

Tower Garden concept were also recommended. In addition to the above, the guidelines recommend the following: (i) greywater intakes must be located close to where the greywater is generated. The maximum distance from a dwelling to the intake should be 25 m; (ii) where communal washing facilities are provided, sediment and fat traps are required before the intake (except the intake empties directly into the sewer); (iii) small sediment and fat traps should be located close (< 3 m) to greywater intakes and no more than 5 intakes should be served by one sediment and fat trap; and (iv) once sediments and fat have been removed, conveyance to the sewer/soakaway/stormwater system can be done using small bore gravity pipelines, where slopes permit. However, in certain extreme situations where it will be necessary to pump, very careful consideration must be given to the design, operation, maintenance, and associated costs of the pump station.

4.4.3. The Durban Metro (1997) guidelines/policy regarding the reuse of treated sewage effluent

The Durban (currently eThekwini) Metro (1997) developed a guideline/policy document for the reuse of treated sewage effluent from its sewage treatment works for industrial and irrigation purposes. Although the document only discusses the reuse of treated sewage effluent and not greywater, the experiences garnered from this reuse may have an impact on greywater reuse initiatives within the Metro. This document discusses, in broad terms, the factors which affect decisions to re-use treated effluent instead of discharging it into a river, watercourse or out to sea. In broad terms, the document highlights potential/actual treated effluent reuse in various sectors of the Metro, i.e. industry (the potential industrial re-use of about 8 million litres of treated effluent from the Southern Wastewater Treatment Works), irrigation of agricultural land using treated effluent from 2 of the Metro's sewage treatment works, and aquaculture (re-use for aquaculture had been attempted twice in Durban and on both occasions the concessions had to be terminated because they were economically unviable). For economical and other reasons, treated effluent reuse was not considered for potable water production, recharge of ground water and domestic use (including toilet flushing).

4.4.4. Greywater management in dense informal settlements (Wood *et al*., 2001)

Wood *et al.* (2001) highlighted the potential for greywater generation to be considered and provided for when planning and developing settlements. They concluded that integration of suitable long-term service provision was essential to alleviating the problems of greywater management which they observed in their study of dense informal settlements of South Africa. Some of the guidelines which were proposed regarding the planning and management of greywater and greywater systems for dense informal settlements are listed below (Rodda *et al*., 2010):

- Settlements should not be established on steep slopes because of the increased risk of erosion;
- No development should occur in the 1:50 year floodline, and natural drainage channels should be maintained;
- Where water points are located near rock outcrops or where the soil in the area is unsuitable, it may be possible to use surface drains to transport greywater to a more suitable area for disposal;
- Provision must be made for the collection of greywater and leakage from water standpipes. Preferably, infiltration beds and soakaways should be provided at the standpipes (or drainage) to gravitate the greywater to an appropriate site for handling and disposal so that ponding of contaminated water is minimised. Standpipes should be no further than 100 m from each household;
- The preferred option for greywater disposal is by gravity to sewer – the collection and treatment of greywater in ponds or wetlands is not a viable option for many high-density settlements owing to the lack of large open spaces, health risks, and safety considerations.

4.4.5. Reporting on the status quo of greywater in informal areas in the Western Cape and guidelines for its management (DWAF, 2005a)

In April 2005, a status quo report was published by DWAF (currently Department of Water Affairs and the Environment, DWAE) on the management of greywater in informal areas of the Western Cape. The report recommends that any discussions on a future national greywater management strategy must include input from Water

Services, as the implementation of the strategy is likely to have financial implications for Water Service Institutions especially if there are design implications in terms of new reticulation systems. Furthermore, the Directorate responsible for the development of the policy must be clearly defined as it affects Water Resource Management, Water Supply and Sanitation.

4.4.6. A scoping study to evaluate the fitness-for-use of greywater in urban and peri-urban agriculture (Murphy, 2006)

Murphy's (2006) study was focused on the use of greywater for irrigation. Murphy (2006) provided a list of steps to be taken when planning greywater use for irrigating garden crops. Several of these steps (listed below) (Rodda *et al*., 2010) may also be broadly applied to other greywater end uses:

- Greywater availability – the available sources of greywater (e.g. laundry, bath, wash basin, and shower) should be identified. For each source, the volume of greywater produced on a daily or weekly basis should be estimated;
- Identification of preferred greywater sources – greywater from different sources should be used in the following order of preference:
  - a) bathroom greywater;
  - b) laundry greywater (preferably use only rinse-wash water);
  - c) kitchen greywater (rinse water only, unless when the greywater is to be used for composting).
- Example of a treatment option – using a sieve at the greywater source for trapping hair, lint and food particles;
- Regulations – applicable regulations (e.g. municipal by-laws) would need to be determined for each case;
- Health risks associated with greywater use – greywater should not be used if any member of the household has an infectious disease;

In addition to the planning steps listed above, Murphy (2006) also provided extensive practical recommendations for day-to-day management of greywater irrigation. Some of these, which may also be broadly applied to other greywater end-uses are summarized as follows:

- For newly-designed houses, greywater outlet pipes should be kept separate until outside the house;
- For piped greywater irrigation systems, a minimum of a simple filter (e.g. a nylon stocking) should be used. It should be possible for greywater irrigation piping to be completely and easily drained. Greywater storage tanks should be covered;
- For piped greywater systems at dwellings connected to sewage systems, there should be a diversion facility to the sewage system at or near the greywater source outlet;
- Greywater should not be allowed to leave the property on which it is generated, except through the sewer;
- Greywater should not be stored for longer than 24 hours;

4.4.7. Understanding the use and disposal of greywater in the non-sewered areas of South Africa (Carden *et al*., 2007)

Carden *et al*. (2007) surveyed greywater (all domestic wastewater except blackwater) generation and provision for greywater management in unsewered settlements across South Africa. They concluded that the density of a particular settlement, together with the consumption of water per dwelling unit, were the most critical factors in determining whether greywater could be safely disposed on-site (including reuse options). However, they observed that it was behavioural patterns that drove the reality of how greywater was disposed. Although the level of service with respect to water supply to unsewered areas varied widely, only two categories seemed to have any influence on the amounts of water consumed in each dwelling, viz. having a yard tap on the property or having to walk to fetch water, irrespective of the distance walked (Carden *et al*., 2007 cited by Rodda *et al*., 2010).

Carden *et al*. (2007) developed a relationship to describe the interdependence of dwelling density and average volume of greywater volume generated by each dwelling. They termed this interdependence the greywater generation rate, *G*. Management guidelines were proposed for different ranges of *G*:

- Low density greywater generation was defined as < 500 ℓ/ha.day, which generally equates to dwelling densities of < 10 du/ha and plot sizes of > 800 $m^{2.}$

Soakaways installed at water collection points and standpipes should be sufficient to protect water resources and prevent health risks;

- Low/medium density greywater generation was defined as 500-1 500 ℓ/ha.day, equating to dwelling densities of 10-30 du/ha and plot sizes of 300-800 m^2. Soakaways must be installed at tap stands and in-home or yard connections should be connected to an on-site disposal system;
- Medium/high density greywater generation was defined as 1 500-2 500 ℓ/ha.day, equating to densities of 30-50 du/ha and plot sizes of 130-150 m^2. If yard connections are supplied as recommended by DWAF, onsite disposal systems should be installed; otherwise formal washing areas with disposal options are required;
- High density greywater generation was defined as > 2 500 ℓ/ha.day, equating to densities of > 50 du/ha and plot sizes of < 150 m^2. There should be off-site disposal of all effluent.

Greywater management options could then be determined by way of rule-based flow diagrams which ask relevant questions for each of the criteria identified to determine options for greywater management and disposal. Limits were given for some of these criteria where it was deemed possible to provide recommendations for off-site disposal of greywater. Decision trees which were also presented in the report could help decision-makers to determine quickly whether on- or off-site disposal of greywater should be considered (Rodda *et al*., 2010).

In Carden *et al*.'s (2007) study, it was observed that people living in non-sewered settlements were generally not prepared to use greywater for irrigation purposes as it is considered harmful to certain species of plants. This is due to the multiple uses of the greywater before it is considered suitable for disposal and the large variation in the concentration of the various pollutants within. The water quality data from the site surveys confirmed that greywater from non-sewered areas is generally unfit for use

4.4.8. Sustainable use of greywater in small-scale agriculture and gardens in South Africa (Rodda *et al.*,2010)

The aim of Rodda *et al.*'s (2010) report was to develop guidelines for the sustainable use of greywater in small-scale agriculture and gardens in rural villages, peri-urban and urban areas of South Africa. Central concepts identified from the literature review and case studies, and deliberations between relevant stakeholders determined the underlying principles and the structure of the developed Guidance Report. The focus of the Guidance Report was defined as (Rodda *et al.*, 2010):

- Minimisation of risks of *illness* in handlers of greywater and greywater irrigated produce, or consumers of greywater-irrigated produce;
- Minimisation of risks of *reduction in growth or yield* of plants/crops irrigated with greywater;
- Minimisation of risks of environmental degradation, especially reduction in the *ability of soil irrigated with greywater to support plant growth*.

The Guidance Report was specifically intended to address irrigation use of greywater only, and was not targeted at providing a general solution for the disposal of greywater. However, some of the recommendations may be applied to other greywater uses.

The structure of the Guidance Report was as follows (Rodda *et al.*, 2010). The core of the Guidance Report is provided by the section "Guidance for greywater use in small-scale irrigation in South Africa":

- What is greywater?
- Why use greywater for irrigation?
- Concerns about the use of greywater for irrigation:
  - Health considerations;
  - Plant growth and yield;
  - Ability of soil to support plant growth;
- Purpose of the Guidance Report:
  - Intended users of the Guidance Report;
  - Focus of the Guidance Report;

- Major sources used;

➢ Legislative context of greywater use for irrigation;

➢ Special considerations;

➢ Guidance for greywater use in small-scale irrigation in South Africa:

  - Guide to managing risks and uncertainty:

    In this sub-section, 3 categories of greywater use are identified, based on the extent of characterisation of greywater and, by implication, on compliance with quality limits. Use restrictions are identified for each category. The most stringent restrictions apply to greywater used without characterisation. Minimum analysis – comprising pH, electrical conductivity, sodium adsorption ratio and *E. coli* –, and compliance with quality limits on these, are associated with less stringent restrictions. The least restrictions are associated with use of greywater undergoing full analysis (minimum analysis plus boron, chemical oxygen demand, oil and grease, suspended solids, total inorganic nitrogen and total phosphorus);

  - Greywater quality: Guide to greywater constituents:

    The quality limits in each category are specified in this sub-section;

  - Greywater quality: Mitigation of greywater quality:

    This section provides means of adjusting to or improving on greywater quality. Two approaches are considered: agricultural practices to mitigate the effect of predominantly chemical constituents such as sodium; and treatment to improve, predominantly, the organic and microbiological quality of greywater;

  - Greywater quantity: Guide to irrigation volumes;

    This sub-section guides users in selecting the volume of greywater to be applied and in adjusting this for site-specific conditions.

Some of the recommendations to emerge from the study which could be generally employed for other uses of greywater are as follows:

➢ Implementation: Capacity building at Local Authority level

  A short educational pamphlet on greywater and greywater irrigation, aimed specifically at local authorities, should be developed and distributed;

➢ Implementation: Education of greywater users

- Potential greywater users need to be involved in planned greywater implementations from the planning stages, informing them of the benefits and risks of greywater use for irrigation, allowing them to express their views and concerns, and providing a mechanism for them to be involved in decision making.
- Potential irrigation users of greywater need information to practice greywater irrigation in a safe and sustainable manner. Although this information is provided in the Guidance Report, it would be helpful to provide users with quick reference sheets to support the more comprehensive document. This could take the use of one-page information sheets.
- Once greywater implementation has been planned and initiated, greywater users need ongoing monitoring and support. This should be tailored to meet the different information and support needs of low income rural and peri-urban settlements and middle to higher income urban settlements.

➢ Legislation: Recognition of greywater and beneficial greywater use in water and waste legislation

  Current legislation pertaining to disposal and use of water and waste falls short in that a definition of greywater as a separate wastewater stream is lacking. Clarity is needed for the future by explicit definition of greywater and the beneficial uses to which it may be put.

4.5. Government pronouncements regarding greywater reuse in South Africa

Table 14 presents references to publications or pronouncements of the national government through the Department of Water Affairs and the Environment, DWAE (formerly DWAF) as regards greywater reuse for different end uses. Of particular note is the fact that DWAE, in various places and through various offices, has proactively encouraged greywater reuse for particularly toilet flushing and garden irrigation.

Table 14. Reference to publications/pronouncements by DWAE regarding greywater reuse in South Africa

Reference	Guideline/Suggestion/Comment
DWAF (2008). National Water Week 2008. http://www.dwa.gov.za/events/waterweek/2008/Tips.aspx	*"Tips to save and manage water:* • *Use greywater – used water from baths, washing machines and other safe sources – to flush your toilet"* • *Use greywater ……. to water your garden."*
DWAF (2007). National Water Week 2007. http://www.dwaf.gov.za/events/WaterWeek/2007/facts.asp	*"Use greywater….to water your garden"*
DWAF (2006b). Handing over ceremony of the *Baswa Le Meetse* Awards prizes. 22 September 2006. http://www.dwaf.gov.za/Communications/MinisterSpeeches/2006/BaswaLeMeetse22Sep06.pdf	Speech by Mrs Lindiwe Hendricks, Minister of Water Affairs and Forestry at Mammutla Primary School, Mammutla Village, Taung, North West. *"I was impressed with the project of our national team, which comprised three young girls from a school in rural KwaZulu-Natal. They used their knowledge of water and science to find useful ways of turning the household wastewater (greywater) into productive water that could be used to effectively grow plants and vegetables."*
DWAF (2005b). National Water Week 2005. http://www.dwaf.gov.za/events/WaterWeek/2005/Documents/WaterWheelJan05d.pdf	*"Minister Sonjica urges water saving at homes through the use of greywater to water your garden and flush your toilets"*
DWAF and NORAD (2004b). *Introductory Guide to appropriate solutions for water and sanitation.* TOOLKIT for WATER SERVICES: Number 7.2. Produced under The NORAD-Assisted Programme for the sustainable development of groundwater sources under the Community Water and Sanitation Programme in South Africa. March. http://www.dwa.gov.za/Groundwater/NORADToolkit/7.2%20Introductory%20Guide%20to%20Appropriate%20Solutions%20for%20Water%20and%20Sanitation.pdf	This document provides simple guidelines on the implementation of greywater reuse systems.

4.6. Pertinent issues from the review of regulations, by-laws and guidelines for greywater reuse in South Africa

From the review of regulations and guidelines conducted above and the overview of government's broad position regarding greywater reuse for various uses, some key issues worth noting are listed below:

i. In South Africa, there are no national regulations specifically addressing greywater reuse and management. There are however some sections/clauses in broad regulations and by-laws which address greywater reuse and/or management, albeit to differing degrees of detail, most of which are very limited;

ii. In the regulatory sections/clauses of broad regulations and by-laws reviewed, there is no fundamental objection in principle to the use of household greywater for non-potable uses, e.g. garden irrigation and toilet flushing, as long as nuisances which compromise public health and the pollution status of the environmental are avoided. In fact, in the publications and pronouncements listed in Table 14, there is broad encouragement for greywater reuse for toilet flushing and garden irrigation.

iii. Current national regulations that mention/discuss the use and disposal of greywater fall short in that a definition of greywater as a separate wastewater stream and distinct from blackwater is lacking. The implication of this is that the understanding (and thus, legal position) of greywater is inconsistent amongst various stakeholders. For example, the City of Cape Town guidelines (CoCT, 2005) define greywater as "*wastewater from the washing of laundry, personal bathing and cooking activities"*, the Moses Kotane Local Municipality Water and Sanitation By-law understands greywater to be domestic wastewater excluding "*water derived from any kitchen …. or from toilet discharges*", and the guidelines for compulsory national standards and norms and standards for water services tariffs (DWAF, 2002) defines greywater as *"wastewater resulting from the use of water for domestic purposes, but does not include human excreta"*;

iv. There are no national guidelines specifically addressing greywater reuse in South Africa. A nationally consistent approach to the management of health and environmental risks from greywater reuse requires high-level national guidance on risk assessment and management. These guidelines will not be mandatory and will have no formal legal status. However, their adoption will provide a shared national objective, and at the same time allow flexibility of response to different circumstances at regional and local levels (EPHC *et al*., 2006);

v. Several WRC funded projects (e.g. Wood *et al*., 2001; Murphy, 2006; Carden *et al*., 2007; and Rodda *et al*., 2010) have developed guidelines for greywater use and management in especially dense, non-sewered and/or informal areas of South Africa and for diverse irrigation purposes. These guidelines need to be compiled into a comprehensive document which addresses greywater use and management and may be expanded to include guidelines addressing other possible end-uses of greywater such as toilet flushing);

vi. The DWAF (2005a) report recommends that any discussions on a future national greywater management strategy must include input from Water Services, as the implementation of the strategy is likely to have financial implications for Water Service Institutions especially if there are design implications in terms of new reticulation systems. Furthermore, the Directorate responsible for the development of the policy must be clearly defined as it affects Water Resource Management, water supply and sanitation;

5. GREYWATER TREATMENT TECHNOLOGIES AND FRAMEWORK FOR EVALUATING LOCALLY AVAILABLE GREYWATER TREATMENT UNITS

The trend of decentralised living and environmental consciousness together with increasing water scarcity has created a market for small wastewater treatment units in South Africa and many other locations around the world. For reasons of cost, convenience and installation, many small wastewater treatment units are manufactured as '*package plants*'. Judd *et al*., (2006) defines a package plant as a complete unit fabricated in a factory and shipped to location for installation. This is in contrast to a conventional wastewater treatment plant that is installed on site. Package plants may be designed to treat flows as low as 7.57 m^3/day or as high as 1892.5 m^3/day. Package plants are used by a variety of users including holiday resorts, private housing estates, hotels, factories, and individual households. As a result of this, most locally available package plants range in capacity from 4 PE to 1000 PE or more. PE represents '*Population Equivalent*' = ±120l/day.

Treatment is necessary to reduce the amount of solids, organic matter, nutrients and pathogenic organisms in greywater. Currently, there have been tremendous successes recorded in terms of wastewater treatment technology. However, despite the successes of treating wastewater at a large scale, treatment is less reliable as volume of influent decreases. This is because:

- Smaller plants are subjected to a wider range of hydraulic loads than their larger counterparts (Gaydon *et al*., 2006);
- The smaller the unit is, the more difficult it becomes to operate. This is due to limitations in the size of pumps, fittings, and pipes. Furthermore, the relative size of debris increases as the size of the unit decreases, making blockages more likely and the requirement for maintenance more frequent;
- Smaller plants, as a result of being packaged, are often left unattended for longer periods of time (e.g. 3-12 months at a time). Break downs therefore occur regularly as a result of neglected preventative maintenance.

With the growth of on-site grey/wastewater reuse, the selection of appropriate package plants has become needful and a challenge. This challenge is more so in the case of novel, emerging or imported package plants where little information and experience under local conditions are known.

This chapter of the report reviews greywater treatment technologies commonly used, presents a database of locally available greywater package plants as at 2009 and develops a framework for the evaluation of locally available, small greywater treatment plants, with the treated effluent specifically for toilet flushing.

Two projects commissioned by the WRC have attempted to provide some guidance on the evaluation of small water and wastewater treatment plants, i.e. Guidebook for the selection of small water treatment systems for potable water supply to small communities (Chris Swartz *et al*., 2007) and Evaluation of sewage treatment package plants for rural, peri-urban and community use (Gaydon *et al*., 2006). This chapter builds on some of the work presented by these reports within the context of greywater reuse for toilet flushing.

5.1. Review of greywater treatment technologies

In Li *et al.* (2009), greywater treatment for unrestricted, non-drinking urban reuses (including toilet flushing) typically requires four processes – pre-treatment; physical, chemical, biological treatment; filtration; and disinfection (if restricted reuse, disinfection may be excluded). Individually, these processes cannot guarantee adequate treatment (see Table 15) and hence, many systems incorporate a combination of these processes. Figure 10 shows Li *et al*.'s (2009) proposed treatment flow for different qualities of greywater for urban non-drinking purposes. Discussion on physical, biological and chemical treatment processes are discussed below.

Table 15. Overview of treatment technologies and their pollutant removal abilities
(Landcom's WSUD strategy, 2003)

Category	Sub-category	Treatment efficiency					
		Suspended solids (TSS)	**Biodegradable organics (BOD removal)**	**Nutrients: nitrogen**	**Nutrients: phosphorus**	**Salts**	**Pathogens**
Biological (suspended and fixed growth)	Membrane bioreactor	Yes	Yes	Function of size	Function of size	No	Function of size
	Recirculating media filter	Yes	Yes	Yes	Limited	No	Limited
Chemical	Disinfection	No	No	No	No	No	Yes
Physical	Sand filtration	Yes	Function of size	Limited	Limited	No	Limited
	Membrane filtration	Yes	Function of size	Function of size	Function of size	Reverse osmosis only	Function of size
Natural	Subsurface flow wetland	Yes	Yes	Yes	Yes	No	Good

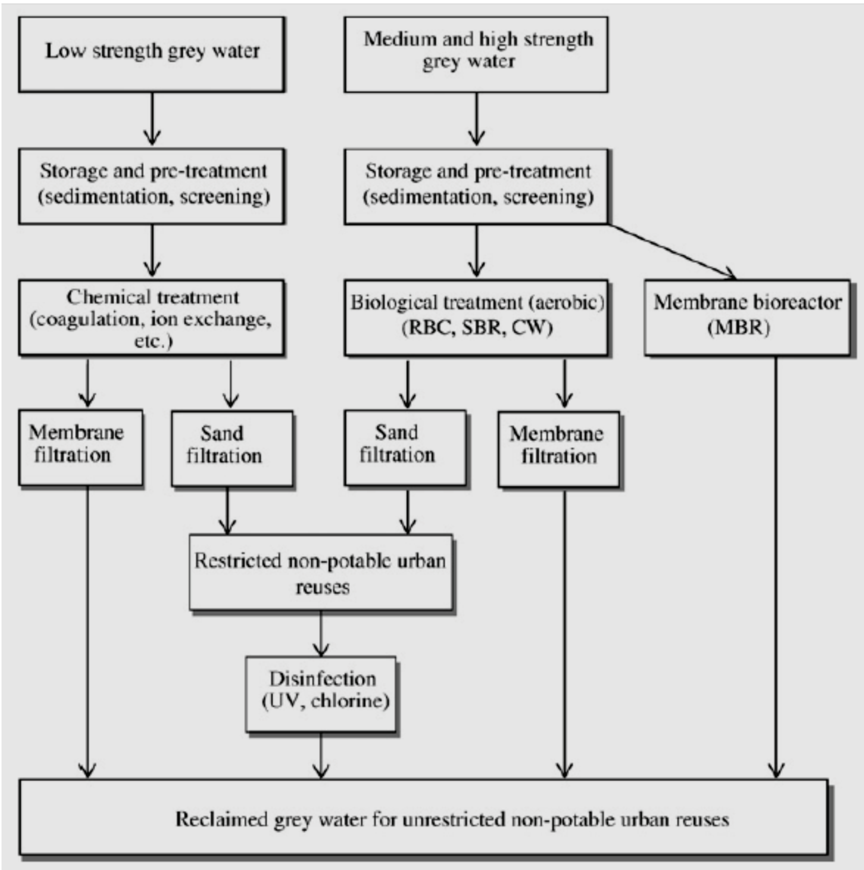


Figure 10. Greywater treatment for non-drinking urban reuses (Li *et al.*, 2009).

5.1.1. Biological treatment technologies

Biological treatment promotes natural processes to break down high nutrient and organic loading waters. Biological treatment alone is not usually sufficient to produce an effluent suitable for reuse. In all cases therefore, the biological reaction must be accompanied by a physical process to retain active biomass and prevent the passage of solids into the effluent (Jefferson *et al*., 2001).

Common amongst most locally available package plants, is the actual treatment of greywater using biological processes, i.e. suspended growth or fixed film/growth systems (presented below) (Laas and Botha, 2004 and Gaydon *et al*., 2006).

Suspended Growth Systems (Münch, 2005)

The activated sludge process is the best-known suspended growth system. This process is most commonly used in large, centralised and small wastewater treatment plants. Activate sludge is the process whereby sewage is aerated (using atmospheric air or pure oxygen) and agitated in order to promote the growth of beneficial microorganisms that break down organic matter and produce biological flocculent. The process usually occurs in two distinct phases (and therefore vessels), i.e. aeration followed by settling. Four processes are common in all activated sludge systems:

i. A flocculent, aerated slurry of microorganisms (which is called "mixed liquor suspended solids" or MLSS) is utilised in a bioreactor to remove soluble and particulate organic matter from the wastewater;
ii. Quiescent settling is used to remove the MLSS from the process stream, producing an effluent that is low in organic matter and suspended solids;
iii. Settled solids are recycled as a concentrated slurry from the clarifier back to the bioreactor;
iv. Excess MLSS (sludge or biosolids) is discharged from the bioreactor to control the solids retention time to a desired value.

There are several process variations to the activated sludge process- the main ones are briefly described below:

a. **Sequencing Batch Reactor (SBR)**

The SBR process is a fill-and-draw-type reactor that acts as aeration basin and final clarifier. Wastewater and biomass are mixed and allowed to react over several hours in the presence of air. At a certain point in time, the aeration is turned off and the mixed liquor in the reactor is allowed to settle, thereby removing the need for a separate settling tank.

After a short settling period, the clarified treated effluent is discharged via a specially designed decanter. One design variant is that the decanter follows the liquid level down enabling only the clear, treated effluent to be discharged, while the biomass continues to settle. Once the treated effluent is discharged the reactor is available to treat a further batch of wastewater. This way, the process operates on a batch treatment principle, with the operations being sequenced. Two or more SBRs are usually operated in parallel unless a sewage storage tank is used.

b. **Membrane Bioreactor (MBR)**

A membrane bioreactor (MBR) combines the process of a suspended growth reactor (system) and membrane filtration into a single unit process. MBRs replace the need for a separate filtration process with a treatment process that has a small footprint and produces high quality effluent with low TSS, BOD, and turbidity that meets almost all health criteria guidelines. There are two basic configurations for a MBR: a submerged integrated bioreactor that immerses the membrane within the suspended growth reactor (Figure 11) and a bioreactor with an external membrane unit. MBRs are usually of a modular design such that it may be located indoors or outdoors and it may be for large or small scale applications. The suitability of MBRs for greywater reuse is strongly influenced by its capability to remove both biological contaminants without the use of chemicals for treatment. MBRs provide a proven and reliable treatment technology, having been used extensively in Japan for greywater and blackwater reuse systems.

Control of membrane fouling is an important operational issue. If fouling is not controlled, membranes will wear quicker, and there will be increased energy costs and decreased effluent quality. MBRs have higher capital (which includes expensive membranes) and energy (chemicals required for membrane cleaning) costs than other treatment systems. It may be susceptible to shock loading of organic matter and bactericidal chemicals.

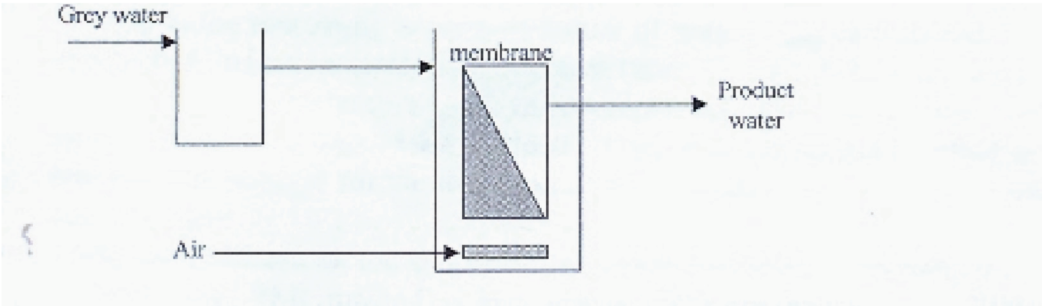


Figure 11. An immersed membrane bioreactor (Jefferson *et al*., 2001)

Fixed Film/Growth Systems (Münch, 2005)
Fixed film/growth systems are systems where the microorganisms are attached to a surface that is exposed to the water. Many locally available package plants employ a purely fixed film system or a combination of fixed film and suspended growth systems.

a. **Rotating Biological Contractor (RBC)**
The Rotating Biological Contactor (RBC) supports a biologically active film, or biomass, of aerobic micro-organisms. An RBC treatment system (Figure 12) typically comprises of three units:

- Primary Zone: A settlement tank where wastewater enters and solids settle and are stored for subsequent removal. Anaerobic digestion may take place within the tank.
- RBC: This is where the biological treatment takes place. Numerous discs attached to a shaft form the RBC assembly, which is partially submerged in a trough to create an environment for an active biomass to develop on the media. The RBC is slowly rotated to bring the biomass into alternate contact with the wastewater and atmospheric oxygen.
- Final Clarification Zone: Here settlement of the mixed liquor and excess biomass takes place.

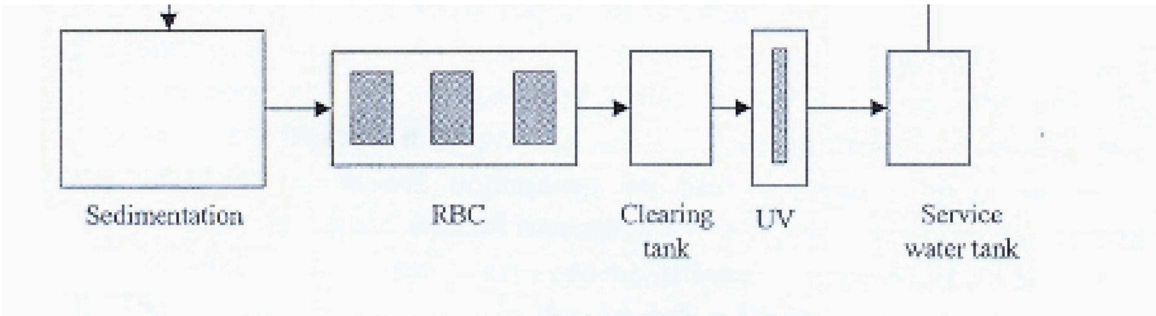


Figure 12. A rotating biological contactor (Jefferson *et al.*, 2001)

b. Submerged Aerated Filter (SAF)

The SAF process can be described as follows: Settled wastewater is fed from a primary tank into the first stage of a reactor at a controlled rate, where it is mixed with the aerated bulk liquid already present. Air is introduced into the reactor through a fine bubble diffuser system at the base of each chamber. A uniquely structured media is suspended over the fine bubble membrane diffuser to provide optimized contact between the oxygen-rich wastewater and the biomass.

With a high surface area to volume ratio, the media supports a biologically active film of micro-organisms, to treat the wastewater by using oxygen from the air provided. Manufactured from lightweight vacuum-formed PVC sheets (for example), bonded together to form packs, the media can easily be removed for maintenance.

When the oxygen-rich wastewater comes into contact with the biomass attached to the surface of the media, organic pollutants are broken down by the biomass. The flow of air can be controlled to optimize the levels of dissolved oxygen within the reactor, ensuring that the process is energy efficient.

Recirculating media filters (Landcom's WSUD strategy, 2003)

Recirculating textile filters (RTF) and recirculating sand filters (RSF) are biological treatment processes removing organic material from the wastewater. Recirculating textile filters are similar to trickling filters. However, the media used for the growth of the biofilms are textiles rather than plastics or rocks. RTFs are available in small compact package plants and therefore, suitable for decentralised treatment. The RTF and RSF consist of two major components. The first is the biological chamber and low-pressure distribution system. The wastewater flows between and through the non-woven lightweight textile material in the RTF and through a bed of sand in the RSF. The second major component is a recirculating tank and pump. The pump typically returns 80% of the filtrate back to the chamber. The pump fills the chamber every 20 to 30 minutes. The remaining effluent may be diverted to a storage tank or discharged.

5.1.2. Chemical treatment technologies

Chemical treatment involves chemicals, typically coagulants and disinfectants, which are used to increase the removal rate of pollutants or destroy pathogenic organisms but does not remove solids. Disinfection destroys pathogenic microorganisms in water to ensure public health. Eradication of waterborne pathogens is the most important public health concern for water treatment. Disinfection ranges from boiling water to large-scale chemical treatment for water supplies. The three most common disinfection methods are ultra-violet radiation, chlorination and ozonation.

Ultraviolet (UV) radiation

Uses UV light to deactivate microorganisms in water. The short UV wavelength irradiates microorganisms. When the UV radiation penetrates the cell of an organism, it destroys the cell's genetic material and its ability to reproduce. UV disinfection has low capital and operating costs, is easy to install and operate and is well suited to small-scale water treatment processes. UV is ineffective in turbid or milky waters as the microorganisms hide behind suspended particles to evade irradiation.

Chlorination

Chlorine, a strong oxidant, is the most common water disinfectant. Chlorine can be added in gaseous form (Cl_2), hypochlorous acid or as hypochlorous salt – typically $Ca(OCl)_2$. Chlorine addition requires chemical handling and storage. Some by-products of chlorination are carcinogenic. Chlorine provides residual microbial control, i.e. it continues to disinfect water after the water has passed through the chlorination point and hence, it is typically selected for drinking water supply systems. Optimal chlorination dosage is dependent on the concentration, water pH and temperature. The pH exerts a strong influence on the chlorination performance and is therefore regulated.

Ozonation

Ozone is a more powerful oxidising agent than the above disinfectants. Ozone is created by an electrical discharge in a gas containing oxygen, i.e. $3O_2 \rightarrow 2O_3$. Ozone production depends on oxygen concentration and impurities such as dust and water vapour in the gas. The breakdown of ozone to oxygen is rapid. It is impossible to maintain free ozone residuals in water for any significant time.

Three of the schemes using predominantly chemical technology for greywater recycling were reported in Parsons *et al*., 2000; and Lin *et al*., 2005. Two of the three schemes were based on coagulation with aluminium. The first scheme used a combination of coagulation, sand filters and granular activated carbon (GAC) for the treatment of laundry greywater. This scheme was effective, with residuals of 10 mg/l for BOD and below 5 mg/l for suspended solids. The coagulation stage alone achieved 51% of BOD removal and 100% of suspended solids removal. The second scheme combined electro-coagulation with disinfection for the treatment of low-strength greywater with BOD residuals of 9 mg/l, a turbidity residual of 4 NTU and undetectable levels of *E. coli*. However, the greywater source had very low organic strength with BOD concentrations of about 23 mg/l. These two schemes achieved the above results in relative short times (20 and 40 minutes respectively). The third scheme was based on photocatalytic oxidation with titanium dioxide and UV disinfection. This scheme achieved good results. Within 30 minutes, this method was reported to achieve a 90% removal of organics and removal of total Coliform of 10^6 cfu/100 ml (Parsons *et al*., 2000).

Advantages of chemical treatment include: the treatment can be located indoors, it has a small ecological footprint, it separates turbidity and organic matter from the effluent, and it efficiently disinfects and thus, this technology is potentially suitable for small scale applications. Disadvantages include that the technology does not remove solids and it often requires a high capital cost.

5.1.3. Physical treatment technologies

(Landcom's WSUD strategy, 2003)

Physical treatment technologies rely on physical separation of the effluent from the pollutant such as filtration, sedimentation and flotation. Physical processes, which achieve a reasonable decrease in organic pollutant load and turbidity of greywater, include:

Sand filtration

Sand filters have been used for water treatment for more than 100 years. Filtration is a tertiary treatment process that typically occurs after secondary (biological or chemical) treatment as it removes residual suspended solids and organic matter prior to disinfection. Sand filters are usually lined excavated structures filled with uniform media over an underdrain system. The wastewater is poured on top of the media and percolates through to the underdrain system. Design variations include recirculating sand filters where the water is collected and recirculated through the filter. For effective microbial control, low flow is desired through the sand filter. This ensures contact between the sand media's biofilm (which forms on the upper layer of the sand filter) and water. The biofilm helps to adsorb colloidal pollutants and encourages oxidation of the organic material as oxygen diffuses within the biofilm. Depth filtration is a variation of the sand filter. Depth filtration uses a granular media, typically sand or a diatomaceous earth, to filter effluent. Typically there are four layers of filter media. The particle size decreases through the filter's layers. The coarser top layer removes larger particles and finer material is removed towards the lower layers, increasing the efficiency of the filter in comparison to the conventional sand filters.

Membrane filtration

Membrane (or cross flow membrane) filtration is a physical separation process to filter pollutants (particles, bacteria, other microorganisms, natural organic matter and salt) using a semi-permeable media. There are 4 broad classes of membrane filtration namely (i) micro-filtration, (ii) ultra-filtration, (iii) nano-filtration and (iv) reverse osmosis. Micro-filtration has the largest pore size, decreasing to ultrafiltration, nanofiltration and reverse osmosis. The treated water is thus generally very low in turbidity and below the limit of detection for coliforms. The key technical limitation of membrane filtration systems is that of fouling of the membrane surface by pollutants. This increases the hydraulic resistance of the membrane, commensurately increasing the energy required for membrane permeation and/or decreasing the permeate flux. The pressure requirements, pore size and typical pollutant removal are summarised in Table 16. Fouling can be suppressed by operating at a lower membrane flux or can be substantially removed by cleaning – the former requiring larger membrane areas to process the same volume of greywater (Jefferson *et al.*, 2001). Advantages include that the technology can be located indoors, it is suitable for large and small applications, the quality of treated effluent is generally very high, and it is not susceptible to chemical shocks. A major disadvantage is the high capital cost of membranes.

Table 16. Key features of membrane filtration
(Landcom's WSUD strategy, 2003)

Filtration	Pore size	Operating pressure	Typical target pollutant
Microfiltration	0.03 to 10 microns	100-400 kPa	Sand, silt, clays, *Giardia lambia*, *Cryptosporidium*
Ultrafiltration	0.002 to 0.1 microns	200-700 kPa	As above plus some viruses (not an absolute barrier) Some humic substances
Nanofiltration	About 0.001 microns	600-1000 kPa	Virtually all cysts, bacteria, viruses and humic materials
Reverse osmosis	About 4 to 8 Å	300-6000 (or 13,000kPa – 13.8 bar) kPa	Nearly all inorganic contaminants Radium, natural organic substances, pesticides, cysts, bacteria and viruses Salts (desalination)

<u>5.1.4. Natural treatment technologies</u>

Natural treatment systems include artificial or constructed wetlands (reed beds, lagoons or ponds) which are a complex collection of water, soils, microbes, plants, organic debris, and invertebrates. Greywater is commonly treated by natural systems in areas without a public sewer system. Fittschen and Niemczynowicsz (1997) reported a 100 PE greywater treatment scheme in Sweden, which included a sedimentation tank, a reed bed and sand filter followed by an artificial pond. *Phragmites communis* were planted on an area of about 600 m^2 with depth of 0.6 m to allow a residence time of 4 days.

Subsurface wetlands are a proven technology to remove organic matter and suspended solids from wastewater. In subsurface flow wetlands, wastewater is treated in horizontal or vertical (Figure 13) flow reed beds where the water is below the surface of a gravel bed to minimise undesired insect breeding and odour formation. The soil typically has a high permeability and contains gravel and coarse sand. Some flora/plants, which are utilized in these wetlands, have bactericidal properties and are able to treat some chemical pollutants. Common plants used include *phragmites, Bauma, water hyacinth (Eichhornia crassipes), Typha* and *schoenoplectus.*

Subsurface wetlands are typically applied in wastewater treatment systems where there is a relatively consistent influent flow rate. In comparison, surface wetlands used to treat stormwater flows must be able to cope with variations in flows as a result of rainfall patterns. Subsurface flow wetlands provide a low cost, very low energy, natural treatment system. As the flow percolates through the wetland, biological oxygen demand (BOD) and total suspended solids (TSS) are predominately reduced by biological decomposition.

Waste treatment levels, seasonal temperature variation and flora characteristics determine the size of the pond and infiltration areas. Infiltration areas vary in size from 0.7 m^2 (Green and Upton, 1995) to 8 m^2 (Bucksteeg, 1990) per person served by the facility and depend on the wastewater characteristics and the targeted effluent quality. Odour formation can result from poor oxygenation, rather than organic overload, which then has an impact on ammonia concentration. Odour problems can generally be ameliorated through improved aeration, light and temperature.

Advantages include inexpensive, energy-efficient, and chemicals not required for treatment while disadvantages include must be located outdoors, may require very regular maintenance, has a large ecological footprint, and is climate-dependent.

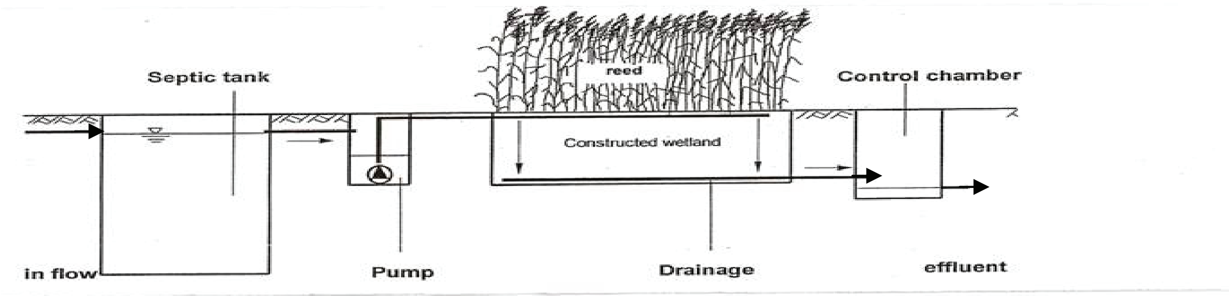


Figure 13. Cross-section of a reed bed (Bart Senekal Inc, 2003)

5.2. Database of locally available greywater units for toilet flushing

A list of locally available greywater treatment unit manufacturers / suppliers whose units have been advertised as capable of treating grey/waste water for toilet flushing is presented in Appendix B1. Initial information on these plants was obtained from several sources including the following:

- Guidebook for the selection of small water treatment systems for potable water supply to small communities. WRC report no TT 319/07. (Chris Swartz *et al*., 2007);
- Evaluation of sewage treatment package plants for rural, peri-urban and community use. WRC report no. 1539/1/06. (Gaydon *et al*., 2006).
- The Global Directory for Environmental Technology (The Green Pages, 2009).

Detailed information on each of the package plants was obtained by directly requesting specific information from individual manufacturers/suppliers using certain performance criteria (discussed in the next session). Manufacturers/suppliers were typically contacted as follows:

1. A letter was drafted explaining the project and requesting plant specific information using a questionnaire (Appendix B2);
2. The letter and questionnaire were then faxed or emailed to the relevant contact personnel and telephone calls were made to confirm receipt and request responses. Thirty manufacturers were originally compiled, 25 were sent the letter and questionnaire and 10 responded.

5.3. Development of the framework for the evaluation of greywater units

5.3.1. Performance criteria for evaluating treatment units

The performance criteria used in the framework for the evaluation of the 10 package plants in order to select the most appropriate for the pilot sites were obtained from the following standard/guideline documents:

1. The revision of the National Water Act of 1998, 37(1) (DWAF, 2004a);
2. Murphy (2006);
3. The Official Journal of the European Union (2005);
4. Landcom's WSUD strategy (2003);
5. The USEPA Code of Practice for Wastewater Treatment Systems for Single Houses (PE < 10) (USEPA, 2007);
6. National and international wastewater quality guidelines in Surendran & Wheatley (1998)

5.3.2. The framework, weights, scores and scoring range

The framework for evaluating package plants for greywater/wastewater recycling for toilet flushing using the 3 key issues are shown in Tables 18, 19 and 20. Specific references for the evaluation of each criterion are included on the framework. The framework was developed using the Triple Bottom Line, TBL approach which provides a robust structure for evaluating alternatives. It is designed to provide decision-makers with a framework to understand the costs, benefits, impacts, etc. of alternatives across a spectrum of social, economic and environmental attributes. In this way, a more balanced view of alternatives is created rather than one that relies on only quantifiable factors. It also allows decision makers to vary or weigh criteria to discover those criteria that have the greatest influence on differentiating alternatives (CRD, 2007).

The TBL approach typically involves the following (Ilemobade *et al*., 2009b): (i) *goals* to be achieved; (ii) *criteria* which determine whether the goals are achieved; (iii) evaluation *questions/statement* by which each criteria is measured, (iv) a range of *scores* for measuring each criterion; and (v) weights for each criterion.

The weights employed in the framework are based on the average weights obtained by Ilemobade *et al*. (2009a) based on decision-makers' ranking of key issues to be considered when assessing the feasibility of implementing a dual water reticulation system in South Africa (Table 17). The three key issues highlighted by decision-makers were technical/engineering, public health and safety, and economics and these key issues represent the goals to be achieved when selecting a greywater treatment unit from amongst a selection of units.

Table 17. Decision-makers' ranking of key issues to be considered when assessing the feasibility of implementing a dual water reticulation system in South Africa

(Ilemobade *et al*., 2009a)

Key issues	Decision-makers ranking	Weight
Technical / Engineering	1	1.00
Public health and safety	2	1.13
Economics	3	1.26
Social acceptance	4	1.93
Legislation	5	2.13
Organisational capacity	6	2.40
Public education	7	2.43

Within the framework, the process of evaluating each greywater treatment units is as follows:

i. Each criteria within each key issue is scored using a scale of 0 (low), 1(moderate) and 2(high);
ii. The score for each criterion is multiplied by its weight to obtain a weighted real score (equation 5.1):

$$Weighted\_Real\_Score = ScorexWeight \quad \text{....5.1}$$

iii. For each key issue, the weighted mean of the real scores is calculated (equation 5.2):

$$Weighted\_Mean\_of\_Real\_Scores = \frac{Weighted\_Real\_Score}{Number\_of\_items\_in\_the\_key\_issue} \quad \text{....5.2}$$

iv. For the framework, the aggregate of the weighted mean of the real scores is calculated (equation 5.3). This aggregate ranges between 0.00 (most preferred package plant) and 6.78 (the least preferred package plant):

$$Aggregate\_of\_Weighted\_Means = \sum_{i=1}^{No\_of\_key\_issues} Weighted\_Mean\_of\_Real\_Scores \ldots 5.3$$

Table 18. Framework for evaluating greywater treatment units for toilet flushing (the Technical key issue)

CRITERIA	SCORES			WEIGHT	LITERATURE REFERENCE
	0	1	2		
TECHNICAL KEY ISSUE					
Treatment Technology	Secondary and tertiary treatment	Primary Treatment only/ no info		1.00	Li *et al.*, 2009
Pre-treatment and storage	Yes	No / no info		1.00	Li *et al.*, 2009
Disinfection	Yes	No / no info		1.00	Li *et al.*, 2009
Operating range (kl/d)	0.5-100 (Covers a wide range 4-500 PE)	0.5-10 (household)	10-100(clustered development<=500 PE) / no info	1.00	Landcom's WSUD strategy (2003)
Footprint (m²)	1.2-124 (Covers a wide range 4-500 PE)	1.2 to 3 (household)	3-124(clustered development<=500 PE) / no info	1.00	Landcom's WSUD strategy (2003)
Life cycle (years)	>= 25	25 to 15	< 15 / no info	1.00	USEPA (2007) Code of Practice for single houses and WRC report No 1539/1/06
Level of operator skill	Low	Moderate	High / no info	1.00	USEPA (2007) Code of Practice for single houses and WRC report No 1539/1/06
Ease to upgrade	Yes	No / no info		1.00	USEPA (2007) Code of Practice for single houses and WRC report No 1539/1/06
WEIGHTED MEAN OF REAL SCORES					

Table 19. Framework for evaluating greywater treatment units for toilet flushing (the Economic key issue)

CRITERIA	SCORES			WEIGHT	LITERATURE REFERENCE
	0	1	2		
ECONOMIC KEY ISSUE					
Cost (Rand)	< 50 000	50 000 -100 000	> 100 000 / no info	1.26	Landcom's WSUD strategy (2003)
Operating cost (Rand/year)	< 5000	5000 to 10 000	>10 000 / no info	1.26	Landcom's WSUD strategy (2003)
				WEIGHTED MEAN OF REAL SCORES	

Table 20. Framework for evaluating greywater treatment units for toilet flushing (the Public health and safety key issue)

CRITERIA	SCORES			WEIGHT	LITERATURE REFERENCE
	0	1	2		
PUBLIC HEALTH AND SAFETY (I.E. WATER QUALITY) KEY ISSUE					
BOD (mg/l)	<= 10	> 10 / no info		1.13	USEPA (2007) Standard
COD (mg/l)	< 75	> 75 / no info		1.13	DWAF, 2004a; Prathapar *et al.* (2006)
Total Suspended Solids (mg/l)	< 30	> 30 / no info		1.13	German Standard
Turbidity (NTU)	<= 2	> 2 / no info		1.13	USEPA (2007) Standard
Free chlorine (mg/l)	>1	<=1/ no info		1.13	USEPA (2007) Standard
PH	6 to 9	no info		1.13	DWAF, 2004a; USEPA (2007) Standard
Total Coliform	Non detected	Detected / no info		1.13	USEPA (2007) Standard
E. coli	Non detected	Detected / no info		1.13	DWAF, 2004a; USEPA (2007) Standard
				WEIGHTED MEAN OF REAL SCORES	
				AGGREGATE OF THE WEIGHTED MEANS	

5.4. Results and discussion on the application of the framework

Table 21 represents the results of the evaluation of the 10 greywater treatment units for which detailed information was available. The identities of the different manufacturers / suppliers whose units were evaluated, are not mentioned for the sake of confidentiality. Most manufacturers / suppliers responded by sending leaflets of their plants with little information on different criteria, e.g. treated effluent quality.

Hence, where no responses were given to specific criteria, the highest score was assigned.

Technical

The Technical key issue refers to the treatment technology employed by the package plant.

- The C, A and G units scored the lowest in this key issue. Most of their treatment is biological followed by disinfection;
- An advantage of the C and A units is that they cover a wide operating range, i.e. from the household level to clustered developments
- The G unit can only treat effluent produced by 35 people;

Economics

Cost determines if a package plant will be affordable. Cost is directly related to the treatment technology employed and hence, the more complex the treatment process, the more expensive the treatment unit will likely be. Actual costs were obtained from A, B, C, F, H, and D;

- The B, A, and D units scored the lowest in this key issue;
- Costs of operating the above units (e.g. disinfection and electricity) range depending on local circumstances.

Table 21. Results of the evaluation of 10 grey/waste water treatment units

CRITERIA	WEIGHT	UNIT A	UNIT B	UNIT C	UNIT D	UNIT E	UNIT F	UNIT G	UNIT H	UNIT I	UNIT J
		REAL SCORE x WEIGHT									
TECHNICAL											
Technology	1.00	0	1	0	0	1	0	0	1	0	2
storage	1.00	1	1	0	0	1	0	0	1	0	2
Disinfection	1.00	0	0	0	0	1	0	0	0	0	2
Operating range (kl/d)	1.00	0	1	0	2	1	1	1	1	2	2
Footprint (m^2)	1.00	1	1	0	2	1	2	2	2	2	2
Life cycle (years)	1.00	1	1	1	2	2	2	0	2	2	2
Level of operator skill	1.00	0	0	0	0	0	0	0	2	2	2
Ease to upgrade	1.00	0	0	0	1	0	0	0	2	2	2
	WEIGHTED MEAN	**0.38**	**0.63**	**0.13**	**0.88**	**0.88**	**0.63**	**0.38**	**1.38**	**1.25**	**2.00**
ECONOMICS											
Cost (Rand)	1.26	0	0	1.26	0	0	1.26	2.52	1.26	2.52	2.52
Operating cost (Rand/year)	1.26	0	0	1.26	0	1.26	2.52	2.52	2.52	2.52	2.52
	WEIGHTED MEAN	**0.00**	**0.00**	**1.26**	**0.00**	**0.63**	**1.89**	**2.52**	**1.89**	**2.52**	**2.52**
PUBLIC HEALTH AND SAFETY (i.e. WATER QUALITY)											
BOD (mg/l)	1.13	1.13	1.13	0	1.13	1.13	1.13	1.13	1.13	1.13	2.26
COD (mg/l)	1.13	0	1.13	0	1.13	1.13	0	1.13	1.13	1.13	2.26
Solids (mg/l)	1.13	0	1.13	0	1.13	1.13	0	1.13	1.13	1.13	2.26
Turbidity (NTU)	1.13	1.13	1.13	0	1.13	0	0	1.13	1.13	1.13	2.26
Free chlorine (mg/l)	1.13	1.13	1.13	0	1.13	1.13	0	1.13	1.13	1.13	2.26
PH	1.13	0	0	0	1.13	0	0	1.13	1.13	1.13	2.26
Total Coliform	1.13	0	0	0	1.13	0	0	1.13	0	0	2.26
E.Coli	1.13	0	0	0	1.13	0	0	1.13	0	0	2.26
	WEIGHTED MEAN	**0.42**	**0.71**	**0.00**	**1.13**	**0.57**	**0.14**	**1.13**	**0.85**	**0.85**	**2.26**
	AGGREGATE OF THE WEIGHTED MEANS	**0.80**	**1.33**	**1.39**	**2.01**	**2.07**	**2.66**	**4.03**	**4.11**	**4.62**	**6.78**

SCORE RANGE 0.00 3.39 6.78

Public health and safety (i.e. water quality)

Public health and safety was evaluated using the quality of the treated effluent released from each package plant. Information from several manufacturers/suppliers was lacking in this regard. This may be because there is limited information regarding most package plants in this regard or for some reason, manufacturers/suppliers were cautious releasing such information.

- C, F and A scored the lowest in this key issue
- Unit F does not specifically mention that its plant's treated effluent can be used for toilet flushing. However, their effluent may be used for toilet flushing as quality parameters are within DWAF (2004a) and international guidelines

Selection of appropriate greywater treatment unit

There is no simple formula for selecting a greywater unit because of the trade-offs that need to be made between the technical, economics and public health and safety key issues:

- Units A, B and C achieved the lowest scores in the framework and were therefore, the most favoured for the pilot project. Certain points of note were:

a. Unit C:
   - is sensitive to influent quality. Hence, a drastic change in influent quality would negatively affect effluent quality;
   - is aesthetic, compact, and an automated system which produces effluent that can also be used for irrigation;
   - is three times the cost of Units A and B;
   - was recommended by users of this installation.

b. Unit B:
   - uses a filter/sieve with Bromine disinfection cubes, The tank is sized to ensure that treated greywater is not stored in the pump chambers for more than 24 hours – thereby reducing the possibility of pathogen growth;
   - has the lowest cost amongst the three;
   - employs indigenous technology;
   - was recommended by previous users.

c. Unit A:
   - is the plant unit with the lowest score on the framework;

- employs indigenous technology;
- water quality parameters were evaluated based on information provided by the manufacturer/supplier;
- was recommended by previous users.

Manufacturers / suppliers of Units A and B were approached to provide quotes for the installation of the greywater units at the proposed sites (next chapter). Unit B provided the most suitable quotes and guarantees and was thus awarded the contract to install the greywater reuse units for toilet flushing at the pilot sites.

6. IMPLEMENTATION OF THE PILOT GREYWATER REUSE SYSTEMS FOR TOILET FLUSHING

This chapter introduces the sites where the pilot systems were located and documents some aspects of the implementation and monitoring of the pilot greywater reuse systems for toilet flushing. Other aspects which are reported in detail are documented in the subsequent chapters of the report. The implementation of the greywater reuse systems at only two sites was decided by the available project funds and the results of the preliminary perception surveys which were carried out in 2008 (details in Chapter 6).

6.1. Location of the pilot systems

6.1.1. The School of Civil and Environmental Engineering, WITS

The building (Figure 14) housing the School of Civil and Environmental Engineering at the University of the Witwatersrand (WITS) currently houses the first greywater reuse system. On a peak working day of the 2011 academic calendar, the building typically houses about 36 staff (academic and support services) and approximately 450 students. There are 7 bathrooms housing a total of 12 Toilets, 1 shower and 12 hand basins within the building. Two male and 3 female toilets (mostly used by students) are located in 2 bathrooms at the south side of the building while 5 male and 2 female toilets (mostly used by staff) are located in 5 bathrooms at the north side of the building. Except for 2 north side female bathrooms which house only 1 hand basin each, the other bathrooms house 2 hand basins each. WITS is representative of a typical high-density educational (non-residential) water user.

Figure 14. View of the (Left) south side and (Right) east side (main entrance) of the School of Civil and Environmental Engineering, WITS

A key driver for the implementation of the first pilot greywater system within WITS was the excitement expressed by most staff and students in the 1st perception survey carried out in 2008 (section 6.2.1) concerning greywater reuse for toilet flushing. There were several challenges however encountered prior to and during the installation of the greywater reuse system for toilet flushing within the building and these included:

i. outdated drawings of the different services making it difficult to determine exactly where different services were located within the building. Hence, most building reconstructions were carried out with outmost care resulting in longer periods of time undertaking certain tasks;
ii. retrofitting the greywater system in the 70 year old building which resulted in the following difficulties
    a. finding available space for the greywater unit;
    b. determining the optimal location for the system given the constraints of the available locations;
    c. the presence of permanent structures which obstructed the preferred path of the unit and hence the need to move large items; and
    d. a major source of greywater (i.e. the shower) is located on the ground floor with the drainage pipe embedded into the ground floor slab.

Since greywater could only be collected from hand basins, the estimated greywater volumes generated and potential reuse for toilet flushing per day are calculated below:

i. there is approximately 1 toilet flush per individual per working day within the building ≈ about 486 flushes;
ii. for each flush, about 0.5 litres of potable water is used for hand washing in the basin ≈ 243 litres of greywater generated per day;
iii. 486 flushes per working day for the 12 toilets ≈ 41 flushes per toilet per day ≈ 246 litres per cistern (average cistern size of 6 litres) per day; and
iv. the estimate above therefore adequately caters for greywater reuse for toilet flushing in only 1 toilet.

It was therefore anticipated that the greywater generated would often be insufficient to cater for toilet flushing in 2 toilets on a typical working day.

6.1.2. Unit 51A, Student Town, UJ Kingsway campus

Similar to WITS, a key driver for the implementation of the second pilot greywater system within the University of Johannesburg was the excitement expressed by the UJ leadership, residents of Student Town and residents of Unit 51A (section 6.2.1) concerning greywater reuse for toilet flushing. Unit 51A, Student Town, University of Johannesburg Kingsway campus (UJ) is a 16 female residence and one of several units within Student Town. The layout of Student Town which provided the potential for isolating a unit, made it an ideal site for the implementation of one of the pilot greywater units. The ground floor and 1st floor of each unit has 8 rooms – each allocated to 1 resident. Ablution and cooking facilities are communal – there are 2 toilets, 1 shower, 1 bath tub and 3 hand basins on each floor. Unit 51A has the wastewater and rainwater drainage pipes located at the rear of the building, outside the walls (Figure 15) and potable water is supplied to the unit via 1 pipe. Electricity consumption within the unit is measured from 1 meter box.

Figure 15. The rear of Unit 51A, Student Town, University of Johannesburg

Some advantages in implementing the 2nd pilot greywater reuse system at the unit at UJ included:

i. the ease to retrofit the greywater reuse system due to the central location of the greywater drainage pipes on the outside of the building;
ii. the ease to harvest rainwater (roof gutters and downpipes were already installed) to supplement greywater; and
iii. the potentially large quantities of greywater that may be collected for toilet flushing from the 2 showers and 2 bath tubs within the unit.

Estimated greywater volumes generated per day and anticipated reuse were calculated as follows:

i. estimated greywater volumes generated from showers and baths at about 50 litres per student ≈ 800 litres per day;
ii. estimated greywater volumes required for toilet flushing @ 4 flushes per student per day (see section 6.3.2) using a 10 litre cistern ≈ 640 litres per day;
iii. hence, per day, it was estimated that there would be sufficient greywater for flushing the 4 toilets within the unit

6.2. Implementation of the pilot systems

<u>6.2.1. Implementation of the pilot greywater reuse system at WITS</u>

Unit B emerged from Section 4.4. as the preferred greywater reuse unit for installation at both sites. After lengthy consultations (due to the fact that the WITS building was not originally intended for greywater reuse and thus, arriving at a mutually satisfactory solution was difficult) and a lengthy period of registration and administration with the university, installation of the greywater reuse system commenced on the 23rd of November 2009. A schematic of the initial greywater system and pictures are shown in Figures 16 and 17 respectively.

In the initial Unit B system, greywater was collected from 12 bathroom hand basins and 2 laboratory hand basins within the building[1]. The greywater then passed through two 2 mm sieves[2] in series (Figure 17) (which are housed within a cylindrical pipe[3]) and disinfected using 200 g Sanni Tabs[4a] (chlorine + bromine tablets) (Figure 17) which were inserted into the sieves once a week. The greywater was then stored within a 200 litre greywater tank[5] which houses 2 submersible pumps (each pump was connected to a toilet – a male toilet on the ground floor and a female toilet (Figure 17) on the first floor). When pressed, the bell switch[6] (Figure 16 and 17), which is attached to the wall close to the toilet cistern, activates the pump it is connected to and conveys the greywater into the toilet bowl[7] for flushing. A second tank[8], situated close to the greywater storage tank[5], stores municipal water and provides a back-up water supply to the greywater tank when greywater drops below a prescribed level. An overflow pipe connected to the tank conveys excess greywater to the sewer[13a].

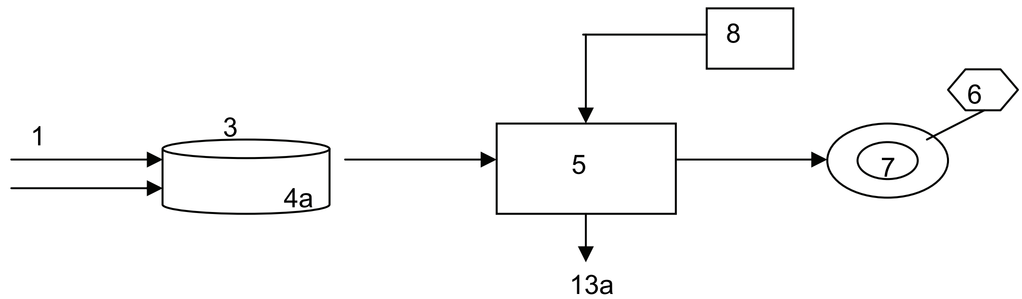


Figure 16. Schematic of the initial greywater system for toilet flushing at WITS

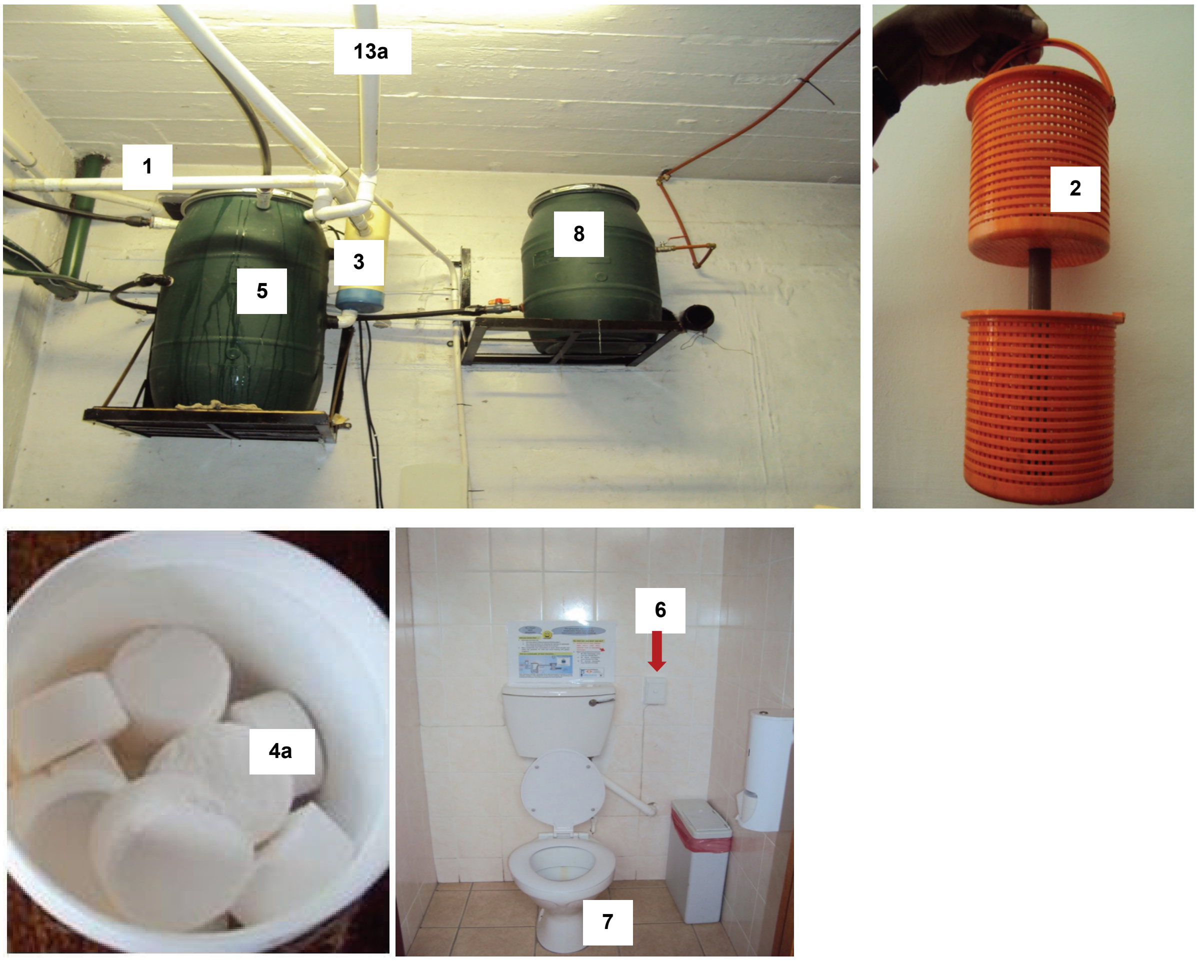


Figure 17. (Top left) The initial Unit B greywater reuse system. (Top right) The 2 mm sieves that filter the greywater. (Bottom left) Samples of the 200 g Sanni Tabs. (Bottom right) The female toilet connected to the greywater system

Prior to, during and after installation of the initial system, certain issues drove the need for the initial greywater reuse system to be modified. These included:

i. blue or green cistern blocks[4b] (Figure 18) were inserted into the sieves weekly in order to dye the greywater to make it aesthetic for users and to distinguish it from potable water;

Figure 18. Cistern blocks used to colour the greywater

ii. an additional back-up was added to the system (Figure 19) – the toilet cistern[9] which previously used municipal potable water supply was not disconnected. It was simply turned off using a valve[10]. Hence, in the event of greywater supply failure, the municipal supply may be turned on at the valve and the toilet will revert to its former use;

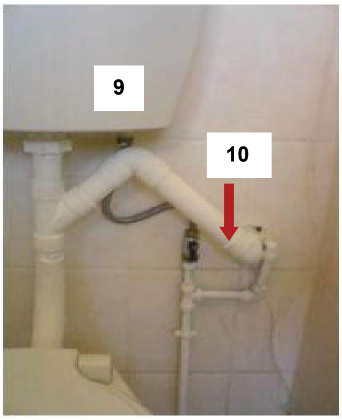


Figure 19. Additional backup measure in the event of greywater supply failure

iii. unknowingly, the laboratory basins were used for washing dishes and disposing cleaning fluids. This unfortunately led to the introduction of foods, cleaning chemicals, dirt, fats and oils within the sieves (Figure 20 -left) and greywater tank and resulted in unpleasant greywater odours and colour during the first few weeks of operation. When this problem was identified, posters were placed near the laboratory basins and an awareness session was held within the school. In addition, strainers were installed as a first barrier at the basin to prevent food and other materials from entering into the greywater system. Initially, these interventions made a significant difference to the physical quality (colour and smell) of the greywater (Figure 20 – left and centre). However over time, foods, fats, etc. continually entered into the greywater system and consequently, all the laboratory basins were disconnected from the greywater system. This made a significant difference to the quality of the greywater (see Figure 20 – right).

Figure 20. The sieves a few days before the awareness session (Left); after the awareness session (Centre); and after disconnecting the laboratory basins (Right)

iv. the need to improve the disinfection of the greywater through the installation of inline chlorine capsules[11] on the greywater collection pipes (Figure 21);

Figure 21. Inline chlorinators installed to improve disinfection of the greywater

v. the creation of a diversion[12] (Figure 22) to allow the greywater system to be shut down during major maintenance actions or university holidays. The diversion conveys the greywater to the sewer without it passing through the greywater system and thus prevents greywater retention in the tank.
vi. the creation of an additional overflow pipe[13b] (Figure 22) to the sewer in the event that a blockage occurred in the sieves during operation.
vii. the installation of meters to measure the electricity consumption of the pumps.

Based on the above, the initial Unit B greywater reuse system (Figure 16) was modified to that shown in Figure 22.

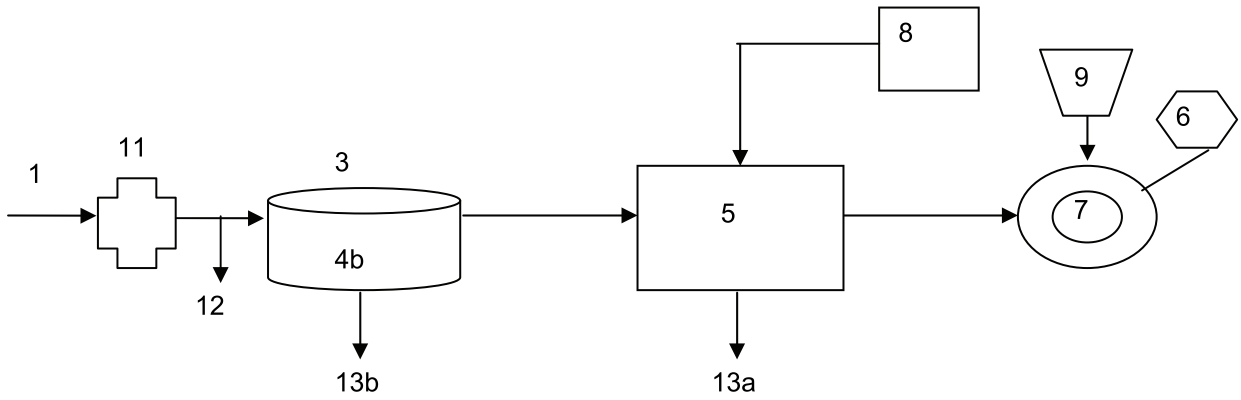


Figure 22. The modified and current schematic of the greywater reuse system for toilet flushing at WITS

6.2.2. Implementation of the pilot greywater reuse system at UJ

The installation of the greywater reuse system at UJ (Figure 23) commenced in April 2010 and was similar to the system installed at WITS, but for the following differences:

- Initially, greywater was sourced from the 2 showers, 2 baths and 6 hand basins within the unit. Subsequently, to avoid food, grease, etc. contamination as experienced at WITS, the hand basins were disconnected;
- A rainwater harvesting system was installed as the primary water supply backup to the greywater tank. The secondary backup supply from the municipal potable water supply system was at 2 points – a valve connected to the toilet cisterns as was done at WITS and regulated supply into the rainwater tank[14];
- The greywater tanks, collection pipes and sieves were buried in the soil within the enclosure behind the unit to allow for the collection of greywater from the ground floor bath and shower;

The schematic of the current greywater system at UJ is shown below.

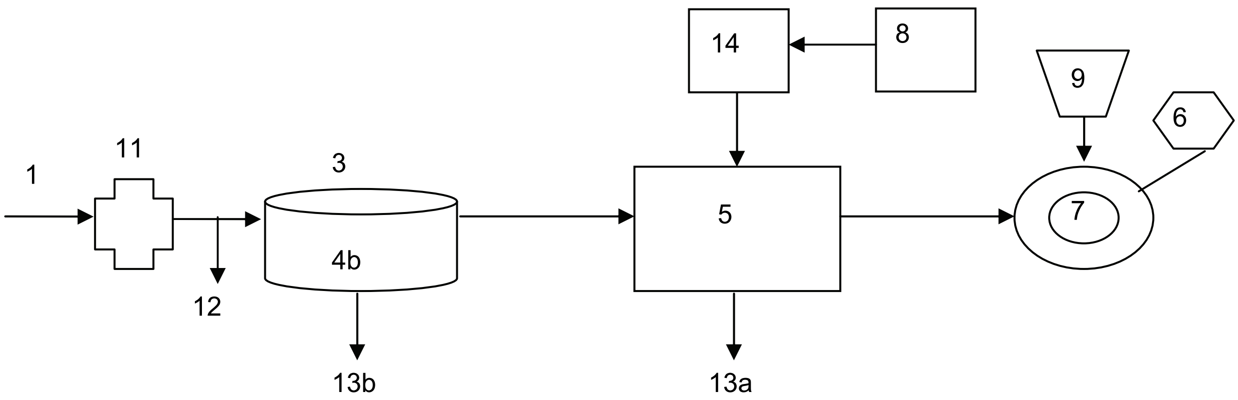


Figure 23. Schematic of the current greywater system for toilet flushing at UJ

[1]*Greywater collection from 2 bath tubs and 2 showers within the unit;*

[3]*The cylindrical pipe housing the two 2 mm sieves in series;*

[4b]*Cistern blocks inserted weekly into the sieves to dye the greywater;*

[5]*The 200 litre greywater tank;*

[6]*The bell switch;*

[7]*The toilet bowl which flushes with disinfected greywater;*

[8]*Potable water backup to the rainwater tank;*

[9]*The greywater toilet cistern which is retained to ensure the toilet can revert to potable water flush if there is greywater supply failure;*

[11]*The chlorinators which provide disinfection to the raw greywater;*

[12]*The diversion to allow the greywater system to be maintained or shut down during university holidays;*

[13a]*An overflow pipe from the greywater tank to the sewer;*

[13a]*An overflow pipe from the filter to the sewer;*

[14]*A rainwater harvesting system (filters, pipes and tank) providing primary backup water supply to the greywater tank.*

7. PERCEPTIONS, AWARENESS AND EDUCATION REGARDING GREYWATER REUSE FOR TOILET FLUSHING WITHIN UCT, WITS AND UJ

Successes in the implementation of dual water reticulation systems have been hinged on several factors including the positive attitudes of communities towards reuse and community participation in the planning and implementation of reuse projects (Po *et al.,* 2003). Several reuse schemes in the United States of America (e.g. the San Diego water repurification project and the San Gabriel Valley groundwater recharge project) failed primarily due to negative attitudes and/or lack of community participation. Some projects were redesigned in the United States of America (i.e. the California Bay water recycling programme) and Australia after strong opposition from local communities (Po *et al.,* 2003). Several factors, recognised to affect public attitudes to reuse schemes include perceived risks to health and degree of human contact (Kantanoleon *et al*., 2007; Hurlimann and McKay, 2007; Friedler *et al*., 2006; Po *et al*., 2003; and Hartley, 2003). Table 22 shows the levels of opposition to reclaimed water reuse from different surveys carried out in the past.

Table 22. Opposition from respondents (%) to specific uses of recycled water in different surveys
(Po *et al*., 2003)

Reclamation Purposes	ARCWIS (2002) N=665 %	Sydney Water (1999) N=900 %	Lohman & Miliken (1985)* N =403 %	Miliken & Lohman (1993)* N = 399 %	Bruvold (1981)* N =140 %	Olson et al. (1979)* N=244 %	Stone & Kahle (1994)* N=1000 %	Bruvold (1972)* N=972 %
Drinking	74	69	67	63	58	54	46	56
Cooking at Home	-	62	55	55	-	52	38	55
Bathing at Home	52	43	38	40	-	37	22	37
Swimming	-	-	-	-	-	25	20	24
Washing Clothes	30	22	30	24	-	19	-	23
Irrigation of vegetable crops	-	-	9	7	21	15	-	14
Home toilet flushing	4	4	4	3	-	7	5	23
Home lawn/garden irrigation	4	3	3	1	5	6	6	3
Irrigation of recreation parks	-	3	-	-	4	5	-	3
Golf course irrigation	2	-	-	-	4	3	5	2

While the public may be willing to accept greywater reuse, water authorities/regulators are usually more cautious. Two factors stand out for this: the potential public health risks involved in reuse and the costs of treatment. Associated with public health is the level of public awareness about reuse, and the monitoring and mitigation systems that should be in the event of system failure. In terms of cost, it is estimated that the costs incurred by a municipal authority to treat and reticulate treated non-potable water far exceeds the costs incurred by individual households who install simple devices to divert untreated greywater onto their gardens.

This chapter summarises the processes and results from perception surveys carried out to monitor evolving perceptions of potential and actual beneficiaries of the pilot greywater reuse systems for toilet flushing. While perceptions were being monitored, awareness/education campaigns were also carried out and this chapter also documents the methods employed to achieve this process and some observed results.

7.1. Perception survey methodology

7.1.1. Objectives of the perception surveys

The perception surveys undertaken in this study were aimed at determining:

i. potential and actual respondents' perceptions to reusing greywater for toilet/urinal flushing prior to implementation. Results from these surveys assisted in identifying the preferred locations for the pilot systems to be implemented, and the key issues that needed to be addressed before, during and after implementation;
ii. actual respondents' perceptions to reusing greywater for toilet/urinal flushing immediately after implementation of the system; and
iii. actual respondents' assessment of the pilot systems after extended use of the greywater system for toilet/urinal flushing.

7.1.2. Structure of the perception survey questionnaires

Po *et al*. (2003) recommend some factors that may influence the acceptance of a water reuse project. In order to garner the relevant perceptions of respondents towards greywater reuse for toilet flushing, the questionnaires were developed using several of these factors, i.e.:

i. socio-demographics;
ii. disgust or “yuck”;
iii. perceptions of risk associated with using recycled water;
iv. the specific uses of recycled water;
v. the sources of water to be recycled;
vi. the issue of choice;
vii. trust and knowledge;
viii. attitudes towards the environment;
ix. environmental justice; and
x. the cost of recycled water;

Three (3) questionnaires were developed (see Appendices B1, B2 and B3):

i. Questionnaire 1 solicits respondents’ perceptions to reusing greywater for toilet/urinal flushing prior to and immediately after greywater system implementation;
ii. Questionnaire 2 follows up on some items in Questionnaire 1 and solicits respondents’ perceptions regarding their levels of satisfaction with the system about 3 months after implementation;
iii. Questionnaire 3 follows up on some items in Questionnaires 1 and 2 and requests respondents’ to assess the system about 7 months after implementation.

The first section of each questionnaire has a number of statements requiring respondents to select the option that is most applicable to them using the 5-point scale provided, i.e. *Strongly agree*, *Agree*, *Neutral*, *Disagree*, and *Strongly disagree*. The next section is open-ended and requests respondents to either list any reasons (personal, cultural, religious or otherwise) why they may not use treated greywater for toilet/urinal flushing or garden watering, or make comments. The third section solicits socio-demographic data, e.g. age, status at university, etc.

7.1.3. Administration of the questionnaires

Typically, each session with the respondents started with the administration of the relevant questionnaires in hard copy form. This was done in order to garner the perceptions of respondents prior to any awareness was carried out. In this form, the initial perceptions of respondents were not tainted by the information subsequently presented. Only after respondents had completed the filling of the questionnaires did the project team proceed with providing information, etc.

7.1.4. Background and profile of respondents

The questionnaires were administered to the following respondents at the indicated times (Table 23):

Table 23. Summarised profile of respondents

Year	Questionnaire	Respondents	Number
2008	Questionnaire 1 (prior to the implementation of the greywater system). Results from these surveys assisted in identifying the preferred locations for the pilot systems to be implemented, and the key issues that needed to be addressed before, during and after implementation.	WITS (students and staff at the School of Civil and Environmental Engineering)	253
		UJ (a random sample of students)	103
		UCT (a random sample of students from 3 university residences – University House, Varietas and Forest Hill)	104
2009	Questionnaire 1 (prior to the implementation of the greywater system)	UJ (Female students residing at the proposed university residence, Unit 51A, Student Town, and some members of the Student Town council)	13
2010	Questionnaire 1 (immediately after the implementation of the greywater system)	UJ (beneficiaries of the greywater reuse system)	14
2010	Questionnaire 1 (immediately after the implementation of the greywater system)	WITS (a random sample of undergraduate students at the School of Civil and Environmental Engineering)	139
2010	Questionnaire 2 (about 3 months after implementation of the greywater system)	WITS (a random sample of undergraduate students at the School of Civil and Environmental Engineering)	120
2010	Questionnaire 2 (about 3 months after implementation of the greywater system)	UJ (beneficiaries of the greywater reuse system)	13
2010	Questionnaire 3 (about 7 months after implementation of the greywater system)	WITS (a random sample of undergraduate students at the School of Civil and Environmental Engineering)	168
2010	Questionnaire 3 (about 7 months after implementation of the greywater system)	UJ (beneficiaries of the greywater reuse system)	15

7.2. Perception survey results

Respondents' perceptions for each questionnaire using several of the factors listed in Section 7.1.2. are shown below:

7.2.1. Location of the pilot greywater systems

Potential respondents at the universities of Cape Town, the Witwatersrand and Johannesburg were surveyed using the 1st questionnaire. Universities were proposed as potential locations for the pilot systems for logistical reasons – the researchers on the project were from the 3 universities and there was the perceived ease to obtain approval for, implement and monitor the systems due to the researchers' proximity to the systems.

As indicated, the questionnaires were administered for a number of reasons including assisting to identify the preferred locations for the pilot systems to be implemented. Relevant management at the University of Cape Town declined the offer to have a pilot system implemented on their campus due to other water saving interventions which had recently been carried out. The appropriate WITS (School of Civil and Environmental Engineering) and UJ (Vice-chancellor's office) managements were however elated about the implementation of the pilot systems at the locations described in section 5.1. After the 1st questionnaires were administered at Student Town in Unit 51A was selected as the preferred location.

7.2.2. Socio-demographics

Some demographic factors (Po *et al*., 2003) have been identified in reuse studies to be influential in public perception of water reuse. For example, McKay & Hurlimann (2003) predicted that the greatest opposition to water reuse schemes would be from people aged 50 years and over. As a result, they recommended education and information campaigns to target this specific age group. Some surveys in California and Colorado, USA (cited in Hartley, 2003) further indicated that "older" women tended to be less supportive of potable water reuse. In contrast, Jeffrey (2002) found no significant variation in public support for greywater reuse across gender, age or socio-economic groups. Sydney Water's (1999) study indicated differences in the responses of participants from different genders, levels of education, place of residence, and language spoken. No discernible differences were, however, found in the respondents from different age groups. In early potable reuse research in Australia (Hamilton and Greenfield, 1991), it was suggested that without prior exposure to negative reuse information, a person who had a higher level of education, was male and had no aversion to change, was more likely to accept potable reuse.

For the 2008 cohort of respondents, statistical analysis of the data generated from responses to the 12 statements in the first section of the 1st questionnaire produced three broad categories of responses: '*Comfort levels*', '*Concern levels*' and '*Other*' (see Table 24). The discussion below is based on the '*Comfort levels*' and '*Concern levels*' categories. The '*Other*' category did not statistically present any significant difference from the '*Comfort levels*' category and is hence omitted from the discussion.

Table 24. Socio-demographic response categories

CATEGORY: '*Comfort levels*'
Using treated greywater for toilet/urinal flushing or garden watering will have a positive impact on the environment
Using treated greywater for toilet/urinal flushing or garden watering will make our limited drinking water resources go further
I am comfortable using treated greywater for toilet/urinal flushing
I am comfortable using treated greywater originating from other buildings for toilet/urinal flushing or garden watering
I am comfortable for a dual water distribution system to be installed where I currently reside
I am comfortable for a dual water distribution system to be installed at the School building
If a dual water distribution system is installed at the School or my residence, I trust the relevant university authorities will ensure that the treated greywater used is safe for toilet/urinal flushing or garden watering
CATEGORY: '*Concern levels*'
I am concerned about people getting sick from using treated greywater for toilet/urinal flushing
I am concerned about people getting sick from using treated greywater for garden watering
Using treated greywater for toilet/urinal flushing or garden watering is disgusting
I will only be prepared to use treated greywater for toilet/urinal flushing or garden watering during a drought or water shortage
CATEGORY: '*Other*'
I am comfortable using treated greywater for garden watering

A summary of the socio-demographic responses garnered are listed below:

i. Age groups:

- In relation to '*Comfort levels*', the average response of the median of the '*15-21 yrs*' (1.8333) was slightly lower than that for the '*22 yrs and older*' (2.0000). This implies that 50% of the '*15-21 yrs*' were generally more comfortable about greywater reuse than the same percentage of the '*22 yrs and older*'. Comparing the 75th percentile for both groups however interprets otherwise.
- The degree of concern about greywater reuse expressed by the '*15-21 yrs*' (median of 2.5000)) was generally less than that for the '*22 yrs and older*' (median of 2.7500).

ii. Status:

- In relation to '*Comfort levels*', the average response of the median for the '*Undergrad*' (1.8571) was lower than that for the '*Other*' (2.1429). The '*Other*' represents postgraduate students, academics and support staff. The same applied while comparing the average response for the 75th percentile of both groups. An implication of these results is that the '*Undergrad*' group are in general, more comfortable about greywater reuse than the '*Other*'. Assuming the majority of the '*15-21 yrs*' are '*Undergrad*', the implication in the latter sentence correlates positively with the median results presented for the different age groups in (i) above.

iii. Living in university residence:

- In relation to '*Comfort levels*', the average response of the median for those living in university residence (2.0000) was higher than that for those not living in university residence (1.8000). The same applies while comparing the average response for the 75th percentile of both groups. An implication of these results is that those not living in university residence were in general, more comfortable about greywater reuse than those living in university residence.
- The implication stated in the above paragraph should result in those living in university residence being more concerned about greywater reuse than those not living in university residence. The analysis confirms this with the average response of the median of those living in university residence (2.7500) being higher than those not living in university residence (2.5000).

iv. Gender:

- In relation to '*Comfort levels*', the average responses of the median for '*Male*' and '*Female*' respondents were the same (1.8571). Also, there was a negligible difference in the average responses of the 75th percentile for the genders. This implies that in general, no difference in '*Comfort levels*' pertaining to greywater reuse exists between the genders.
- A marginal difference does however exist between the genders in terms of '*Concern levels*' – the average response of the median for '*Female*' (2.5000) was less than for the '*Male*' (2.7500). This implies females may be generally less concerned about greywater reuse than males.

v. Racial background:

- In relation to '*Comfort levels*', the '*White*' racial category seemed generally more comfortable (median value of 1.5000) about greywater reuse than the '*Other*' (representing Asian and Coloured) (median value of 2.0000) and '*Black*' (median value of 2.0000) racial categories.
- The '*Black*' racial category generally expressed more concern (median value of 3.0000) about greywater reuse than the '*Other*' (median value of 2.7500) and '*White*' (median value of 2.0000) racial categories.

7.2.3. Disgust or "yuck"

There was overwhelming disagreement to the statement "*Using treated greywater for toilet/urinal flushing or garden watering is disgusting*" from the respondents (Table 25). Of particular note is the significant increase in disagreement between the responses prior to and immediately after implementation. This could imply an overwhelming appreciation for the concept of greywater reuse for toilet/urinal flushing even after implementation when certain problems were experienced.

Table 25. Using treated greywater for toilet/urinal flushing or garden watering is disgusting

Scale	Prior to implementation of the greywater system				Immediately after implementation of the greywater system		About 3 months after implementation of the greywater system		About 7 months after implementation of the greywater system	
	WITS – 2008	UCT – 2008	UJ – 2008	UJ – 2009	WITS – 2010	UJ – 2010	WITS – 2010	UJ – 2010	WITS – 2010	UJ – 2010
Strongly agree	4.5%	4.0%	7.1%	16.00 %	1.5%	0.0%	-	-	-	-
Agree	7.3%	7.0%	11.1 %	15.00 %	5.2%	7.1%	-	-	-	-
Neutral	17.5%	18.0%	26.3 %	15.00 %	17.9%	28.6%	-	-	-	-
Disagree	40.2%	45.0%	40.4 %	46.00 %	33.6%	42.9%	-	-	-	-
Strongly disagree	30.5%	26.0%	15.2 %	8.00%	41.8%	21.4%	-	-	-	-

7.2.4. Perceptions of risk associated with reusing greywater

Perceptions of risk are often related to public health issues from reusing wastewater. People may perceive the reuse of greywater to be too risky because (i) the use of the water source is not natural (ii) it may be harmful to people (iii) there might be unknown future consequences (iv) their decision to use the water may be irreversible, and (v) that the quality and safety of the water is not within their control.

Responses to the statements "*I am concerned about people getting sick from using treated greywater for toilet/urinal flushing*" or "*I am concerned about my health when I use the toilet that flushes with greywater*" are shown in Table 26. On average, about 40% of respondents were concerned and about 40% unconcerned about greywater reuse for toilet flushing at WITS (2008 and 2010) and UCT (2008) prior to implementation. At UJ however, the percentages concerned, were much higher (average of 65% for 2008 and 2009) than at WITS and UCT. Immediately after implementation at UJ in 2010, the female residents recorded a percentage of concern (50%) which was significantly lower than the results for 2008 and 2009. This may have resulted from an increased level of confidence in the project team to ensure that the greywater system is safe and hygienic for their use. It must however be noted that the 2010 UJ cohort were not entirely the same residents as those in the unit in 2009 and 2008. Overall, the results underscore the need for the project team to ensure that the implemented greywater reuse systems are consistently hygienic.

Table 26. I am concerned about people getting sick from using treated greywater for toilet/urinal flushing

Scale	Prior to implementation of the greywater system				Immediately after implementation of the greywater system		About 3 months after implementation of the greywater system*		About 7 months after implementation of the greywater system	
	WITS – 2008	UCT – 2008	UJ – 2008	UJ – 2009	WITS – 2010	UJ – 2010	WITS – 2010	UJ – 2010	WITS – 2010	UJ – 2010
Strongly agree	14.3%	21.4%	35.0%	46.00 %	11.5%	7.1%	3.5%	30.8%	-	-
Agree	19.1%	19.4%	30.1%	18.00 %	28.8%	42.9%	17.4%	7.7%	-	-
Neutral	24.7%	17.5%	21.4%	27.00 %	15.1%	7.1%	16.5%	23.1%	-	-
Disagree	31.1%	35.0%	9.7%	9.00%	33.1%	21.4%	33.0%	23.1%	-	-
Strongly disagree	10.8%	6.8%	3.9%	0.00%	11.5%	21.4%	29.6%	15.4%	-	-

**The statement within the questionnaire reads "I am concerned about my health when I use the toilet that flushes with greywater"*

7.2.5. The specific uses of recycled water

In Table 27, a significant percentage of the WITS and UCT respondents were comfortable with using treated greywater for toilet flushing. For WITS, this trend is consistent prior to, immediately after and after about 3 months of use. At UJ however after 3 months of use, respondents responded less enthusiastically as they had done prior to and immediately after implementation. Certain operational issues at UJ (e.g. turbid greywater in the toilet bowl due to scum and the ring of scum that develops above the greywater level within the toilet bowl, unpleasant smells resulting from a lack of regular maintenance, and backflow problems from the 1st floor drains into the ground floor bath and shower) resulted in the dampened response to the statement.

In comparison to garden watering, most respondents preferred toilet flushing. Some comments made to this effect include:

- "*I am a bit reluctant to use it for garden watering as this might have a negative impact on the plants due to the chemicals used during processing. However for toilet flushing, I don't have a problem*"

- “*I am very concerned about using greywater for gardening because sometimes people drink water that they use to water plant, and it will be a little bit unsafe*”
- “*My only concerns are watering vegetable gardens ……and as far as the dual system goes for residential areas, that people and more especially children will be aware of the difference. That the greywater supply outside will be out of reach of children*”

Table 27. I am comfortable using treated greywater for toilet/urinal flushing

Scale	Prior to implementation of the greywater system				Immediately after implementation of the greywater system		About 3 months after implementation of the greywater system		About 3 months after implementation of the greywater system*	
	WITS – 2008	UCT – 2008	UJ – 2008	UJ – 2009	WITS – 2010	UJ – 2010	WITS – 2010	UJ – 2010	WITS – 2010	UJ – 2010
Strongly agree	61.1%	46.6%	34.0%	46.00%	56.1%	42.9%	56.3%	7.7%	50.8%	7.7%
Agree	24.6%	27.2%	34.0%	23.00%	30.9%	35.7%	31.9%	38.5%	36.4%	38.5%
Neutral	9.9%	20.4%	20.4%	31.00%	7.2%	21.4%	7.6%	30.8%	8.5%	30.8%
Disagree	3.2%	4.9%	5.8%	0.00%	5.0%	0.0%	4.2%	7.7%	3.4%	7.7%
Strongly disagree	1.2%	1.0%	5.8%	0.00%	0.7%	0.0%	0.0%	15.4%	0.8%	15.4%

**The statement within the questionnaire reads “I am comfortable using treated greywater originating from the hand basins (WITS) / bath tubs and showers (UJ) within the building”*

7.2.6. The sources of water to be recycled

Generally, people prefer reusing wastewater produced within their property as opposed to wastewater generated elsewhere. In Table 28, a larger proportion of WITS respondents are comfortable using greywater from other sources. In addition, a larger proportion of the WITS respondents, after 3 months of using the system, indicated comfort using greywater from the bathroom hand basins within the building. On the other hand, the positive response is less at UJ for the 2008 and 2009 respondents with a higher proportion of respondents (in comparison with WITS) strongly opposed to using greywater from other buildings. The same is also true for responses to the level of comfort with using greywater from the baths and showers within the unit after 3 months of using the system. Two factors are suspected at play in the UJ responses, i.e. the respondents were all female who are very conscious of personal hygiene and therefore cautious of technologies that may be seen to threaten their expected hygienic expectations; and wastewater reuse systems in peoples' residences are typically viewed with higher suspicion as a result of its proximity to residents' 'private space' in comparison to reuse systems in non-residential properties (this is confirmed in Section 7.2.2 iii).

Table 28. I am comfortable using treated greywater originating from other buildings for toilet/urinal flushing or garden watering

Scale	Prior to implementation of the greywater system				Immediately after implementation of the greywater system		About 3 months after implementation of the greywater system		About 7 months after implementation of the greywater system	
	WITS – 2008	UCT – 2008	UJ – 2008	UJ – 2009	WITS – 2010	UJ – 2010	WITS – 2010	UJ – 2010	WITS – 2010	UJ – 2010
Strongly agree	36.0%	24.0%	20.4%	15.00%	34.3%	28.6%	-	-	-	-
Agree	31.6%	31.7%	22.3%	23.00%	32.8%	28.6%	-	-	-	-
Neutral	22.5%	23.1%	22.3%	31.00%	17.9%	35.7%	-	-	-	-
Disagree	7.1%	11.5%	22.3%	31.00%	10.4%	7.1%	-	-	-	-
Strongly disagree	2.8%	9.6%	12.6%	0.00%	4.5%	0.0%	-	-	-	-

7.2.7. The issue of choice

In relation to choice (Table 29), a higher proportion of WITS respondents (53% in 2008, 73% in 2010 immediately after implementation and 61%, 3 months after implementation) and UCT were willing to consider greywater reuse for toilet/urinal flushing or garden watering without the compulsion of a water shortage. With neutral responses of about 10%, this skews the data in favour of WITS respondents willing to consider reuse. UJ respondents depict an initial high percentage of willing respondents prior to implementation (59% in 2009 and 64% in 2010) but this percentage decreases significantly to 39%, 3 months after implementation. This response increased the percentage of UJ 2010 respondents only willing to consider greywater reuse during a water shortage from 21% to 46%. Similar to the response to the statement "*I am comfortable using treated greywater for toilet/urinal flushing*" in Section 7.2.5., the UJ 2010, 3 months after implementation response, is likely attributed to the operational challenges/problems encountered at UJ (i.e. turbid greywater in the toilet bowl due to scum and the ring of scum that develops above the greywater level within the toilet bowl, unpleasant smells resulting from a lack of regular maintenance, and backflow problems from the 1st floor drains into the ground floor bath and shower);

Table 30 also displays similar trends to that discussed above – WITS respondents were generally comfortable for a greywater system to be installed where they resided and in the future, while the high percentages of comfort recorded for UJ prior to (63% in 2008 and 73% in 2009) and just after implementation (79%), decreases drastically to about 15%, 3 months after implementation. Many of the 2010 respondents, who were initially comfortable, became neutral 3 months after experiencing the system's operational problems.

Table 31 shows significant percentages of WITS respondents comfortable with the installation of a greywater system at the school building.

In general, the results indicate a higher percentage of comfort with installing a greywater reuse system for toilet flushing at a non-residential than residential premises.

Table 29. I will only be prepared to use treated greywater for toilet/urinal flushing or garden watering during a water shortage

Scale	Prior to implementation of the greywater system				Immediately after implementation of the greywater system		About 3 months after implementation of the greywater system		About 7 months after implementation of the greywater system	
	WITS – 2008	UCT – 2008	UJ – 2008	UJ – 2009	WITS – 2010	UJ – 2010	WITS – 2010	UJ – 2010	WITS – 2010	UJ – 2010
Strongly agree	7.6%	10.7%	11.7%	25.00%	5.0%	0.0%	10.3%	23.1%	-	-
Agree	16.1%	11.7%	23.3%	8.00%	10.8%	21.4%	12.8%	23.1%	-	-
Neutral	17.7%	21.4%	28.2%	8.00%	10.8%	14.3%	15.4%	15.4%	-	-
Disagree	34.9%	40.8%	28.2%	34.00%	42.4%	42.9%	38.5%	38.5%	-	-
Strongly disagree	23.7%	15.5%	8.7%	25.00%	30.9%	21.4%	23.1%	0.0%	-	-

Table 30. I am comfortable for a dual water distribution system to be installed where I currently reside

Scale	Prior to implementation of the greywater system				Immediately after implementation of the greywater system		About 3 months after implementation of the greywater system*		About 7 months after implementation of the greywater system	
	WITS – 2008	UCT – 2008	UJ – 2008	UJ – 2009	WITS – 2010	UJ – 2010	WITS – 2010	UJ – 2010	WITS – 2010	UJ – 2010
Strongly agree	36.1%	17.3%	27.2%	9.00%	30.1%	42.9%	21.4%	7.7%	-	-
Agree	36.1%	39.8%	35.9%	64.00%	41.2%	35.7%	37.6%	7.7%	-	-
Neutral	17.4%	29.6%	22.3%	18.00%	11.8%	21.4%	23.1%	61.5%	-	-
Disagree	6.6%	6.1%	10.7%	9.00%	9.6%	0.0%	10.3%	15.4%	-	-
Strongly disagree	3.7%	7.1%	3.9%	0.00%	7.4%	0.0%	7.7%	7.7%	-	-

**The statement within the questionnaire reads "I would consider installing a greywater system in my household one day"*

Table 31. I am comfortable for a dual water distribution system to be installed at the School of Civil and Environmental Engineering, WITS

Scale	Prior to implementation of the greywater system				Immediately after implementation of the greywater system		About 3 months after implementation of the greywater system		About 7 months after implementation of the greywater system	
	WITS – 2008	UCT – 2008	UJ – 2008	UJ – 2009	WITS – 2010	UJ – 2010	WITS – 2010	UJ – 2010	WITS – 2010	UJ – 2010
Strongly agree	46.2%	-	-	-	38.1%	-	-	-	-	-
Agree	38.1%	-	-	-	48.5%	-	-	-	-	-
Neutral	10.5%	-	-	-	10.4%	-	-	-	-	-
Disagree	2.4%	-	-	-	2.2%	-	-	-	-	-
Strongly disagree	2.8%	-	-	-	0.7%	-	-	-	-	-

7.2.8. Trust

A significant percentage of WITS responses prior to (88%), immediately after (84%) and 3 months after implementation (76%) depict respondents confidence that the relevant authorities will ensure that greywater is safe (Table 32). Although the percentages are marginally lower, the same perception is mirrored at UCT (64% in 2008) and UJ (69% in 2009, 86% just after implementation, and 69% 3 months after implementation).

Table 32. I trust the authorities will ensure that the treated greywater is safe for toilet/urinal flushing

Scale	Prior to implementation of the greywater system				Immediately after implementation of the greywater system		About 3 months after implementation of the greywater system*		About 7 months after implementation of the greywater system	
	WITS – 2008	UCT – 2008	UJ – 2008	UJ – 2009	WITS – 2010	UJ – 2010	WITS – 2010	UJ – 2010	WITS – 2010	UJ – 2010
Strongly agree	45.5%	20.4%	-	54.00%	34.8%	64.3%	27.4%	23.1%	-	-
Agree	42.3%	43.7%	-	15.00%	48.9%	21.4%	48.7%	46.2%	-	-
Neutral	7.7%	20.4%	-	31.00%	15.6%	14.3%	20.5%	23.1%	-	-
Disagree	2.4%	11.7%	-	0.00%	0.7%	0.0%	3.4%	7.7%	-	-
Strongly disagree	2.0%	3.9%	-	0.00%	0.0%	0.0%	0.0%	0.0%	-	-

**The statement within the questionnaire reads "I am confident that the relevant authorities would ensure that the treated greywater used for toilet flushing is safe"*

7.2.9. Attitudes towards the environment

Prior to, immediately after and 3 months after implementation, a significant percentage of respondents affirmed that greywater reuse will be beneficial to the environment (Table 33).

Table 33. Using treated greywater for toilet/urinal flushing or garden watering will have a positive impact on the environment

Scale	Prior to implementation of the greywater system				Immediately after implementation of the greywater system		About 3 months after implementation of the greywater system*		About 7 months after implementation of the greywater system	
	WITS – 2008	UCT – 2008	UJ – 2008	UJ – 2009	WITS – 2010	UJ – 2010	WITS – 2010	UJ – 2010	WITS – 2010	UJ – 2010
Strongly agree	59.9%	43.6%	31.1%	54.00%	57.2%	71.4%	60.5%	53.8%	-	-
Agree	28.6%	43.6%	47.6%	46.00%	34.8%	28.6%	37.0%	38.5%	-	-
Neutral	7.1%	8.9%	11.7%	0.00%	5.1%	0.0%	2.5%	0.0%	-	-
Disagree	3.6%	2.0%	7.8%	0.00%	2.2%	0.0%	0.0%	7.7%	-	-
Strongly disagree	0.8%	2.0%	1.9%	0.00%	0.7%	0.0%	0.0%	0.0%	-	-

7.2.10. Environmental justice

Perceived injustices prior to, during, or after the implementation of a reuse project can result in project failure. Perceived injustices can arise from (Po *et al*., 2003):

i. the perception that low and/or medium income communities are targeted for reuse projects while higher income communities are not targeted;

ii. perceived unfairness in the decision making process.

iii. the lack of consultation or involvement of potential beneficiaries;

iv. the location of treatment plants close to residential areas. This may lead to unpleasant smells and potential contamination. This is a highly contentious issue for many households in Australia currently implementing treated wastewater reuse;

v. community members feeling they are being targeted for water reuse initiatives whereas water reuse projects should start with big water users such as industries before domestic households.

Tables 34 and 35 address the 3rd bullet point. Complaints and suggestions voiced in the questionnaires administered about 3 months after implementation of the greywater system assisted in the improvements made to the system to reduce unpleasant smells and improve the greywater colour. At WITS and UJ, there was an overall significant increase in the percentage of respondents satisfied with the reduction in unpleasant smells and improvement in colour. These increases have positively influenced the average number of times respondents use the greywater reuse toilets during each toilet event (Table 36)

Table 34. I am satisfied with the reduction in unpleasant smells emanating from the greywater toilet while flushing.

Scale	**Prior to implementation of the greywater system**				**Immediately after implementation of the greywater system**		**About 3 months after implementation of the greywater system**		**About 7 months after implementation of the greywater system**	
	WITS – 2008	UCT – 2008	UJ – 2008	UJ – 2009	WITS – 2010	UJ – 2010	WITS – 2010	UJ – 2010	WITS – 2010	UJ – 2010
Strongly agree	-	-	-	-	-	-	12.2%	23.1%	30.3%	33.3%
Agree	-	-	-	-	-	-	42.6%	23.1%	47.9%	46.7%
Neutral	-	-	-	-	-	-	33.0%	15.4%	19.4%	13.3%
Disagree	-	-	-	-	-	-	5.2%	23.1%	0.6%	6.7%
Strongly disagree	-	-	-	-	-	-	7.0%	15.4%	1.8%	0.0%

Table 35. I am satisfied with the improvement in the colour of the greywater.

Scale	Prior to implementation of the greywater system				Immediately after implementation of the greywater system		About 3 months after implementation of the greywater system		About 7 months after implementation of the greywater system	
	WITS – 2008	UCT – 2008	UJ – 2008	UJ – 2009	WITS – 2010	UJ – 2010	WITS – 2010	UJ – 2010	WITS – 2010	UJ – 2010
Strongly agree	-	-	-	-	-	-	14.7%	23.1%	28.8%	13.3%
Agree	-	-	-	-	-	-	41.4%	38.5%	41.7%	53.3%
Neutral	-	-	-	-	-	-	33.6%	15.4%	23.9%	26.7%
Disagree	-	-	-	-	-	-	7.8%	15.4%	4.3%	6.7%
Strongly disagree	-	-	-	-	-	-	2.6%	7.7%	1.2%	0.0%

Table 36. How often do you use the greywater toilet?

Scale	Prior to implementation of the greywater system				Immediately after implementation of the greywater system		About 3 months after implementation of the greywater system		About 7 months after implementation of the greywater system	
	WITS – 2008	UCT – 2008	UJ – 2008	UJ – 2009	WITS – 2010	UJ – 2010	WITS – 2010	UJ – 2010	WITS – 2010	UJ – 2010
Every time (100%)	-	-	-	-	-	-	15.4%	0.0%	19.3%	0.0%
3 out of 4 times (75%)	-	-	-	-	-	-	22.1%	33.3%	22.9%	40.0%
2 out of 4 times (50%)	-	-	-	-	-	-	34.6%	25.0%	30.1%	40.0%
1 out of 4 times (25%)	-	-	-	-	-	-	22.1%	25.0%	21.1%	20.0%
Not at all (0%)	-	-	-	-	-	-	5.8%	16.7%	6.6%	0.0%

7.2.11. The cost of recycled water

The paragraph below is based on a study by Ilemobade *et al*., (2009b). Hence, the effect of the cost of recycled water was not assessed in this survey.

"*Tariffs for non-potable water conveyed via dual water reticulation systems are usually lower than potable water tariffs and this has encouraged non-potable water reuse. In the CoCT (City of Cape Town), treated effluent tariffs in 2007 ranged from 7% to 40% of the potable water tariffs and this has encouraged several large users of non-potable water (e.g. the Chevron oil refinery) to reuse treated effluent. The percentage of willing respondents in the perception survey increased from 36% to 71% if tariffs for non-potable water were lower than for potable water. In the modelling exercise where a treated effluent system replaced the existing potable* *water supply system for toilet flushing, landscape irrigation, paving and masonry production, cost savings of about 67% (R17,150,048) were achieved over 20 years*"

7.3. Awareness and education

7.3.1. Awareness and education at WITS

In addition to the perception surveys discussed above, the following education and awareness activities were carried out at WITS:

i. on the 26th of February 2010, a seminar regarding the pilot greywater system was presented by 4th year students involved on the project. This seminar was attended by students, staff and visitors to the school and was part of a showcase of projects which were geared towards "greening" the building;
ii. shortly after the greywater system was implemented, brief awareness sessions were held with the school's technical staff and the 1st, 2nd, 3rd and 4th year students of the School. These sessions were aimed at describing the system, allaying fears due to the intermittent functionality of the system at the time, and the unpleasant odours which were emanating from within the greywater tanks due to decomposing foods, fat, oils and grease that had entered into the system from the laboratory basins. Prior to these awareness sessions, the relevant questionnaires were administered;
iii. Two groups of students undertook their 4th year investigational projects on the greywater reuse system. These projects required the students to undertake a series of tasks (e.g. surveys and awareness) which involved interaction with students and staff;
iv. The greywater system is one of the exhibits annually showcased by the school to visitors and potential students during its annual information days;
v. Size A3, A4 and A5 posters were put up within the building and bathrooms (Figure 24 (a), (b), (c) and (d)). These posters provide awareness of the system and describe how to use the system.

Hi, two South side toilets within this building flush with greywater

The greywater used in these toilets is wastewater from hand basins within this building INCLUDING this one!

Did you know that.....

Each time you wash your hands in this basin:

i. You help to save scarce drinking water?
ii. You reduce pollution by reducing the quantity of wastewater that is daily discharged into the environment?

This is what you must do:

Do not wash down the basin any substances except water and soap and of course, the dirt on your hands!

This research is undertaken by:

UNIVERSITY OF JOHANNESBURG

UNIVERSITY OF CAPE TOWN

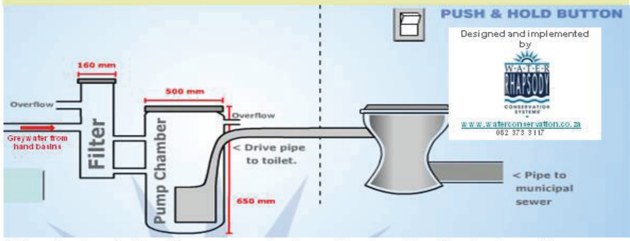
Hi, I flush with greywater

The greywater used here is wastewater from many of the hand basins within this building

Did you know that.....

1. Each time you flush me:
   i. You save about 8 litres of scarce drinking water?
   ii. You reduce pollution by reducing the quantity of wastewater that is daily discharged into the environment?
2. Many households and communities in South Africa proudly and safely use greywater for toilet and urinal flushing and garden irrigation?

This is a schematic of how I function....



After sieving in the filter, greywater from the hand basins is stored in a pump chamber located in the basement of the School building. By pressing and holding the bell-push, the water is pumped into the toilet bowl

So, how can you best use me?

1. **AFTER TOILET USE, PRESS AND HOLD THE BELL SWITCH FOR 5 SECONDS TO FLUSH;**
2. Report any problems/concerns to
   i. Mr Wale Olanrewaju, room 214A (Tel: 079 900 7931)
   ii. Mr Wayne Costopoulos, room 13A (011 717 7109)
   iii. Dr Adesola Ilemobade, room 303 (011 717 7153)

This research is undertaken by:

UNIVERSITY OF JOHANNESBURG

UNIVERSITY OF CAPE TOWN

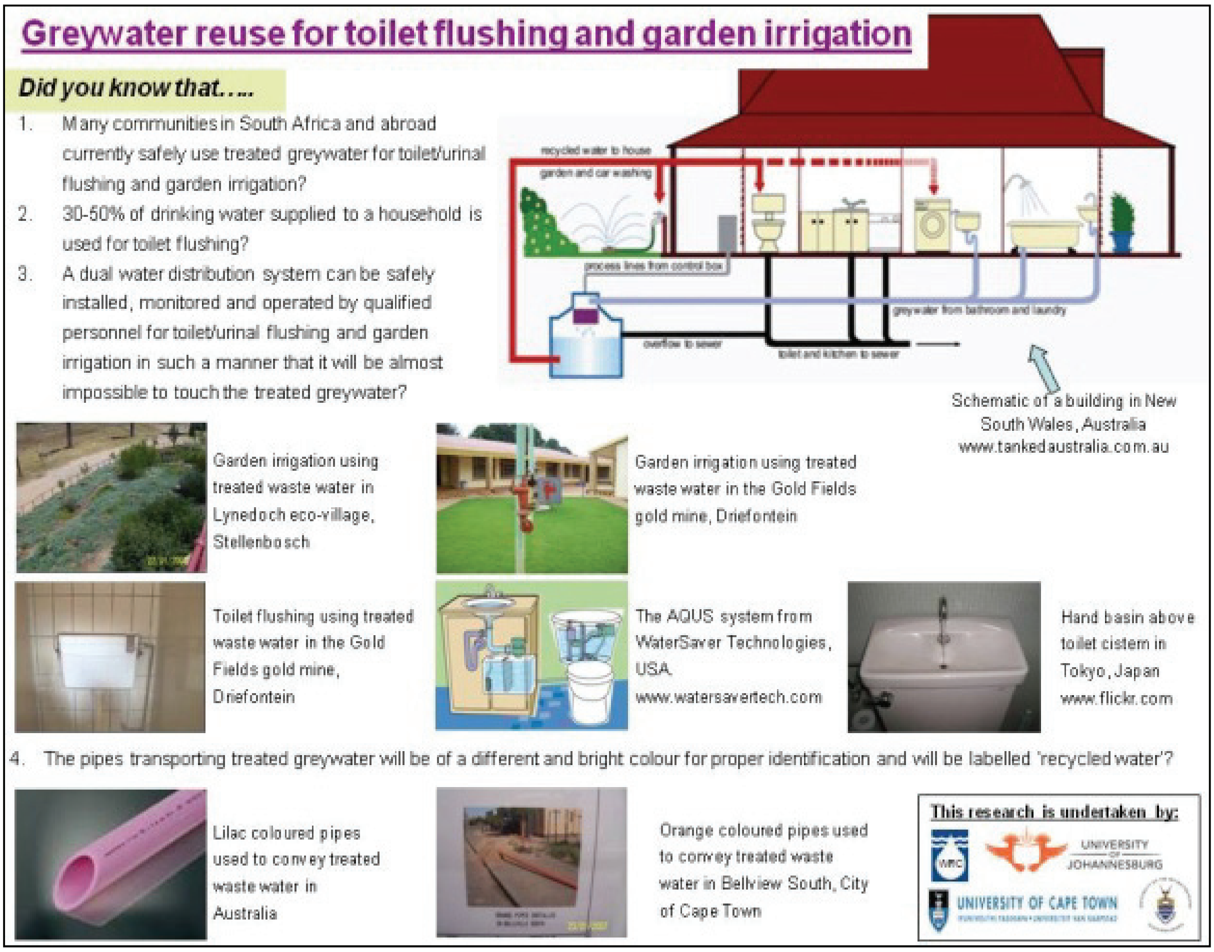


Figure 24 (1st). A5 posters placed in front of each hand basin; (2nd) A3 posters placed above toilet cisterns; (3rd) A4 awareness posters about wastewater reuse; (4th) One of the bathrooms displaying the above posters.

vi. The greywater concept and system comprised a section (lectures, long essay and exam) of a 4th year and postgraduate course. An excerpt of the 4th year exam question is shown in the box below:

> **University of the Witwatersrand, Johannesburg**
> **CIVN4006: Integrated Resources Management**
> **EXAM: September 9, 2010**
>
> **Question A1**
>
> In fulfilling its mandate to drive research to protect and conserve depleting water resources in South Africa and to provide viable supplemental sources for future water demands, the Water Research Commission provided funding for the installation of 2 pilot greywater recycling units at the WITS School of Civil and Environmental Engineering and at Unit 51A (a 16 student residence), Student Town, the University of Johannesburg (UJ) Kingsway campus. The purpose of these pilots is to determine the appropriateness and sustainability of greywater recycling within urban communities in South Africa. At WITS, greywater refers to wastewater from only bathroom hand basins and at UJ, greywater refers to wastewater from only showers and bath tubs.
>
> Due to the sensitive nature of this project, provide a brief, yet concise write-up responding to the following questions/statements:
>
> i. Which resources are involved on this project?
> ii. What are the potential constraints/limitations/challenges of this project?
> iii. Which professionals need to be involved in the project from inception to implementation?
> iv. Propose a framework that will guide decision-makers in assessing the appropriateness and sustainability of greywater recycling within urban communities in South Africa based on the 2 pilot greywater units.

7.3.2. Awareness and education at UJ

i. The 1st awareness meeting was held with residents of Unit 51A on Tuesday, 22nd September 2009 (Figure 25). The aim of the meeting was to determine residents' perceptions (using the 1st questionnaire) towards the installation of the greywater reuse system for toilet flushing in their unit, and introduce to the residents the proposed project and the project team. The meeting was advertised using posters placed at strategic spaces within the unit and invitation notes under residents' doors. The meeting started with the administration of the 1st questionnaires. This was done in order to garner the perceptions of respondents prior to any awareness was carried out. In this form, the initial perceptions of respondents were not tainted by the information subsequently presented. This was the typical format of all the meetings where the questionnaires were administered.

Figure 25. (Left) Some residents from Unit 51A and the residents association; (Right) Some members of the project team responding to questions.

ii. The 2nd stakeholder meeting took place on the 18th of March 2010. Seven of the 16 female residents of Unit 51A were present at this meeting. Some of the residents present were not resident in the unit in 2009 when the 1st meeting was held and hence needing to be informed of the project;

iii. The 3rd stakeholder meeting took place on the 25th of March 2010. This meeting was held with relevant personnel of the UJ maintenance department to acquaint them with the plans and progress on the project;

iv. Similar to WITS, size A3, A4 and A5 posters were put up within the unit (see Figure 24);

v. The 4th meeting with residents took place on the 5th of August 2010. This meeting took place immediately after implementation of the greywater system and thus provided residents with an opportunity to learn about the system, air their concerns, and receive responses to certain questions. The concerns raised were recorded and addressed subsequently. Some of these concerns and responses are listed below:

- Residents' concern: the often back flow of bath and shower greywater into the ground floor bath and shower when released from the 1st floor. Project team response: the plumbing was subsequently modified to separate the ground and 1st floor greywater collection pipes;
- Residents' concern: unpleasant smells from the greywater during flushing at the beginning of the semester. Project team response: Due to the 6 week inter-semester break when the residents were on holiday, the greywater in the

tank had gone septic. The project team had omitted to undertake the regular maintenance on the system prior to residents returning to the unit and hence the unpleasant odours in the greywater during flushing after residents return to the unit. Subsequent to this meeting, diversion pipes were introduced into the system to prevent greywater storage during periods when the system was not being used;

- Residents' concern: the effect of the greywater on feminine hygiene especially if there is a splash of greywater on the skin during toilet use. Project team response: the project team were not aware of any negative impacts on dermal or related health if splashes of greywater occurred during toilet use. However, ingestion of the greywater, if contaminated with pathogenic microorganisms, could compromise health. Respondents were therefore advised to observe hygiene practices when using the toilets that flush with greywater similar to what would typically happen when they use toilets that flush with municipal water;
- Residents' concern: the ring of scum often seen in the greywater toilet bowl. Project team response; the ring of scum was often a result of either limited use of the greywater toilets and hence, the deposition of scum around the surface of the greywater within the toilet bowl or the lack of regular maintenance. The project team committed to undertake maintenance twice a week and encourage residents to use the greywater toilet as often as possible.
- Residents' concern: Low flushing pressure in the ground floor greywater toilet. Project team response: This may be a result of a blockage in the pipe supplying the toilet bowl and will be checked.

vi. The 5th meeting was held on the 28th of October 2010 and provided the project team with the opportunity to field questions and thank the residents for their cooperation on the project throughout the year.

Figure 26. Fifth awareness meeting between Unit 51A residents and the project team

7.4. Highlights of the perception surveys, awareness and education

i. Overall, a very high percentage of all respondents affirmed that the concept of greywater reuse will be beneficial to the environment. Respondents therefore overwhelmingly disagreed with the statement that treated greywater for toilet/urinal flushing was disgusting;
ii. In comparison to garden watering, most respondents preferred toilet flushing;
iii. There was a higher percentage of comfort amongst respondents with installing a greywater reuse system for toilet flushing at a non-residential building than at a residential building. Consequently, those living in university residence were more concerned about greywater reuse;
iv. The 15-21 yrs (undergraduate cohort) were generally more comfortable about greywater reuse than the same percentage of the cohort of 22 yrs and older or postgraduate students, academic and support staff. Consequently, the concern expressed by the former was generally less than that for the latter;
v. Concern about getting sick from greywater reuse for toilet flushing was high at all institutions. This highlighted the need to ensure that the implemented greywater reuse systems were consistently safe and hygienic. The incidents regarding greywater back flow into the ground floor bath tub and shower at UJ, unpleasant

odours from the greywater during flushing, scum in the greywater, and concern for dermal and related health resulted in increased concern about greywater reuse;

vi. A significant percentage of responses prior to, immediately after and 3 months after implementation depicted respondents confidence that the relevant authorities will ensure that greywater is safe;

vii. The overall significant increases in the percentages of respondents satisfied with the reduction in unpleasant smells and improvement in colour positively influenced the average number of times respondents subsequently used the greywater reuse toilets;

viii. The awareness sessions undertaken after administration of the perception survey questionnaires ensured that the perceptions collected were not tainted by the information or assurances provided by the project team and were thus, a true reflection;

ix. In addition to the above point, the awareness sessions which were undertaken earlier in the project, provided the project team with the opportunity to determine or confirm the different areas of concern (e.g. unpleasant odour, greywater colour, and concern for health) utmost in the minds of the respondents. These areas of concern were therefore included in the subsequent questionnaires and thus monitored over time;

x. An overall assessment of the greywater system is presented in Table 37. A larger proportion of surveyed respondents at WITS (78 of the 90 respondents) and UJ (9 of the 15 respondents) passed the system. However, it can be seen that likely due to the negative experiences at UJ, 6 of the 15 respondents were neutral.

Table 37. Respondents' overall assessment of the greywater reuse system

Scale	**About 7 months after implementation of the greywater system**	
	WITS – 2010	UJ – 2010
Pass (No.)	78	9
Neutral (No.)	11	6
Fail (No.)	1	0
Total (No.)	90	15

8. TECHNICAL AND ECONOMIC ANALYSES REGARDING THE PILOT GREYWATER REUSE SYSTEMS FOR TOILET FLUSHING

8.1. Logging of water consumption

The logging of toilet flushing and bulk potable water consumption at WITS and UJ was aimed at determining the potable water savings (and consequently costs) at both institutions as a result of greywater reuse for toilet flushing. A summary of the methodologies employed and some of the results of this exercise are presented below.

8.1.1. Logging of water consumption at WITS

Data on toilet flushing at WITS were collected from the 21st of May 2009. Initially, this data was generated using manual counters which were installed in each toilet cistern (Figure 27). Each time a toilet was flushed, the lever connected to the counter was activated, causing the counter to record a digit. The number of digits registered by the counter during a specified period indicated the number of times the toilet was flushed. Due to moisture within the cisterns, several of the counters repeatedly malfunctioned and thus, this method of measuring flushes had to be abandoned. Electronic data loggers were subsequently installed in each toilet in October 2009 to replace the manual counters.

The electronic data loggers employed (Figure 27), typically measure and store up to 32,510 voltage readings over a 0-30V d.c. measurement range. The user can easily set up the logging rate and start time, and download the stored data by plugging the data logger into a PC's USB port and running the purpose designed software under Windows 2000, XP and Vista (32-bit). The data can then be graphed, printed and exported to other applications. The data logger is supplied with a lithium battery. Correct functioning of the unit is indicated by flashing red and green LEDs. The data logger features a pair of screw terminals and a set of measurement leads terminating in crocodile clips

Figure 27. (Top left) A toilet cistern housing a manual counter with a lever; (Top right) An electronic data logger; (Bottom left) A probe from an electronic logger which measures voltage difference within water in the toilet cistern; (Bottom right) Downloading data from an electronic logger unto a computer.

An implication of the change in loggers was the incompatibility between the data generated using the manual counters (which were read every 3 hours between 06h00-18h00 and every 6 hours between 18h00 to 06h00) and the electronic loggers (which logged flushing approximately every minute).

Table 38 shows the measured toilet flushing consumption within WITS prior to and after implementation of the greywater reuse system. Due to the difficulty in synchronising the data collected by the manual and electronic loggers, and the limited data available on same months of multiple years, it was only possible to compare the average toilet flushing consumption data for November 2009 and November 2010 – these are the only months during the period of logging in which electronic loggers were used and which present data for the before and after greywater system implementation scenarios. These months are predominantly examination periods where students are sparsely present and therefore, are not reflective of teaching periods which would be considered peak periods for toilet flushing.

Table 38. Potable water savings due to greywater reuse for flushing in 2 toilets at WITS

Equipment	Month	Monthly toilet flushing consumption (litres)	No of days logged	Average potable water consumption for toilet flushing per day (litres)	No of toilets logged	For similar months and using the same mode of logging, average savings in potable water per day due to greywater reuse in 2 toilets (litres)	Comment
Manual counters	May-09	10,098.00	11	918	12		
	Jun-09	25,227.00	30	841	12		
	Jul-09	37,134.00	31	1198	12		
	Aug-09	39,366.00	31	1270	12		
	Sep-09	39,105.00	30	1304	12		
	Oct-09	25,452.00	31	821	12		
Electronic loggers	Nov-09	18,162.00	30	605	12		
	Dec-09	6,804.00	31	219	12		
	Mar-10	14,301.00	22	650	10		Greywater system implemented
	Apr-10	16,389.00	30	546	10		
	May-10	10,881.00	31	351	10		
	Jun-10	6,615.00	30	221	10		
	Jul-10	12,267.00	31	396	10		
	Aug-10	11,403.00	31	368	10		
	Sep-10	12,276.00	30	409	10		
	Oct-10	12,555.00	31	405	10		
	Nov-10	7,695.00	20	385	10	220	Nov 2009 minus Nov 2010

Based on the data for November 2009 and November 2010, the potable water savings due to greywater reuse in 2 of the 12 toilets within WITS amounted to 220 litres per day. Assuming a peak factor of 2 (to represent demand during peak periods), the potable water savings due to greywater reuse in 2 of the 12 toilets would amount to about 440 litres per day. Other results to proceed from the data generated at WITS include:

- There was on average, a bulk potable water savings of about 6% within the building during off-peak teaching periods due to the greywater reuse system for toilet flushing in 2 of the 12 toilets;

➢ There was on average, a bulk potable water savings of about 10% within the building during peak teaching periods due to the greywater reuse system for toilet flushing in 2 of the 12 toilets.

8.1.2. Logging of water consumption at UJ

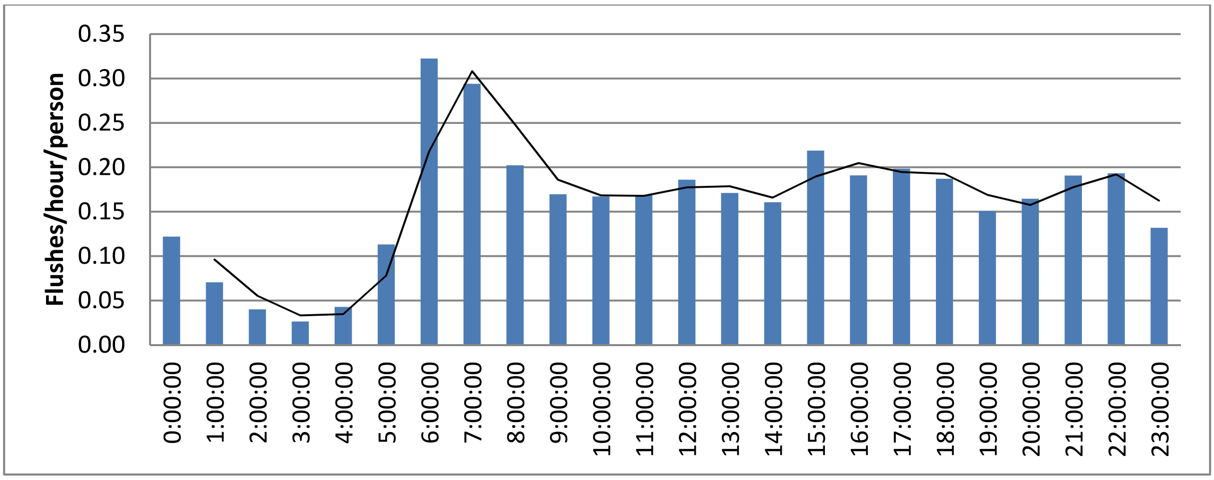
At UJ, data on toilet flushing was metered using the electronic data loggers described in section 8.1.1. There were however several problems with the loggers often resulting in unreliable data. Table 39 shows toilet flushing consumption within Unit 51A for 2 months of 2009 and 7 months of 2010 – periods when generated data were considered reliable.

Table 39. Potable water savings due to greywater reuse for flushing in 2 toilets at Unit 51A, Student Town, UJ

Mode of logging	Month	Monthly toilet flushing consumption (litres)	No of days logged	Average potable water consumption for toilet flushing per day (litres)	No of toilets logged	For similar months and using the same mode of logging, average savings in potable water per day due to greywater reuse in 2 toilets (litres)	Comment
Electronic	Aug-09	6678	22	607.09	4		
	Sep-09	6210	21	591.43	4		
	Mar-10	3780	15	252.00	4		
	Apr-10	4725	30	157.50	4		
	May-10	7704	28	275.14	4		
	Jun-10	1809	13	139.15	2		Greywater system installed
	Jul-10	9810	22	445.91	2		
	Aug-10	16821	28	600.75	2	6.34	August 2009 minus August 2010
	Sep-10	6786	15	452.40	2	139.03	September 2009 minus September 2010

Based on the data presented, and calculation of potable water savings which were only possible by comparing August and September 2009 (prior to greywater implementation) with August and September 2010 (after greywater implementation), the maximum potable water savings due to greywater reuse in 2 of the 4 toilets amounted to 139 litres per day. Applying a peak factor of 2 (to represent demand during peak periods – see below), the potable water savings due to greywater reuse in 2 of the 12 toilets would amount to 278 litres per day. Other results to proceed from the data generated at UJ include:

- Average number of flushes per resident per day was 3.89;
- the instantaneous peak factor calculated for toilet flushes was 1.98. This implies that on average, the number of times the toilet is flushed during peak periods is approximately twice the average number of flushes per resident;
- Over an 83 day period of measurement (11 June 2010 to 01 October 2010), total toilet flushing consumption within the unit comprised 25% greywater and 75% municipal potable water supply;
- Typical weekday (Monday to Thursday) and weekend (Saturday) toilet flushing trends are depicted in Figure 28;
  - The fact that there is 1 clear peak and a relatively constant demand thereafter throughout the weekday may be favourable for the operation of the greywater system as treated greywater would be continually used through most of the day and not retained in the tank for long periods of time;
  - Three distinct peaks are noticed for Saturday. The first peak is due to the use of the toilets in the morning when residents wake up, albeit one hour later (07h00) than during weekdays. The residents who remain in the unit most of the day, have their lunch and supper approximately between 12h00-15h00 and 17h00-19h00 and therefore use the toilets at the times when the second and third peaks occur.



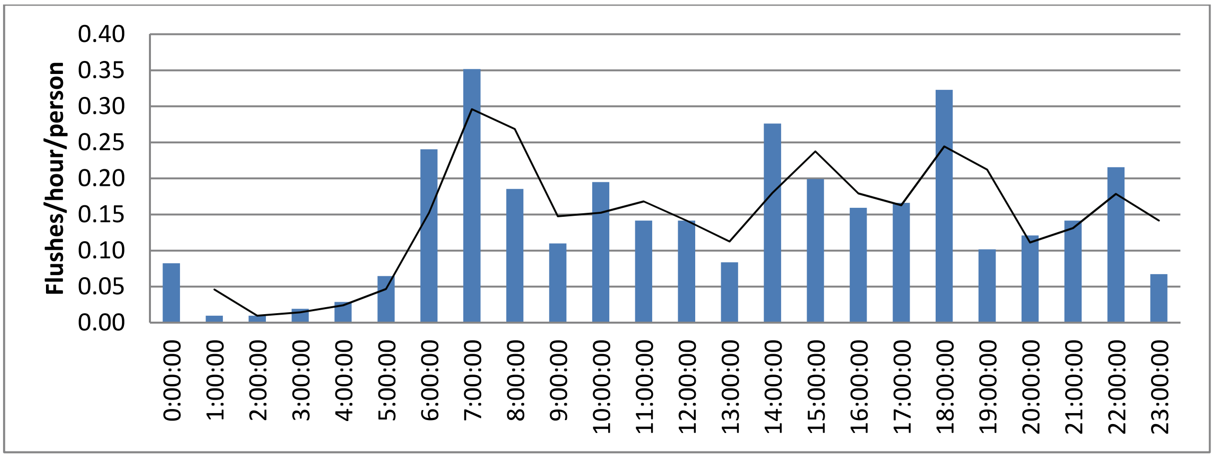


Figure 28. Flushing trends for a typical Monday-Thursday (Top) and Saturday (Bottom) at UJ

8.2. Maintenance of the greywater systems at WITS and UJ

Maintenance tasks on the greywater systems typically required between 30-60 minutes at each instance – the lower limit during routine maintenance and the upper limit during major maintenance. Maintenance was recommended weekly at WITS and twice a week at UJ in order to guarantee optimal performance and typically involved:

i. cleaning the sieves which would likely have trapped substances (hair or other material) from the influent greywater;
ii. brushing down the scum which would have collected on the tank walls and on the surface of the greywater in the tank;

iii. inspecting the chlorine capsules to remove any trapped sediments and to ensure there are adequate chlorine tablets for disinfection;
iv. Inserting a cistern block in the sieves (and in the tank once in a while) to dye the disinfected greywater;
v. Using a toilet brush to remove scum within the toilet bowl; and
vi. Recording of metered electricity (for the greywater pumps) and water readings (for the toilet flushes, bulk municipal supply and rainwater tank at UJ).

8.3. Pros and cons of the pilot greywater reuse systems

A list of the pros and cons of the low-technology, low-cost greywater reuse systems, as indicated by the beneficiaries, is presented below. Several of the points listed below have been mentioned in Section 6.2. and Chapter 7. As a result of some of the failures below, the initial pilot system (Figure 16) was modified as detailed in section 6.2.1.

8.3.1. Pros

i. the systems were easily modifiable to suit site conditions;
ii. the systems required no specialised skill to conduct weekly maintenance which required on average 30 minutes, and typically involved cleaning the sieves, brushing down the scum within the tank, inspecting the chlorine capsules, inserting a cistern block in the sieves, cleaning out scum in the toilet bowl and recording metered readings for electricity and water;

8.3.2. Cons

i. The greywater system, which only performed sieving and disinfection, did not remove the scum in the greywater and this resulted in visually unpleasing greywater in the toilet bowl. The scum typically developed an unsightly ring above the greywater level within the toilet bowl and this was particularly of concern at UJ where the greywater was more turbid due to soaps, shampoos, detergents, etc. than at WITS;
ii. When greywater was retained in the tanks for more than 48 hours, as was often the case at UJ during term breaks/holidays , and/or when the chlorine tablets

were not regularly replenished, the greywater became septic and produced unpleasant smells during flushing;

iii. Due to an erroneous greywater pipe connection at UJ after installation, greywater from the 1st floor bath and shower flowed into the ground floor bath and shower and was a major concern and discomfort for the residents of the ground floor especially during ablution;

iv. Preliminary microbiological tests of the greywater were conducted after the initial greywater system was implemented. At the time, disinfection involved placing bromine based tablets in the sieves once a week. These tests showed high microbiological. As a result, the initial greywater system was modified to include 2 inline chlorinators which provided increased disinfection and reduced the microbiological counts;

v. In order to ensure the retention time of greywater in the tanks was kept to about 24 hours, the volume of the tanks were deliberately kept small (~200 litres). At WITS during peak (teaching) periods when the frequency of toilet flushing was high, the greywater tanks often emptied out. As a result, the back-up municipal potable water supply, which was only to be rarely used, kicked in. The regular use of municipal supply negated some of the savings which were to be achieved by implementing the greywater system;

8.4. Economic analysis of the pilot greywater reuse systems

In relation to economics, the case studies reviewed specified that long pay-back periods tended to infer non-profitability, and thus tended to dampen potential and actual users' and decision-makers' interests in greywater reuse. In these case studies, greywater systems had a payback period of between 8-14 years (Sayers, 1998; Surendran and Wheatley, 1998; March *et al.*, 2004; and Ghisi and Ferreira, 2007) with preference for between 2-4 years amongst potential respondents in Melbourne, Australia (Christova-Boal *et al.*, 1996). Payback period was therefore the factor computed in the economic analysis of the pilot greywater reuse systems.

Costs considered over the systems 20 year design life included:

i. capital costs related to:

- purchasing the greywater treatment unit;
- installing/retrofitting the greywater treatment unit (which includes piping, plumbing and workmanship);

ii. energy costs related to:

- operating the pumps;
- adding colour to the greywater;
- disinfecting the greywater;
- maintenance;

Assumptions made while computing payback periods from the year 2009 included:

- The design life of the greywater system is 20 years;
- The pumps will be replaced at the end of 10 years;
- Potable water prices will increase at an annual rate of 10% over the 20 year period;
- Sewage prices will increase at the rate of 8% per annum over the 20 year period;
- Electricity tariffs will increase at an annual rate 30% from 2010 to 2012 and thereafter 10%;
- Price of cistern blocks will increase at an annual rate of 5%;
- The service agreement is a once-off cost for 12 months after installation of greywater system;
- Sewage from a building is estimated to be about 55% of the bulk potable water supply;
- Due to the nature of business occurring in the different buildings, it is expected that the WITS building would effectively be open and hence greywater system functional, for 330 days (90%) of the year while greywater system at UJ effectively functional for 200 days (55%) of the year.

8.4.1. Payback period computation at WITS

Table 40 presents capital and recurrent costs of the greywater reuse system, Table 41 presents potable and sewage savings due to greywater reuse in the 2 toilets, and Table 42 presents cumulative cash flows and hence, payback period for the greywater reuse system.

[1]*Purchase and installation of the greywater reuse system:*

- *1 No. 200 litre greywater tank*
- *pipes and appurtenances*
- *pipe filter and 2 No. 2 mm sieves*
- *wall supports and braces*
- *retrofitting of 2 toilets while retaining the previous function*
- *1 No. 9 metre head pump and 1 No. 14 m head pump**
- *workmanship, excavation, drilling of basement cores and equipment*
- *1st year service agreement*
- *2 chlorinators*
- *1 No. 75 litre municipal water back-up tank*

[2]*Electricity consumption = approximately 2 KW.hr per month (1 KW.hr ~ R0.50) with a monthly surcharge and 14% VAT of ~ R2.00 = ~R3 per month;*

[3]*Chlorine = 80 tablets per annum at ~ R10 per tablet;*

[4]*Cistern blocks = 45 blocks per annum at ~R8 per week;*

[6]*Pump replacement: assume both pumps are replaced at the end of 10 years at present value of R4,000.00*

Table 40. Capital and recurrent costs at WITS

Year	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Cost of the greywater treatment unit (R)[1]	38,045	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Electricity consumption (R)[2]	36	47	61	79	87	96	105	116	127	140	154	170	186	205	226	248	273	300	330	363
Chlorine tablets (R)[3]	800	840	882	926	972	1,021	1,072	1,126	1,182	1,241	1,303	1,368	1,437	1,509	1,584	1,663	1,746	1,834	1,925	2,022
Cistern blocks (R)[4]	360	378	397	417	438	459	482	507	532	558	586	616	647	679	713	748	786	825	866	910
Service agreement (R)[5]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Replacement of pumps (R)[6]	0	0	0	0	0	0	0	0	0	0	7,787	0	0	0	0	0	0	0	0	0
Total (R)	39,241	1,265	1,340	1,422	1,497	1,576	1,660	1,748	1,841	1,940	9,831	2,154	2,270	2,392	2,522	2,660	2,805	2,959	3,122	3,295

Table 41. Savings at WITS

	Year	***2009***	***2010***	***2011***	***2012***	***2013***	***2014***	***2015***	***2016***	***2017***	***2018***	***2019***	***2020***	***2021***	***2022***	***2023***	***2024***	***2025***	***2026***	***2027***	***2028***
Economic benefit (i.e. annual average savings in potable water)	Daily savings in potable water (litres) due to greywater reuse in 2 toilets	440																			
	Annual savings in potable water (kilo litres) (x 330 days)	1,45.20																			
	Annual savings (R) in potable water at R10.58 per kilolitre (2009 tariff)	1,536.22	1,689.84	1,858.82	2,044.70	2,249.17	2,474.09	2,721.50	2,993.65	3,293.02	3,622.32	3,984.55	4,383.00	4,821.30	5,303.43	5,833.78	6,417.16	7,058.87	7,764.76	8,541.23	9,395.36
Environmental benefit (i.e. reduced sewage treatment costs due to reduced return flows)	Daily savings in sewage (litres) due to greywater reuse in 2 toilets (55% of potable water savings)	242.00																			
	Annual savings in sewage (kilo litres) due to greywater reuse in 2 toilets (x 330 days)	79.86																			
	Annual savings in sewage at R7.00 per KL (2009 tariff)	559.02	603.74	652.04	704.20	760.54	821.38	887.09	958.06	1,034.71	1,117.48	1,206.88	1,303.43	1,407.71	1,520.32	1,641.95	1,773.31	1,915.17	2,068.38	2,233.85	2,412.56

Table 42. Cumulative cash flow at WITS

Year	***2009***	***2010***	***2011***	***2012***	***2013***	***2014***	***2015***	***2016***	***2017***	***2018***	***2019***	***2020***	***2021***	***2022***	***2023***	***2024***	***2025***	***2026***	***2027***	***2028***
Outflow (capital + recurrent) costs (R)	39,241.00	1,264.80	1,339.74	1,421.94	1,496.99	1,576.19	1,659.78	1,748.04	1,841.23	1,939.66	9,830.65	2,153.53	2,269.69	2,392.50	2,522.38	2,659.78	2,805.18	2,959.09	3,122.07	3,294.69
Inflow (potable water + sewage) savings (R)	2,095.24	2,293.58	2,510.86	2,748.91	3,009.71	3,295.48	3,608.59	3,951.71	4,327.72	4,739.80	5,191.43	5,686.44	6,229.01	6,823.76	7,475.73	8,190.46	8,974.04	9,833.14	10,775.09	11,807.92
Net cash flow (R)	-37,145.76	1,028.78	1,171.12	1,326.97	1,512.73	1,719.29	1,948.81	2,203.68	2,486.50	2,800.14	-4,639.21	3,532.90	3,959.32	4,431.26	4,953.35	5,530.68	6,168.86	6,874.05	7,653.02	8,513.23
Cumulative cash flow (R)	-37,145.76	-36,116.98	-34,945.86	-33,618.89	-32,106.17	-30,386.88	-28,438.07	-26,234.39	-23,747.89	-20,947.75	-25,586.96	-22,054.06	-18,094.74	-13,663.48	-8,710.13	-3,179.45	2,989.41	9,863.46	17,516.48	26,029.72

8.4.2. Payback period computation at UJ

Table 43 presents capital and recurrent costs of the greywater reuse system at UJ, Table 44 presents potable and sewage savings due to greywater reuse in the 2 toilets, and Table 45 presents cumulative cash flows and hence, payback period for the greywater reuse system.

[1]*Purchase and installation of the greywater reuse system:*

- *1 No. 200 litre greywater tank*
- *pipes and appurtenances*
- *pipe filter and 2 No. 2 mm sieves*
- *wall supports and braces*
- *retrofitting of 2 toilets while retaining the previous function*
- *1 No. 6 metre head pump and 1 No. 9 m head pump**
- *workmanship, excavation and equipment*
- *2 chlorinators*

[2]*Electricity consumption = approximately 2 KW.hr per month (1 KW.hr ~ R0.50) with a monthly surcharge and 14% VAT of ~ R2.00 = ~R3 per month;*

[3]*Chlorine = 80 tablets per annum at ~ R10 per tablet;*

[4]*Cistern blocks = 45 blocks per annum at ~R8 per week;*

[5]*Service agreement for the 1st year;*

[6]*Pump replacement: assume both pumps are replaced at the end of 10 years at present value of R4,000.00;*

[7]*A 2.5 kl rainwater tank, piping and diversion system.*

Table 43. Capital and recurrent costs at UJ

Year	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Cost of the greywater treatment unit (R)[1]	38,200	0	0	0	0	0	0	0	0	0
Electricity consumption (R)[2]	36	47	61	79	87	96	105	116	127	140
Chlorine tablets (R)[3]	800	840	882	926	972	1,021	1,072	1,126	1,182	1,241
Cistern blocks (R)[4]	360	378	397	417	438	459	482	507	532	558
Service agreement (R)[5]	7,200	0	0	0	0	0	0	0	0	0
Replacement of pumps (R)[6]	0	0	0	0	0	0	0	0	0	0
Cost of the rainwater harvesting system (R)[7]	9,300	0	0	0	0	0	0	0	0	0
Total (R)	55,896	1,265	1,340	1,422	1,497	1,576	1,660	1,748	1,841	1,940

Year	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Cost of the greywater treatment unit (R)[1]	0	0	0	0	0	0	0	0	0	0
Electricity consumption (R)[2]	154	170	186	205	226	248	273	300	330	363
Chlorine tablets (R)[3]	1,303	1,368	1,437	1,509	1,584	1,663	1,746	1,834	1,925	2,022
Cistern blocks (R)[4]	586	616	647	679	713	748	786	825	866	910
Service agreement (R)[5]	0	0	0	0	0	0	0	0	0	0
Replacement of pumps (R)[6]	7,787	0	0	0	0	0	0	0	0	0
Cost of the rainwater harvesting system (R)[7]	0	0	0	0	0	0	0	0	0	0
Total (R)	9,831	2,154	2,270	2,392	2,522	2,660	2,805	2,959	3,122	3,295

Table 44. Savings at UJ

	Year	***2009***	***2010***	***2011***	***2012***	***2013***	***2014***	***2015***	***2016***	***2017***	***2018***	***2019***	***2020***	***2021***	***2022***	***2023***	***2024***	***2025***	***2026***	***2027***	***2028***
Economic (i.e. annual average savings in potable water)	Daily savings in potable water (litres) due to greywater reuse in 2 toilets	278																			
	Annual savings in potable water (kilo litres) (x 200 days)	55.60																			
	Annual savings (R) in potable water at R10.58 per kilolitre (2009 tariff)	588.25	647.07	711.78	782.96	861.25	947.38	1,042.12	1,146.33	1,260.96	1,387.06	1,525.76	1,678.34	1,846.17	2,030.79	2,233.87	2,457.26	2,702.98	2,973.28	3,270.61	3,597.67
Environmental (i.e. reduced sewage treatment costs due to reduced return flows)	Daily savings in sewage (litres) due to greywater reuse in 2 toilets (55% of potable water savings)	152.90																			
	Annual savings in sewage (kilo litres) due to greywater reuse in 2 toilets (x 200 days	30.58																			
	Annual savings in sewage at R7.00 per KL (2009 tariff)	214.06	231.18	249.68	269.65	291.23	314.52	339.69	366.86	396.21	427.91	462.14	499.11	539.04	582.16	628.74	679.03	733.36	792.03	855.39	923.82

Table 45. Cumulative cash flow at UJ

Year	***2009***	***2010***	***2011***	***2012***	***2013***	***2014***	***2015***	***2016***	***2017***	***2018***	***2019***	***2020***	***2021***	***2022***	***2023***	***2024***	***2025***	***2026***	***2027***	***2028***
Outflow (capital + recurrent) costs (R)	55,896.00	1,264.80	1,339.74	1,421.94	1,496.99	1,576.19	1,659.78	1,748.04	1,841.23	1,939.66	9,830.65	2,153.53	2,269.69	2,392.50	2,522.38	2,659.78	2,805.18	2,959.09	3,122.07	3,294.69
Inflow (potable water + sewage) savings (R)	802.31	878.26	961.46	1,052.61	1,152.48	1,261.90	1,381.80	1,513.19	1,657.17	1,814.96	1,987.90	2,177.45	2,385.21	2,612.95	2,862.61	3,136.29	3,436.34	3,765.31	4,126.00	4,521.49
Net cash flow (R)	-55,093.69	-386.54	-378.28	-369.32	-344.51	-314.28	-277.98	-234.84	-184.05	-124.69	-7,842.74	23.92	115.53	220.46	340.23	476.51	631.16	806.21	1,003.93	1,226.80
Cumulative cash flow (R)	-55,093.69	-55,480.23	-55,858.51	-56,227.84	-56,572.35	-56,886.63	-57,164.61	-57,399.46	-57,583.51	-57,708.20	-65,550.95	-65,527.03	-65,411.50	-65,191.05	-64,850.82	-64,374.31	-63,743.15	-62,936.93	-61,933.00	-60,706.20

From Table 42, the payback period at WITS was achieved 17 years after implementation while at UJ (Table 45) payback could not be achieved within the 20 year design life for the infrastructure. The payback at WITS (which was within the 20 year design life of the infrastructure) resulted from larger savings in both potable water and sewage treatment due to greywater reuse for flushing 2 toilets, and the lower initial cost of the greywater system in comparison to UJ. Therefore, on the basis of users paying the full costs of the reuse systems and a preferred payback period of 8 years, the systems at WITS and UJ were economically unviable.

In many of the communities where payback has been within the preferred durations, governments have been known to provide subsidies, e.g. 50% of capital costs in Cyprus (Kambanellas, 2007) and about 50% of capital costs in Japan (Chung and White, 2010). Hence, in order to achieve a payback period of 8 years for the reuse systems, the 2009 capital costs at WITS will have to reduce to about 30% of its 2009 value (Table 46). At UJ however, an 8 year payback could only be realised when users paid only 76.5% of the recurrent costs. This means that in order to obtain a payback period of 8 years at UJ, initial (2009) capital costs, the cost for replacing 2 pumps at the end of 10 years, and 23.5% of the recurrent costs will not be borne by the user (Table 47).

Table 46. Cumulative cash flow at WITS with capital costs at 30% of initial value

Year	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*	*2021*	*2022*	*2023*	*2024*	*2025*	*2026*	*2027*	*2028*
Outflow (capital + recurrent) costs (R)	12,609.50	1,264.80	1,339.74	1,421.94	1,496.99	1,576.19	1,659.78	1,748.04	1,841.23	1,939.66	9,830.65	2,153.53	2,269.69	2,392.50	2,522.38	2,659.78	2,805.18	2,959.09	3,122.07	3,294.69
Inflow (potable water + sewage) savings (R)	2,095.24	2,293.58	2,510.86	2,748.91	3,009.71	3,295.48	3,608.59	3,951.71	4,327.72	4,739.80	5,191.43	5,686.44	6,229.01	6,823.76	7,475.73	8,190.46	8,974.04	9,833.14	10,775.09	11,807.92
Net cash flow (R)	-10,514.26	1,028.78	1,171.12	1,326.97	1,512.73	1,719.29	1,948.81	2,203.68	2,486.50	2,800.14	-4,639.21	3,532.90	3,959.32	4,431.26	4,953.35	5,530.68	6,168.86	6,874.05	7,653.02	8,513.23
Cumulative cash flow (R)	-10,514.26	-9,485.48	-8,314.36	-6,987.39	-5,474.67	-3,755.38	-1,806.57	397.11	2,883.61	5,683.75	1,044.54	4,577.44	8,536.76	12,968.02	17,921.37	23,452.05	29,620.91	36,494.96	44,147.98	52,661.22

Table 47. Cumulative cash flow at UJ with users only paying 76.5% of present value of 2009 recurrent costs

Year	Outflow (capital + recurrent) costs (R)	Inflow (potable water + sewage) savings (R)	Net cash flow (R)	Cumulative cash flow (R)
2009	914.94	802.31	-112.63	-112.63
2010	967.57	878.26	-89.31	-201.95
2011	1,024.90	961.46	-63.44	-265.39
2012	1,087.78	1,052.61	-35.17	-300.56
2013	1,145.20	1,152.48	7.28	-293.27
2014	1,205.78	1,261.90	56.12	-237.15
2015	1,269.73	1,381.80	112.07	-125.08
2016	1,337.25	1,513.19	175.94	50.86
2017	1,408.54	1,657.17	248.63	299.49
2018	1,483.84	1,814.96	331.13	630.62
2019	1,563.39	1,987.90	424.51	1,055.13
2020	1,647.45	2,177.45	530.00	1,585.13
2021	1,736.31	2,385.21	648.90	2,234.03
2022	1,830.26	2,612.95	782.69	3,016.73
2023	1,929.62	2,862.61	932.99	3,949.71
2024	2,034.73	3,136.29	1,101.56	5,051.27
2025	2,145.96	3,436.34	1,290.38	6,341.65
2026	2,263.71	3,765.31	1,501.60	7,843.25
2027	2,388.38	4,126.00	1,737.62	9,580.87
2028	2,520.44	4,521.49	2,001.05	11,581.93

9. SUMMARY OF FINDINGS, RECOMMENDATIONS AND CONCLUSION

The question that drove the need for a South African investigation into the reuse of greywater for toilet flushing was:

"Given the increasing scarcity of high quality water resources in many South African communities and the need for sustainable supplemental water resources for large quantity but lower quality water requirements (e.g. toilet flushing), how viable are greywater reuse systems for toilet flushing in high density urban buildings?"

In response to this question, several objectives were framed within context of the triple bottom line attributes of sustainability, i.e.:

i. To review knowledge and experience in greywater reuse and reuse systems specifically for toilet flushing;
ii. To interrogate regulations and guidelines pertaining to greywater reuse for toilet flushing in South Africa and to propose a structure for a national guideline;
iii. To collate a database of locally available greywater reuse systems suitable for toilet flushing and to develop a robust framework for evaluating these systems for local implementation;
iv. To monitor perceptions of potential and actual beneficiaries towards the implementation of greywater reuse systems primarily for toilet flushing;
v. To implement and monitor a pilot greywater reuse system for toilet flushing at 2 distinct water users, i.e. a residential and educational building; and
vi. To undertake an economical analysis of the pilot greywater reuse systems;

The above objectives were achieved through undertaking several tasks, i.e. a detailed literature survey, which attempted to garner varied local and international experiences regarding greywater reuse for toilet flushing; an extensive review of regulations and guidelines pertaining to greywater reuse and the development of a proposed structure for a national guideline; the development of a database of locally available greywater reuse systems for toilet flushing and a framework to guide the evaluation of the diverse systems or similar technologies; implementation of a pilot greywater reuse system for toilet flushing in a non-residential (educational) and residential (student residence) building, and monitoring certain parameters over time;

surveys of perceptions across potential and actual users of the implemented pilot greywater reuse systems over time and awareness exercises; and an economical analysis (using payback period) of the pilot systems.

The following sections summarise the findings of this project and recommendations for the future. These sections are classified according to the social and economic attributes of sustainability which helped to frame the objectives and tasks carried out in this project.

9.1. Summary of findings and recommendations related to the social (including regulatory) attribute

9.1.1. Summary of findings and recommendations relating to perceptions

i. Amongst the potential uses for greywater presented to respondents in this study (i.e. toilet flushing and irrigation), toilet flushing was the preferred use. This was due to the perception of possibly lesser contact with the greywater if used for flushing than if used for irrigation. In essence, the further away the greywater was to dermal contact or ingestion, the better for respondents. Reinforcing this perception was the preference amongst respondents for the pilot systems to be installed in non-residential (public) than residential (private) buildings. It was therefore no surprise to see that the overall assessment of the pilot greywater system after about 7 months of operation (Table 37) received a higher pass mark from respondents at WITS (non-residential) (78 out of 90 = 87%) than at UJ (residential) (9 out of 15=60%);

ii. Prior to the implementation of the pilot greywater reuse systems at the 2 sites, most of the respondents surveyed affirmed that the concept of greywater reuse for toilet flushing was a good idea that could benefit the environment (Table 33). After implementation of the systems, and the problems and/or discomforts experienced by the respondents (e.g. turbid/foamy greywater in the toilet bowls often forming an unsightly ring, unpleasant odours during flushing during certain times, and back flow of greywater from the 1st floor drain into the ground floor bath tub and shower at UJ) there was increased concern about hygiene.

Surprisingly, this did not negate the earlier affirmation about the concept of greywater reuse, nor did it result in the reduced use of the greywater toilets (Table 36). The pro-action of the project team in regularly allaying concerns during the awareness sessions and speedily rectifying reported problems is suspected to have played a significant role in sustaining positive perceptions amongst respondents.

In essence therefore, a critical component that will sustain beneficiaries' confidence in greywater reuse for toilet flushing (or similar interventions using non-conventional water resources) and the effective functioning of these systems, will be the pro-active and regular community engagement, awareness and maintenance/repair interventions. At the onset of projects of this nature, beneficiaries often need to be assured that the systems are not a threat to health, are hygienic, and can be reliably operated and it is the responsibility of the implementing authorities to guarantee this until such a time that beneficiaries are confident to operate the systems themselves. In addition, based on the negative user perceptions due to the unpleasant visual appearance of the greywater, it is evident that greywater systems will need to include a final, polishing filter to significantly reduce turbidity and remove scum from the greywater prior to use;

iii. With regards to demographics, respondents younger than 21 years were generally more comfortable about greywater reuse than older respondents and therefore should be targeted when considering greywater reuse for toilet flushing (or similar non-conventional water resource use interventions);

9.1.2. Summary of findings and recommendations relating to regulations and guidelines

From the review of regulations and guidelines conducted and the overview of government's broad position regarding greywater reuse for various uses, some key issues worth noting are listed below:

i. In South Africa, there are no national regulations specifically addressing greywater reuse and management. There are however some sections/clauses in broad regulations (i.e. EAF, 1984; DWAF, 2001; DWAF, 2004a; and DWAF, 2004c) and by-laws (CoCT, 2010; The Durban Metro, 2008; and The Moses Kotane Local Municipality Water and Sanitation By-Laws, 2008) which address greywater reuse and/or management, albeit to differing degrees of detail. In these sections/clauses, there is no fundamental objection in principle to the use of household greywater for toilet flushing, as long as nuisances, which compromise public health and the pollution status of the environment, are avoided. In fact, in most of the pronouncements made by national governments (Table 14), there is encouragement to reuse greywater for flushing toilets. What is missing is the absence of national regulations which has created a chasm between national governments' unequivocal encouragement for greywater reuse for toilet flushing (and irrigation) and the actual implementation of greywater reuse and reuse systems in provinces, municipalities, institutions and households;

ii. Developing a national regulation that specifically addresses greywater reuse and management would require input from different departments, e.g. water services, water supply, sanitation and water resource management;

iii. In addition to the lack of national regulations for greywater reuse and management, is the lack of a definition for greywater as a separate wastewater stream that is distinct from blackwater (Rodda *et al*., 2010). The implication of this is that the understanding (and thus, legal position) of greywater is inconsistent amongst the various municipal councils that have by-laws addressing greywater. For example, the City of Cape Town guidelines (CoCT, 2005) define greywater as "*wastewater from the washing of laundry, personal bathing and cooking activities"* while the Moses Kotane Local Municipality Water and Sanitation By-laws (2008) understands greywater to be domestic wastewater excluding "*water derived from any kitchen ….discharges*". A national definition, and thus shared understanding of greywater is urgently needed;

iv. A consequence of the lack of national regulations is the lack of national guidelines/plumbing codes specifically addressing greywater reuse in South Africa. A nationally consistent approach to the management of health and environmental risks from greywater reuse requires high-level national guidance on risk assessment and management. These guidelines will not be mandatory and will have no formal legal status. However, their adoption will provide a shared national objective, and at the same time allow flexibility of response to different circumstances at regional and local levels (EPHC *et al*., 2006). The proposed structure for a national guideline for greywater reuse for toilet flushing is presented in Section 9.3. The proposed structure is based on the structure proposed by Rodda *et al*. (2010) for small-scale agriculture and gardens, and incorporates some of the recommendations of several guidelines that have been developed in the past for greywater use and management in South Africa, e.g. Wood *et al*., 2001; Murphy, 2006; and Carden *et al*., 2007.;

9.2. Summary of findings and recommendations relating to the economic (including technical) attribute

9.2.1. Summary of findings and recommendations relating to technical criteria

Listed below are summaries of the findings and recommendations addressing technical criteria which were involved in this study, i.e. the evaluation of greywater systems; implementation, operation and maintenance of the pilot systems; and the determination of municipal potable water savings due to greywater reuse for toilet flushing.

i. It is imperative that prior to the selection of a package plant for greywater reuse, it is evaluated alongside other plants using the proposed framework developed in this study (or similar). This is because there exists a variety of package plants which purport to treat greywater for toilet flushing but for which limited or no data is available to verify the claims. Preferably, a physical evaluation of the plant and its effluent should be carried out. If an independent institution (e.g. the South African Bureau of Standards, SABS or the Joint Acceptance Scheme for Water Services Installation Components, JASWIC) undertook the testing and certification (or non-certification) of these plants, the evaluation and selection process will be much more effective and implemented systems will function as expected;
ii. As a result of the diverse range of locally available technologies employed for greywater reuse, the quality of treated greywater, and consequently beneficiaries' perceptions, is bound to vary. The technology selected for greywater reuse in this study (i.e. low-technology and low-cost) determined the visual quality of sieved

greywater (e.g. turbid/foamy greywater and unpleasant odours) and consequently, influenced beneficiaries' perceptions;

iii. The low-technology, low-cost greywater reuse system implemented (Section 6.2) produced several pros and cons.

The pros were: (a) the systems were easy to modify to suit site conditions; and (b) the systems required no specialised skill to conduct weekly maintenance which required on average 30 minutes, and typically involved cleaning the sieves, brushing down the scum within the tank, inspecting the chlorine capsules, inserting a cistern block in the sieves, cleaning out scum in the toilet bowl and recording metered readings for electricity and water;

The cons which had a major impact on beneficiaries' perceptions were: (a) the greywater system, which did not remove scum, produced visually unpleasing (turbid/foamy) greywater especially at UJ and this was a particular concern in terms of health and hygiene for beneficiaries. In effect, the quality of influent that flowed into the system determined to a large extent the quality of effluent. To overcome this, greywater systems will need to include a final, polishing filter to significantly reduce turbidity from the greywater prior to use; (b) sieved greywater retained in the tanks for more than 48 hours and/or depleted chlorine, resulted in septic greywater which produced unpleasant smells during flushing; (c) an erroneous pipe connection at UJ resulted in greywater from the 1st floor bath and shower flowing into the ground floor bath and shower and this was a major cause for concern and discomfort for residents; (d) preliminary microbiological tests of the greywater produced by the initial implemented greywater system showed high microbiological counts, and thus the system was modified to include 2 inline chlorinators which provided increased disinfection; (e) the small volume of the tank at WITS (~200 litres) in order to reduce the retention time of the greywater often resulted in the tank emptying out during peak (teaching) periods when the frequency of toilet flushing was high. As a result, the back-up municipal potable water supply was often used, thus negating the potable water savings which were to be achieved by implementing the greywater system;

iv. In order to avoid the difficulties and consequently, additional costs associated with retrofitting greywater reuse systems for toilet flushing into existing buildings not originally designed for these systems, it is preferable that reuse be incorporated into the designs for new buildings. To achieve this, there will be need to create awareness amongst decision-makers, builders, plumbers, product manufacturers, architects, etc. to the potential of greywater reuse for toilet flushing.

v. It was difficult to appreciate the municipal potable water savings due to greywater reuse for toilet flushing due to the fact that only 2 out of 12 toilets (at WITS) and 2 out of 4 toilets (at UJ) were retrofitted for greywater flushing. However, At WITS, there was on average, a bulk potable water savings of about 6% during off-peak teaching periods and 10% during peak teaching periods due to greywater reuse for toilet flushing in 2 of the 12 toilets. In volumetric terms, this amounted to an average of about 440 litres per day during the academic term. At UJ, there was on average, a 25% saving in total potable water used for toilet flushing during the academic term. In volumetric terms, this amounted to an average of about 278 litres per day. From these results, WITS (non-residential), due to larger total potable water volumes, achieved larger potable water savings (and consequently costs) than UJ (residential);

9.2.2. Summary of findings and recommendations relating to the economic analysis of the pilot greywater systems

i. From the analysis undertaken of the implemented greywater reuse systems, the payback period at WITS was 17 years (Table 42) while at UJ (Table 45) payback could not be realised within the 20 year design life for the infrastructure. The payback at WITS (which was within the 20 year design life of the infrastructure) resulted from larger savings in both potable water and sewage treatment due to greywater reuse for flushing 2 toilets, and the lower initial cost of the greywater system in comparison to UJ. Therefore, on the basis of users paying the full costs of the reuse systems and a preferred payback period of 8 years, the systems at WITS and UJ were economically unviable;

ii. In many of the communities where payback has been within the preferred durations (8-14 years), governments have been known to provide subsidies, e.g. 50% of capital costs in Cyprus (Kambanellas, 2007) and about 50% of capital costs in Japan (Chung and White, 2010). Hence, in order to achieve a payback period of 8 years for the reuse systems, the initial costs at WITS will have to reduce to about 30% of its 2009 value (Table 46). At UJ however, an 8 year payback will only be realised when users paid only 76.5% of the recurrent costs (Table 47).

From the above, it is clear that the implemented pilot greywater reuse systems for toilet flushing will not be economically viable in relation to payback period for prospective beneficiaries unless (i) subsidies are applied; (ii) the costs of potable water and/or sewage treatment increase substantially over time; (iii) there is a larger proportion of flushing with greywater within each site resulting in increased potable water and sewage treatment savings; and/or (iv) the initial costs of these systems decrease due to market competition over time. This is especially considering the fact that the pilot systems implemented in this study, which comprised of low technology, were one of the lowest priced systems evaluated in the framework.

9.3. Proposed structure of a national guideline for greywater reuse systems for toilet flushing

Based on the key issues highlighted above, the following sub-sections present the structure of a proposed guideline for greywater reuse for toilet flushing. This structure is based on that presented by Rodda *et al.* (2010) (for consistency and ease to amalgamate if considered in the future) but adapted to greywater reuse for toilet flushing.

9.3.1. The intended users for this guideline will be:

i. Municipalities who wish to initiate, support, implement or regulate on-site greywater reuse for toilet flushing;

ii. Non-residential institutions who wish to initiate, support, implement or monitor on-site greywater reuse for toilet flushing;
iii. Residential communities and individuals who wish to plan for (or implement) greywater reuse systems for toilet flushing on their properties or in their settlements, and need guidance in doing so.

<u>9.3.2. The focus of the guidelines will be to:</u>

i. Minimize the of risks of illness in users of toilets that flush with greywater;
ii. Minimize the of risks of illness which may occur in residents or users of a building where greywater is reused for toilet flushing and where contamination of potable water supplies has a probability of occurring due to a cross-connection; and
iii. Publicize best practice in the planning, implementation, use, operation, monitoring and management of greywater systems for toilet flushing.

<u>9.3.3. Major sources of information:</u>

i. As indicated above, the major source of information employed in the development of the structure of the guideline is the Water Research Commission Report No 1639/1/10, titled "*Sustainable use of greywater in small-scale agriculture and gardens in South Africa*" by Rodda *et al*., 2010) which incorporates information and recommendations from Murphy (2006), Carden *et al*. (2007), and WHO (2006);
ii. In addition to the above references, the proposed structure below incorporates some information and recommendations from DWAF (2004a), The Official Journal of the European Union (2005), Landcom's WSUD strategy (2003), (USEPA, 2007), and Surendran & Wheatley (1998);

<u>9.3.4. The proposed elements of the guideline will be:</u>

i. Managing risks and uncertainty in greywater reuse for toilet flushing;
ii. Greywater quality: guide to greywater constituents;
iii. Greywater quality: mitigation of greywater quality;

iv. Collation of best practices regarding greywater reuse and plumbing.

Managing risks and uncertainty in greywater reuse for toilet flushing

Risks describe the probability of exposure to a hazard. In Rodda *et al*. (2010), 3 major risk management scenarios were identified, all relating to the extent of characterisation of the greywater to be used for irrigation. In order of decreasing risk and decreasing uncertainty, these were:

- Category 1: No analysis of greywater prior to use;
- Category 2: Minimum analysis of greywater prior to use (defined as pH, EC, SAR and *E. coli*), and compliance with quality limits set on these; and
- Category 3: Full analysis of greywater prior to use (defined as minimum analysis plus boron, COD, oil and grease, SS, total inorganic nitrogen and total phosphorus), and compliance with quality limits set on these.

For greywater reuse for toilet flushing, similar risk management scenarios as above could be applied. The basis for these scenarios would be the quality of greywater that can be reused for toilet flushing in decreasing order of risk and uncertainty. This categorization is important because decreasing order of risk and uncertainty is typically related to higher technologies and therefore high costs and this is often not realistic for on-site greywater reuse projects in buildings where reduction of cost is critical. Hence, by permitting higher risk and uncertainty in greywater reuse for toilet flushing (and thus lower costs) it will be necessary to prescribe certain levels of analysis of the greywater to guarantee some level of hygiene and reduced risks to health. Based on the constituents (identified in the next section) typically measured for unrestricted urban reuse, a proposed categorization is:

- Category 1: No analysis of greywater prior to use.
- Category 2: Minimum analysis of greywater prior to use (defined as BOD_5, TSS or Turbidity, Total Coliform, Faecal Coliform, *E. coli* and chlorine residual), and compliance with the quality limits set on these; and
- Category 3: Full analysis of greywater prior to use (defined as potable water quality), and compliance with quality limits set on this quality of water.

In the review of regulations and guidelines presented on unrestricted urban reuse (which incorporates toilet flushing), it is standard practice that greywater to be reused for toilet flushing is regularly analysed and mitigated. Some basic handling rules that mitigate risks when reusing greywater include (Murphy, 2006):

- Do not store greywater for more than 24 hours (and preferably no more than a few hours) before use;
- Do not use greywater if anyone on the premises is suffering from an infectious health condition; and
- Wash hands after contact with greywater.

Greywater quality: guide to greywater constituents

This sub-section is aimed at providing the quality criteria against which measured greywater constituents are compared. As sample, the section below is specifically for Category 2 (minimum analysis) listed in the sub-section above.

The constituents for inclusion in this section of the guidelines were identified from the review of regulations and guidelines (USEPA and USAID, 2004; EPHC *et al.*, 2006; Surendran and Wheatley, 1998; etc.) carried out in Chapter 4 for greywater reuse for unrestricted urban reuse (which includes toilet flushing). The table below shows the greywater constituents that should be regularly measured and the average and or maximum values or ranges against which greywater constituents may be measured.

Table 48. Greywater constituents typically measured for unrestricted urban reuse (including toilet flushing)

Constituent	Average	Maximum
BOD_5 (mg/l)	5 -10	20-30
TSS (mg/l)	5-10	20-30
Turbidity (NTU)	2	5
E. coli (cfu/100 ml)	0-10	200
Faecal coliform (cfu/100 ml)	0-10	23-200
Total coliform (cfu/100 ml)	2.2-10	23
Chlorine residual (mg/l)	>0.5	

This sub-section should also provide guidance on the greywater sampling frequency and number of samples to be collected.

Greywater quality: mitigation of greywater quality

Greywater quality typically requires mitigation to make it suitable for use in toilet flushing. Treatment may vary from primary treatment (e.g. sieving/filtering) to advanced treatment (e.g. coagulation, sedimentation, membrane filtration and UV disinfection) and there exists different treatment system configurations which have been developed and that achieve different pollutant efficiencies. A review of these technologies is presented in Chapter 5.

Collation of best practices regarding greywater reuse and plumbing.

This sub-section is intended at both minimising the risks of illness to users and residents, and presenting best practice in the planning, implementation, use, operation, monitoring and management of greywater systems for toilet flushing. Some items proceeding from the experiences garnered in this study which relate to plumbing best practice are listed below:

- Simple technological solutions should be explored for greywater reuse systems for toilet flushing so that these systems can be easy to modify, operate and maintain;
- Technological validation – It is important that greywater systems are validated by the relevant regulatory body, e.g. the South African Bureau of Standards, SABS, after conforming to certain standards. This will ensure that validated greywater reuse systems provide the expected service over the system's expected design life and discourage the proliferation of non-validated systems;
- Installation should only be carried out by designated plumbers;
- Clear design and layout specifications need to be provided for the greywater piped reticulation in relation to other infrastructural services;
- Prevent cross connections: A cross-connection is a physical connection between a potable water pipe used to supply water for potable purposes, and a greywater pipe. To prevent this, there is a need to recognise or develop procedures and regulations that prevent cross-connections. These procedures or regulations should consider the following:
  - The need to develop/recognise a uniform system of labelling and colour-coding of all pipes and greywater system components.

- Where the possibility of a cross-connection between a potable and greywater pipe exists, authorized backflow prevention devices should be installed on the potable water pipe to prevent potential backflow of greywater from the greywater pipe.
- The need to design for horizontal and vertical separation of potable and greywater pipes. The USEPA and USAID (2004) document requires a 3 m horizontal interval and a 0.3 m vertical distance between potable and non-potable pipes that are parallel to each other

- Overflow to sewer: There must be an overflow line from the greywater collection pipes to the sewer for times when there is an abundance of greywater, when harmful chemicals are introduced into the collection pipes, or other reasons. The overflow line should have the capacity to handle the total inflow into the greywater system;
- Pump systems: The pump system should be able to completely empty the storage tank if necessary to avoid extended storage of greywater;
- Prevention of accidental ingestion: In addition to pipes being clearly labelled and colour-coded, appropriate warning signs should be used on all greywater system components;
- Periodic tracer studies to detect cross-connections between potable and greywater systems should be carried out;
- Quality: Aim for greywater quality that is visually similar to municipal potable water. If not possible, ensure there is regular monitoring of treated greywater quality;
- Greywater reused for toilet flushing may need to be dyed to prevent confusion with potable water;
- Isolation valves, which allow for repair to certain parts of the system without affecting other parts, should be designed into the greywater system to minimise disruptions to normal system functionality; and
- The operational requirements of a greywater reuse system are typically dependent on the technology used. It is ideal however, that the greywater system would require minimal operation and maintenance.

9.4. Recommendations in brief

In brief, twelve key recommendations from this study in relation to greywater reuse for toilet flushing were:

i. Develop (or adopt) and enforce regulations and/or guidelines for greywater reuse;
ii. Incorporate greywater reuse for toilet flushing into the design of new buildings;
iii. Do not take the technology for granted. Select a greywater treatment technology only after a broad scrutiny and clear understanding (on the part of both the implementing agency and beneficiaries) of available technologies, how they function, operation and maintenance requirements, and the expected greywater output quality. There is no "*one size fits all*" greywater reuse technology.
iv. If possible, only select greywater treatment technologies that have received local certification by, e.g. SABS or JASWIC;
v. Insist on a purchase and prolonged (e.g. 12 month) service agreement with the supplier/manufacturer of the greywater system;
vi. Budget for regular operation and maintenance, modification, and replacement costs when installing especially low-technology and low-cost greywater treatment systems;
vii. Aim to achieve payback on the system within 8 years. Payback periods of more than 8 years are most likely to be unattractive to potential beneficiaries;
viii. Ensure greywater is collected from the correct sources within the building and that sufficient quantities of greywater for the intended use(s) can be collected;
ix. Aim for greywater quality that is visually similar to municipal potable water. If not possible, ensure there is regular monitoring and assurance of treated greywater quality and the monitoring of users' perceptions towards the quality;
x. Ensure there is regular engagement and awareness with beneficiaries before and after implementation;
xi. Target young people; and
xii. Target non-residential buildings.

9.5. Conclusion

The broad concepts of greywater reuse for toilet flushing, and potential beneficiaries' attitudes towards adopting greywater reuse for toilet flushing as one way of preserving/improving the environmental, are laudable. However, the experiences garnered from this study show that implementing greywater reuse for toilet flushing in South African high density urban buildings already supplied with municipal potable water, must be approached carefully. Implementation of greywater reuse systems for toilet flushing should only proceed after a rigorous evaluation and conclusion on several critical issues including: the availability of regulations or guidelines to which the reuse system would be accountable; consideration (on the part of both the implementing agency and beneficiaries) of the trade-offs between implementing low-technology, low-cost, high maintenance but minimum skill required, and low greywater quality reuse systems versus other greywater reuse system permutations; employing accredited greywater reuse systems; targeting the most appropriate end users, i.e. young people and non-residential buildings; achieving economic viability based on a maximum payback period of 8 years; and the need for regular beneficiary awareness and engagement operations. A cursory evaluation of the above issues would likely result in the failure of such systems.

9.6. Future work

i. A rigorous water quality testing and monitoring programme was not undertaken in this project in order to determine if the measured greywater parameters conformed to specific international standards/guidelines. An investigation into this matter will be useful to assist in the management of the risks and uncertainties associated with greywater reuse for toilet flushing;
ii. It is anticipated that greywater reuse for toilet flushing will impact on sewerage in sewered areas. Greywater reuse could potentially result in diminished sewer flow quantities, which may be insufficient to flush sewers. Diminished sewer flow quantities may also result in highly concentrated sewer wastewaters which may lead to increased odours, toxicities and resulting corrosion problems within the sewers and increased costs for treatment at wastewater treatment works. An investigation into this matter will be useful to assist in understanding the implications of implementing city-wide greywater reuse systems for toilet flushing;

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APPENDIX A. DATABASE OF LOCALLY AVAILABLE GREYWATER TREATMENT UNITS FOR TOILET FLUSHING

APPENDIX A1: LIST OF LOCALLY AVAILABLE GREYWATER TREATMENT UNIT MANUFACTURERS/SUPPLIERS FOR TOILET FLUSHING

Company Name	Email	Website
Amitek Solution	info@amitek.co.za	http://www.amitek.co.za
Aquator MBR Technology		http://www.vwsenvig.co.za
Beacon Watertech		
Bio Remediation Consultants		
Biobox W&WW treatment system	info@biobox.co.za	http://www.biobox.co.za
Biwater(PTY)LTD	corporate.communications@biwater.com	www.biwater.co.za
Chem-free Aqua Pty	info@chemfreeaqua.com	www.chemfreeaqua.com
Clearage project	luke@clearaedgeprojects.com	www.clearedgeprojects.com
David Harris Engineering Sytems		
Effluent management		
Fam System	juan@famsys.co.za	www.famsystems.com
Flowline Technology		http://flowlinetechnology.co.za
Hemcro Africa	hennie@hemcro.co.za	www.hemcro.co.za
Lilliput Sewage treatment	mross@mweb.co.za	http://www.lilliput.za.net
Overberg Water		www.overbergwater.co.za
Ozone services	office@ozonize.co.za	http://www.ozonize.co.za/
Pontos	detlev.traut@akwadoc.co.za	www.pontos.aquacycle.com
Prentec	prentec@iafrica.com	
SAME SA mechanical ErectionPty Ltd	same@netactive.co.za	
Sannitree	info@sannitree.co.za brian@sannitree.co.za	http://www.sannitree.co.za/
Scarab technologies CC	steve@scarabsa.co.za gordon@scarabsa.co.za	www.scarabsa.co.za
Siyageza systems CC		
Sud-Chemie Water and process Technology(Pty) Ltd	scsa@sc-world.co.za	www.seperations.co.za
Sustainable Living Projects (SLP)	Zeke@sustainableprojects.co.za	www.sustainableprojects.co.za
Swan's water treatment(Pty) Ltd	peter@swanswatertreatment .co.za	www.swanswatertreatment.co.za
Tecroveer		www.tecroveer.co.za
Total Water Solutions	info@totalwatersolutions.com.au	
Water-Rhapsody	info@water-rhapsody.co.za	www.water-rhapsody.co.za
Wettech SA	erich@wettech-sa.com	www.wettech-sa.com
WPCP Water Purification Chemical and Plants	ipmdbn@iafrica.com	

APPENDIX A2: TEMPLATE LETTER AND QUESTIONNAIRE FOR GREY/WASTE WATER REUSE SYSTEM MANUFACTURERS/SUPPLIERS

School of Civil and Environmental Engineering

Private Bag 3, WITS 2050. South Africa *Tel: +27 11 717-7104 *Fax: +27 11 717 7045

Date:

Address:

Dear Sir/Madam,

DEVELOPMENT OF A FRAMEWORK FOR SELECTING GREY/WASTE WATER TREATMENT PACKAGE PLANTS FOR EFFLUENT REUSE IN TOILET FLUSHING

A group of researchers from the Universities of the Witwatersrand, Johannesburg and Cape Town have been awarded a Water Research Commission project (K5/1821) titled “Dual grey and drinking water reticulation systems for high-density urban residential dwellings in South Africa”. Within this project, a framework and database is to be developed to guide decision-makers in the selection of locally available grey/waste water treatment units that can produce treated effluent for reuse in toilet flushing. This information, we believe, will assist decision-makers, institutions, individuals, households and communities intending to implement a dual greywater reticulation system.

As an institution in South Africa involved in the development of grey/waste water treatment units, we would appreciate if you would provide us with details of one or more of your units that may be used in producing treated effluent for toilet flushing. The table on the next page may be used as a guide.

Your positive response to this request, at your earliest convenience, will be most appreciated.

Yours truly,

Mr Olawale Olanrewaju; Ph.D. candidate

011 717 7112; 011 717 7104 (Fax); 079 900 7931;OLAWALE.OLANREWAJU@STUDENTS.WITS.AC.ZA

Dr. Adesola A. Ilemobade; WRC K5/1821 Project leader

011 717 7153; 086 553 5330 (Fax); 072 128 2903; ADESOLA.ILEMOBADE@WITS.AC.ZA

DEFINITIONS:

- ***Greywater*** *– wastewater originating from showers, baths, and hand wash basins;*
- ***Treated greywater*** *– greywater that has passed through some processes to remove impurities (e.g. soaps & dirt). Treated greywater can be used to meet some water needs (e.g. toilet flushing);*
- ***A dual water distribution system*** *– separate pipes supplying drinking water & treated greywater to a building for drinking and non-drinking (e.g. toilet/urinal flushing) water needs respectively.*

<table>
<tr><td>Company/Logo</td><td colspan="4"></td></tr>
<tr><td>Features of the package plant (e.g. treatment technology)</td><td colspan="4"></td></tr>
<tr><td>Operating range in L/Hour or L/Day</td><td colspan="4"></td></tr>
<tr><td>Cost of purchasing the plant
Approximate cost of operating the plant</td><td colspan="4"></td></tr>
<tr><td>Maintenance requirements</td><td colspan="4"></td></tr>
<tr><td>Energy consumption</td><td colspan="4"></td></tr>
<tr><td>Footprint</td><td colspan="4"></td></tr>
<tr><td>Storage capacity</td><td colspan="4"></td></tr>
<tr><td>Expected functional life of the plant</td><td colspan="4"></td></tr>
<tr><td rowspan="2">Level of skill required for operation and maintenance.</td><td>High</td><td colspan="2">Moderate</td><td>Low</td></tr>
<tr><td></td><td colspan="2"></td><td></td></tr>
<tr><td rowspan="2">Ease to Upgrade</td><td colspan="2">Yes</td><td colspan="2">No</td></tr>
<tr><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td rowspan="15">Quality of the treated effluent after processing within the package plant (a single value or range would be acceptable)</td><td colspan="4">Physical quality</td></tr>
<tr><td colspan="2">Suspended Solids (mg.ℓ-1)</td><td colspan="2"></td></tr>
<tr><td colspan="2">Turbidity (NTU)</td><td colspan="2"></td></tr>
<tr><td colspan="4">Chemical quality</td></tr>
<tr><td colspan="2">• pH</td><td colspan="2">•</td></tr>
<tr><td colspan="2">• Chemical Oxygen Demand (mg.ℓ-1)</td><td colspan="2">•</td></tr>
<tr><td colspan="2">Biochemical Oxygen Demand (mg.ℓ-1)</td><td colspan="2"></td></tr>
<tr><td colspan="2">Ammonia (mg.ℓ-1)</td><td colspan="2"></td></tr>
<tr><td colspan="2">Total Nitrogen (mg.ℓ-1)</td><td colspan="2"></td></tr>
<tr><td colspan="2">Free Chlorine (mg.ℓ-1)</td><td colspan="2"></td></tr>
<tr><td colspan="2">Phosphorous (mg.ℓ-1)</td><td colspan="2"></td></tr>
<tr><td colspan="4">Microbiological quality</td></tr>
<tr><td colspan="2">Faecal Coliform (100 mℓ-1)</td><td colspan="2"></td></tr>
<tr><td colspan="2">Total Coliform (100 mℓ-1)</td><td colspan="2"></td></tr>
<tr><td colspan="4" style="display:none"></td></tr>
<tr><td>Physical address:
URL:
Email :</td><td colspan="4"></td></tr>
</table>

APPENDIX B. PERCEPTION SURVEY QUESTIONNAIRES

APPENDIX B1. QUESTIONNAIRE 1 ADMINISTERED PRIOR TO AND IMMEDIATELY AFTER GREYWATER SYSTEM IMPLEMENTATION

WRC UNIVERSITY OF JOHANNESBURG UNIVERSITY OF CAPE TOWN IYUNIVESITHI YASEKAPA • UNIVERSITEIT VAN KAAPSTAD UNIVERSITY OF THE WITWATERSRAND JOHANNESBURG

AIM: This questionnaire aims to determine (i) perceptions to using treated greywater for toilet/urinal flushing or garden watering and (ii) willingness to use a dual water distribution system. Your responses will be confidential.

DEFINITIONS:

- **Greywater** – wastewater originating from the hand basins.
- **Treated greywater** – greywater that is filtered and disinfected for toilet flushing.
- **A greywater system** – separate pipes within a building supplying treated greywater for toilet flushing.

1. To what extent do you agree with each of the following statements? Please tick (√) against the option that is most applicable to you using the 5-point response scale provided.

Statement	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
Using treated greywater for toilet/urinal flushing or garden watering will have a positive impact on the environment					
Using treated greywater for toilet/urinal flushing or garden watering will make our limited drinking water resources go further					
I am comfortable using treated greywater for toilet/urinal flushing					
I am comfortable using treated greywater for garden watering					
I am comfortable using treated greywater originating from **other** buildings for toilet/urinal flushing or garden watering					
I am concerned about people getting sick from using treated greywater for toilet/urinal flushing					
I am concerned about people getting sick from using treated greywater for garden watering					
Using treated greywater for toilet/urinal flushing or garden watering is disgusting					
I will only be prepared to use treated greywater for toilet/urinal flushing or garden watering during a drought or water shortage					
I am comfortable for a dual water distribution system to be installed where I currently reside					
STATEMENT BELOW FOR STUDENTS & STAFF AT THE SCHOOL OF CIVIL AND ENV ENGINEERING ONLY: I am comfortable with the dual water distribution system that is installed at the School building					
I trust the relevant university authorities will ensure that the treated greywater used is safe for toilet/urinal flushing or garden watering					

2. Might there be any reasons (personal, cultural, religious, etc.) why you may not use treated greywater for toilet/urinal flushing or garden watering? Please list and briefly explain.

3.	Age bracket	☐ 15-18	☐ 19-21	☐ 22-25	☐ 26-35	☐ 36-45	☐ Above 45
4.	Current status	☐ 1st year	☐ 2nd year	☐ 3rd year	☐ 4th year		☐ ___ year
		☐ Postgraduate		☐ Academic staff		☐ Support staff	
5.	Living in university residence? (**for students only**)			☐ Yes	☐ No		
6.	Gender	☐ Male	☐ Female				
7.	Racial category	☐ Black	☐ White	☐ Asian	☐ Coloured		

8. Make any comments you have on treated greywater use, this questionnaire, the interviewer, etc.

9. Your current university ☐ WITS ☐ UJ ☐ UCT

Thank you for your time and input

APPENDIX B2. QUESTIONNAIRE 2 ADMINISTERED ABOUT 3 MONTHS AFTER GREYWATER SYSTEM IMPLEMENTATION

AIM: This questionnaire aims to determine (i) perceptions to using treated greywater for toilet flushing and (ii) willingness to use a greywater recycle system for toilet flushing. Your responses will be confidential.

DEFINITIONS:

- **Greywater** – wastewater originating from the hand basins.
- **Treated greywater** – greywater that is filtered and disinfected for toilet flushing.
- **A greywater system** – separate pipes within a building supplying treated greywater for toilet flushing.

1. To what extent do you agree with each of the following statements? Please tick (√) against the option that is most applicable to you using the 5-point response scale provided.

Statement	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
Using treated greywater for toilet flushing in the student bathrooms will have a positive impact on the environment.					
I am comfortable using treated greywater for toilet flushing.					
I am comfortable using treated greywater originating from the hand basins within the Hillman building.					
I will only use the toilet that flushes with greywater when the toilets that flush with normal water are occupied.					
I will only be prepared to use treated greywater for toilet flushing when normal water is unavailable.					
I am concerned about my health when I use the toilet that flushes with greywater.					
I am satisfied with the reduction in unpleasant smells emanating from the greywater toilet while flushing.					
I am satisfied with the improvement in the colour of the greywater.					
I would consider installing a greywater system in my household one day.					
I would recommend greywater recycling for toilet flushing to friends and family					
I am confident that the relevant authorities would ensure that the treated greywater used for toilet flushing is safe.					
	Every time (100%)	**3 out of 4 times(75%)**	**2 out of 4 times (50%)**	**1 out of 4 times (25%)**	**Not at all (0%)**
How often do you use the greywater toilet?					

2. Any comments you would like to make?

3.	Age bracket	☐ 15-18	☐ 19-21	☐ 22-25	☐ 26-35	☐ 36-45	☐ Above 45
4.	Current status	☐ 1st year	☐ 2nd year	☐ 3rd year	☐ 4th year		☐ ___ year
		☐ Postgraduate		☐ Academic staff		☐ Support staff	
5.	Living in university residence? (**for students only**)			☐ Yes	☐ No		
6.	Gender	☐ Male	☐ Female				
7.	Racial category	☐ Black	☐ White	☐ Asian	☐ Coloured		
8.	Your current university	☐ WITS	☐ UJ	☐ UCT			

Thank you for your time and input

APPENDIX B3. QUESTIONNAIRE 3 ADMINISTERED ABOUT 7 MONTHS AFTER GREYWATER SYSTEM IMPLEMENTATION

AIM: This questionnaire aims to determine (i) perceptions to using treated greywater for toilet flushing and (ii) willingness to use a greywater reuse system for toilet flushing. Your responses will be confidential.

DEFINITIONS:

- **Greywater** – wastewater originating from the bathroom hand basins only.
- **Treated greywater** – greywater that is filtered and disinfected for toilet flushing.
- **A greywater reuse system** – separate pipes within a building supplying treated greywater for toilet flushing.

1. To what extent do you agree with each of the following statements? Please tick (√) against the option that is most applicable to you using the 5-point response scale provided.

Statement	**Strongly agree**	**Agree**	**Neutral**	**Disagree**	**Strongly disagree**
I am satisfied with the reduction in unpleasant smells from the greywater toilet while flushing.					
I am satisfied with the improvement in the colour of the greywater.					
	Every time (100%)	**3 out of 4 times(75%)**	**2 out of 4 times**	**1 out of 4 times**	**Not at all (0%)**
How often do you use the greywater toilet?					
This is my overall assessment of the greywater reuse system at the School of Civil and Environmental Engineering	**Pass**		**Neutral**	**Fail**	

2. Any comments you would like to make/suggestions for improvements?

3. Age bracket ☐ 15-18 ☐ 19-21 ☐ 22-25 ☐ 26-35 ☐ 36-45 ☐ Above 45

4.	Current status	☐ 1st year	☐ 2nd year	☐ 3rd year	☐ 4th year	☐ ___ year
		☐ Postgraduate		☐ Academic staff		☐ Support staff
5.	Living in university residence? (**for students only**)			☐ Yes	☐ No	
6.	Gender	☐ Male	☐ Female			
7.	Racial category	☐ Black	☐ White	☐ Asian	☐ Coloured	
8.	Your current university	☐ WITS	☐ UJ	☐ UCT		

Thank you for your time and input

APPENDIX C: PUBLICATIONS AND OTHER OUTPUT FROM THIS STUDY

Degree related research projects

Ms K Rahube	B.Sc. (Eng) Investigational project, UCT, 2008
Mr P van Rensburg	B.Ing. (Civil Eng) Investigational project, UJ, 2009
Mr W du Plessis	B.Ing. (Civil Eng) Investigational project, UJ, 2010
Mr S Natha	B.Ing. (Civil Eng) Investigational project, UJ, 2011
Mr M van Rooyen	B.Ing. (Civil Eng) Investigational project, UJ, 2011
Ms D Botes	B.Ing. (Civil Eng) Investigational project, UJ, 2011
Ms I Deka	B.Sc. (Eng) Investigational project, WITS, 2010
Ms T Pitso,	B.Sc. (Eng) Investigational project, WITS, 2010
Ms D Maboea	B.Sc. (Eng) Investigational project, WITS, 2011
Mr P Cebani	B.Sc. (Eng) Investigational project, WITS, 2011
Mrs P Chooka	M.Sc. research project, WITS, 2010
Mr O Olanrewaju	Ph.D. research, WITS, ongoing

Conferences

- Adesola Ilemobade, Olawale Olanrewaju and Marietjie Griffioen (2011). Experiences of greywater reuse for toilet flushing within a university academic and residential building. *Proceedings*. Computing and Control in the Water Industry (CCWI) 2011 conference. Dragan A. Savic, Zoran Kapelan and David Butler (eds). Centre for Water Systems, University of Exeter, UK. 5-7 Sept.161-166.
- Ilemobade AA, Adewumi JR and van Zyl JE (2011). The use of dual water reticulation systems in South Africa: a strategic review. Water Research Commission 40 year celebration conference. Emperor's Palace, Kempton Park, South Africa. 31 Aug-01 Sept (*Invited paper*).
- O.O. Olanrewaju and A.A. Ilemobade (2011). The costs and benefits of greywater reuse in a university academic and residential building. 2nd regional conference of the Southern African Young Water Professionals (SAYWPC) 2011. CSIR International Convention Centre, Pretoria, South Africa. 5-6 July.

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Awards

- 2010. Best poster. 1st Southern Africa Young Water Professionals conference 2010. Water Institute of Southern Africa (WISA). Authored by O.O. Olanrewaju (Ph.D. student) and A.A. Ilemobade (supervisor)
- 2009. 1st prize in the Faculty of Science for Non-Presented Posters. Postgraduate Cross Faculty Symposium @ WITS. Authored by P.S. Chooka (M.Sc. student) and A.A. Ilemobade (supervisor)