INTEGRATED RISK MANAGEMENT IN THE IMPLEMENTATION OF DUAL GREY AND POTABLE WATER RETICULATION SYSTEMS IN SOUTH AFRICA.

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DECLARATION

I declare that this thesis is my own unaided work. It is being submitted for the degree of Doctor of Philosophy in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University.

(Signature of candidate)

...................day of 2012

ABSTRACT

Water is an essential and scarce resource that must be protected. Greywater reuse (GWR) presents a promising option to the growing pressure on fresh water resources. In spite of government and public interest and opportunities for water conservation, the potential for GWR has not been fully exploited in many countries, including South Africa. The limiting factors hindering GWR have been the potential risks of failure due to several factors including negative perceptions, selecting inappropriate GWR technology, economic non-viability, and hazards to beneficiaries' health due to cross-connection between a greywater pipe and a potable water pipe. If holistically and adequately addressed, these risks can be mitigated.

This thesis develops and implements integrated risk management in the implementation of dual grey and potable water reticulation systems in South Africa. This aim was achieved by undertaking research targeted at addressing five objectives i.e. (i) to monitor the evolving perceptions of users towards GWR for toilet flushing in high-density urban buildings before and after GWR implementation; (ii) to measure toilet flushing water consumption in high density urban buildings and develop a model for estimating historical toilet flushing demand; (iii) to develop and apply a robust framework for evaluating available package plants for GWR for toilet flushing; (iv) to investigate the economic viability of the implemented pilot GWR systems; and (v) to model and simulate the transport of contaminants (specifically nitrate and phosphorus) within a dual grey and potable water reticulation system. This last objective was carried out to investigate the degree of human exposure to these contaminants at various times of the day, due to varying contaminant quantities, and at different injection points.

A detailed literature survey was carried out and this provided extensive knowledge, and experience of water resources in South Africa, motivations for GWR, greywater characteristics, success and controversial GWR case studies, and lessons learnt. In addition, the literature survey focused on identifying, assessing, and quantifying potential health risks associated with the implementation of GWR for toilet flushing. The literature survey thus assisted in the development of an integrated risk management framework which was employed in this study based on various frameworks published in the literature.

The original contributions of this thesis were focused on certain technical and economic, social, and environmental risk management measures investigated, developed and/or implemented. The social measures implemented to manage and therefore mitigate the risks of failure associated with the implementation of GWR for toilet flushing at the pilot sites were the evaluation of perception surveys carried out on potential and actual beneficiaries of GWR for toilet flushing, public awareness and involvement, and an analysis of the attributes that are important to beneficiaries regarding GWR and understanding the willingness of beneficiaries to pay for some of these attributes. The above measures involved designing, administering, collecting and coding the questionnaires used to determine perceptions; regular community engagement; a review of the analytical methods available to analyse perceptions and selection of a suitable method; and modelling the factors that influence respondents' attitudes to some attributes of greywater using conjoint analysis. Levels of respondents' trust and confidence in the GWR implementing team, and the importance attributed to a pleasant smell of the greywater in comparison to colour and tariff emerged as the critical areas requiring attention.

The technical measures implemented to manage and therefore mitigate the risks of failure associated with the implementation of GWR for toilet flushing at the pilot sites includedthe development of a framework for evaluating locally available GWR systems using sustainability criteria and thus mitigating the risks associated with choosing inappropriate systems for a specific reuse application; measuring and modelling toilet flushing demand; and the analysis of the economical viability of the pilot GWR systems using cost benefit analyses. The framework developed was valuable in holistically evaluating locally available GWR technologies, although it became more evident that there were no simple formulas for selecting a technology due to the trade-offs that had to be made between the three key evaluation criteria i.e. technical, economics and public health. The model developed for estimating toilet flushing demand within a non-residential (specifically academic) building was based on 4 factors (i.e. bulk water demand, rainfall, maximum and minimum temperature) and was proven to be reliable. Economically, the cheapest of the locally available GWR systems which were implemented at WITS and UJ were not viable with payback periods at WITS and UJ computed at 18 yrs and longer than 20 yrs respectively.

The environmental measure implemented to mitigate the risks of failure associated with the implementation of GWR for toilet flushing at the pilot sites involved the modelling of greywater contaminant transport within a residential (UJ) potable water network due to accidental or deliberate ingress. Some key results that emerged from the modelling and simulation exercise were (i) the degree of human exposure to the contaminants was directly dependent on the demand occurring adjacent to the period of ingress; (ii) based on the typical quantities of nitrate and phosphorus in shower and bath greywater which has been sieved and disinfected with chlorine, there is an insignificant immediate risk to human health from ingestion of these contaminants as specified in the South African National Standards for Drinking Water; (iii) the risk of contaminant ingestion is directly proportional to the distance from the point of injection; and (iv) the movement of contaminants is affected by the demand pattern of the users and thus, if a contaminant is injected prior to or during a peak period, the contaminant is certain to reach all the water use fixtures and at a shorter space of time i.e. in minutes or seconds depending on the size of the network. Despite the low risks to human health that emerged from the contaminant analysis, it is recommended in the thesis that standard precautions be observed in the use of the greywater toilets and in the maintenance of the GWR system. For example, the use of more natural soap products that contain less chemical constituents, hand washing after toilet use, dropping the greywater toilet seat cover before flushing, and proper labelling of the greywater system.

In conclusion therefore, the planning and sustainability of GWR initiatives in South Africa will immensely benefit from addressing the above measures which have been shown to mitigate the risks of failure associated with GWR.

DEDICATION

This thesis is dedicated to God Almighty, who protected me and made it possible for me to complete this project successfully. May His Name be praised forever, Amen.

To my wife Bukola Arinola, and our lovely kids Emmanuel and Elizabeth.

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LIST OF PUBLICATIONS

Journal Articles

- **OO Olanrewaju**, AA Ilemobade and M L Griffioen. Socio-Economic Experiences of Greywater Reuse for Toilet Flushing at a University Academic and Residential Building. *Submitted for publication*.
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LIST OF SYMBOLS AND ABBREVIATIONS

BAF	Biologically aerated filter
BDOC	Biodegradable organic carbon
BOD_5	5-day Biochemical Oxygen Demand
COD	Chemical Oxygen demand
DALY	Disability Adjusted life Year
DSS	Decision Support System
DWAF	Department of Water Affairs and Forestry
EA	Environmental Agency
EC	Electrical conductivity
FC	Faecal Coliforms
GAC	Granular activated carbon
HPC	Heterotrophic plate count
LAS	Linear alkylbenzenesulfonate
LPM	liter per minute
MBAS	Methylene blue active substances
MBR	Membrane Bioreactor
MDGs	Millennium Development Goals
MLSS	mixed liquor suspended solids
NPV	Net Present Value
O & M	Operation and Maintenance
O & G	Oil and grease
RBC	Rotating Biological Contactor
SEM	Structural Equation Modelling
SAR	Sodium adsorption ratio
TBLs	Triple Bottom Lines
TC	Total Coliforms
TDS	Total Dissolved Solids
TKN	Total Kjehldahl Nitrogen
TN	Total Nitrogen
TOC	Total Organic Carbon
TOD	Total Oxygen Demand
TP	Total Phosphorus
TPB	Theory of Planned Behaviours
TS	Total Solid
TSS	Total Suspended Solids
Turb	Turbidity
USEPA	United State Environmental Protection Agency
WHO	World Health Organisation
WTP	Willingness to pay
WWTWs	Wastewater Treatment Works
XOC	Xenobiotic organic compound

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CHAPTER 1

INTRODUCTION AND BACKGROUND TO THE STUDY

1.1 Introduction

There is increasing interest in the reuse of greywater in many parts of the world, most especially in urban residential areas of industrialized and developing countries (Friedler and Hadari, 2006). This is as a result of the rapid increase in urban populations. Some other factors include climate change, which has resulted in diminishing natural water resources, changing lifestyle patterns which require increased water supplies, the requirement to reduce environmental pollution, and political and economic instability in neighbouring countries resulting in significant immigration. Today, many urban areas, even in regions that were traditionally considered as water ample (e.g. Japan and Europe), suffer from water scarcity (Friedler and Hadari, 2006).

In addition to the above, South Africa is a water scarce country with a highly skewed rainfall distribution pattern and mean annual precipitation of 464mm. This is low compared to the world average of 860 mm per annum (DEAT, 2011). Sixty five percent of South Africa's land area receives less than 500 mm per annum while 21% receives less than 200 mm of precipitation per annum (Mukheibir, 2005).

Table 1.1 depicts the six sectors of water demand totalling 12 871 x 10^6 m^3/a in the different water management areas of South Africa (DWAF, 2004). Of the six sectors, the largest proportion of water demand (62%) occurs in irrigation (DWAF 2004). In principle, not all irrigation requirements need fresh water and some non-conventional water resources, such as greywater, may suffice. Another major consumer of high quality water is toilet flushing. In the developing world such as South Africa, toilet flushing can consume 20-40 percent of the domestic water resources used in a sewered city (Sanio *et al.*, 1998). Internationally, these figures are 30% in England (Hall et al., 1998; Butler et al, 1995; and Edward and Martin, 1995), 29% in Germany (Kresig, 1991), and 28% in the USA (Konent, 1989 and Sanders and Thurow, 1983). In office and hotel developments, 35-43% of the total municipal water supply is typically used for toilet flushing while 15-20% is used for urinal flushing in the UK (Mann, 1979 and DOE, 1992). A range of 39-54% was reported by Surendran and Wheatley (1998) for water usage for toilet flushing at Loughborough University, UK. In principle also, similar to irrigation requirements, toilet flushing does not require high quality water. Any savings that can therefore be achieved from irrigation and toilet flushing will certainly make a significant difference in the reallocation of scarce fresh and potable water to other dire water needs.

Table 1.1: Water requirements (million m³/a) in the various water sectors of South Africa in 2000 (DWAF, 2004)

Water management area	Irrigation	Urban	Rural	Mining & Industry	Power Generation	Afforestation	Total requirement
Limpopo	238	34	28	14	7	1	322
Luvuvhu/Letaba	248	10	31	1	0	432	333
Crocodile West and Marico	445	547	37	127	28	0	1 184
Olifants	557	88	44	94	181	3	967
Inkomati	593	63	26	24	0	138	844
Usutu to Mhlatuze	432	50	40	91	0	104	717
Thukela	204	52	31	46	1	0	334
Upper Vaal	114	635	43	173	80	0	1 045
Middle Vaal	159	93	32	85	0	0	369
Lower Vaal	525	68	44	6	0	0	643
Mvoti to Umzimkulu	207	408	44	74	0	65	798
Mzimvubu to Keiskamma	190	99	39	0	0	46	374
Upper Orange	780	126	60	2	0	0	968
Lower Orange	977	25	17	9	0	0	1 028
Fish to Tsitsikamma	763	112	16	0	0	7	898
Gouritz	254	52	11	6	0	14	337
Olifants/Doring	356	7	6	3	0	1	373
Breede	577	39	11	0	0	6	633
Berg	301	389	14	0	0	0	704
Total for Country	**7 920** **62%**	**2 897** **23%**	**574** **4%**	**755** **6%**	**297** **2%**	**428** **3%**	**12 871** **100%**

Several water management strategies have been proposed around the world. These strategies either require the reduction of water demand or water supplementation. One area of water supplementation is the reuse of wastewater. Wastewater represents return flows from domestic and non-domestic sources. In several locations around the world, many local authorities have implemented wastewater reuse and this has been possible for several reasons including:

- the availability of reliable treatment technologies to remove contaminants (Bixio et al.,2006; Angelakis and Durham, 2008);
- growing demands by consumers for 'greener' strategies (Bixio et al.,2006);
- the aridity of a region (Jeppesen and Solley, 1994; Prathapar et al., 2005);
- significantly lower costs for recycled effluent in comparison to potable water (Prathapar et al., 2005);
- the opportunity to provide reliable water services in remote or environmentally sensitive locations;
- relieving overburdened traditional water sources;
- subsidies for households that wish to implement greywater reuse such as in Cyprus (Kambanellas 2007); and
- enforcement of greywater reuse in buildings with an area over 30,000 square meters or with potential of 100 cubic meters/day such as in Tokyo (Hanson 1997).

Greywater refers to waste water originating from showers, baths, bathroom sinks, laundry tubs and washing machines and does not includes water from toilets and urinals. In South Africa, Greywater reuse (GWR) has the potential to reduce urban potable water demand used for toilet flushing, fire fighting and irrigation by between 30 - 70% (Radcliffe, 2003). The replacement of potable water with water of a lower quality to perform these functions will help, in addition to some of the above listed motivations, towards the supply of potable water to un-serviced South African areas/populations.

Despite the several benefits of greywater reuse listed above, several risks and barriers hinder the successful implementation of greywater reuse (Mustow et al, 1998 and Ilemobade et al, 2008) e.g.:

- Economic issues such as long pay back periods and difficulties in obtaining historical operation cost data during the planning of proposed greywater reuse;

- Technical issues such as (i) insufficient information and experience on the uses and challenges (economic, technical and environmental) of various treatment plants within the South African context, thus making it difficult to select an appropriate treatment unit; and (ii) poor estimation of potable water savings that could accrue from reuse and thus under-or over-design of greywater reuse systems.
- Public health hazards that may result from the exposure to certain pathogenic organisms and/or chemical constituents in greywater;
- The lack of regulations and guidelines to steer GWR planning, implementation, operation and management; and
- Social issues such as the unwillingness of potential users to participate in GWR.

Amongst the list above, the possible hazards to public health due to pathogenic organisms (e.g. bacteria, protozoa and viruses) is the most important concern to users. The accidental ingestion of greywater containing pathogens, in particular rotaviruses, could cause severe gastrointestinal illness (Gerba et al., 1995). In dual (grey and potable) water reticulation systems, this risk of exposure to greywater can proceed from cross contamination. It can also occur through compromised components of the water mains including broken or leaking pipes, corroded corrosion pinholes, and faulty or deteriorated gaskets. Compromised sewers in close vicinity of potable water supply pipes can also become a source of contamination (Sadiq et al., 2006).

The degree of exposure to contaminants in greywater is predominantly a function of the intended application (Anda et al. 1996; Mustows et al. 1998). Harm to human health may occur through ingestion (voluntary or involuntary), skin contact or inhalation (Grayman and Buchberger, 2006). It is this risk to human health that has contributed to the limited interest in implementing greywater reuse all around the world. Therefore, in attempting to provide a safe, conducive, and sustainable environment for reuse, a risk management framework has to be developed using a triple bottom line (TBL) approach. Triple bottom line approach is an “accounting framework” that incorporates three dimensions of performance: social, environmental and financial. This differs from traditional reporting frameworks as it includes ecological (or environmental) and social measures that can be difficult to assign appropriate means of measurement. The TBL dimensions are also commonly called the three Ps: people, planet and profits. We will refer to these as the 3Ps (Slaper, 2011). Therefore in implementing the measures to reduce the risks associated with greywater reuse, there is a need to ensure that GWR is:

- Socially sustainable by ensuring that potential users and decision-makers are fully in support of the reuse project and willing to participate in its implementation;
- Technically and economically sustainable by ensuring that:
  - i.) there will be sufficient generation of greywater from the different sources which will be adequate for the potential uses;
  - ii.) reuse demand is accurately estimated in order to determine the potential savings in potable water that can be achieved and to optimally design the greywater reuse system(s);
  - iii.) the most appropriate treatment technologies for GWR (e.g. for toilet flushing) in terms of cost, reliability, and footprint is selected; and
  - iv.) the reuse of greywater is economically viable and attractive when compared with potable water;
- Environmentally sustainable by ensuring that:
  - i.) the possibility of health hazards due to exposure to greywater is minimized or adequately contained in the event of potable water contamination; and
  - ii.) the possibility of other types of contamination (e.g. ground water contamination) are minimised.

1.2 Research Problems in Greywater Reuse (GWR)

The research problems discussed below employ the same framework presented immediately above i.e. the triple bottom aspects of sustainability.

1.2.1 The social aspects of sustainability requiring investigation

Perceptions towards GWR

The successful implementation of GWR depends not only on engineering and environmental parameters but also on other factors such as the perceptions of health, safety and hygiene and therefore, willingness of potential users. Several reuse schemes have failed because decision-makers underestimated or ignored the importance of potential users' perceptions to reuse

(Lundqvist and Gleick 1997; May-Le 2004; Po et al., 2004). It is therefore critical that prior to detailed planning/implementation, perceptions of decision-makers and potential users are investigated. Although waste water reuse in South Africa has gained prominence in recent times, information on people's perceptions to GWR have not been specifically targeted and documented. The studies which have been undertaken in this subject area are Ilemobade et al. (2009a), Wilson and Pfaff (2008) and Adewumi et al. (2008).

By employing some of the factors influencing perceptions in the model presented by Po et al. (2005), Ilemobade et al. (2009a) carried out perception surveys across a spectrum of technical and non-technical water decision-makers and potential users of non-potable water in Emahlaleni, Mpumalanga Province. The surveys were carried out to determine perceptions regarding direct potable reuse of acid mine water, the use of fully or partially treated acid mine water and sewage effluent for some domestic non-potable uses, and the implementation of dual reticulation systems. In their study, the highest proportions of respondents (69%) were willing to rather use fully or partially treated sewage effluent for toilet flushing than other domestic non-potable water uses e.g. car washing (65%), landscape irrigation (54%), laundry (40%) and vegetable/crop/fruit irrigation (29%). The study also reported that the extent of the aridity of an area was a major driver for non-potable water reuse and the implementation of dual systems in South Africa, and that when tariffs for non-potable water conveyed via a piped reticulation system were lower than potable water tariffs, this encouraged non-potable water reuse.

Similarly, Adewumi et al. (2008) investigated the perceptions of institutional non-potable water consumers in the City of Cape Town where treated wastewater effluent was implemented. Adewumi (ibid) specifically investigated the major factors governing intention to use non-potable water. The authors confirmed that information played a vital role in maintaining public trust and confidence in service providers and as well as the vehicle for information sharing.

Wilson and Pfaff (2008) carried out surveys to determine if there were religious or philosophical objections to the direct potable reuse of wastewater at eThekwini Municipality. One of the objectives of their study was to determine if objections were likely to emerge amongst potential users should the municipality embark upon direct potable reuse of wastewater. The study showed that there was no fundamental religious objection to potable wastewater reuse and that the awareness about sustainability had made people to have a re-think towards greywater recycling. However, 2 major concerns identified in the study were emotional (people considered direct potable reuse as disgusting) and concerns about the technical competency of potential water service providers. The authors concluded that in general, people were not comfortable with the idea of recycling treated wastewater for potable uses.

None of the South African studies on perceptions towards GWR mentioned above specifically investigated perceptions towards greywater as a distinct non-potable water resource and toilet flushing as the preferred end use. In addition, these studies focused on reuse from a centralised municipal scale and not onsite scale which from literature obtained from other countries, predominates greywater reuse initiatives. High-density residential buildings (including halls of residence in educational institutions) generate significant volumes of greywater daily. Rather than the traditional practice of channelling greywater to wastewater treatment works, which is often a significant distance from sources of generation, onsite GWR for toilet flushing can provide tangible benefits in reducing wastewater treatment costs and encouraging appropriate use. Thus, an investigation into the perceptions of potential and actual users in relation to GWR for toilet flushing in high density urban buildings would be beneficial. If undertaken, the investigation would be valuable for decision-makers faced with managing scarce water resources for competing uses in similar high density communities.

1.2.2 The technical and economic aspects of sustainability requiring investigation

a) Estimating and modelling toilet flushing demand

As mentioned earlier, domestic toilet flushing typically consumes between 20-40% of total urban water demand (DWAF, 2007), while commercial and public institutions typically consume between 39-63% of bulk potable water supplied (Surendran and Wheatley, 1998; Lazarova et al., 2003). Hence, in designing a dual greywater reticulation system for toilet flushing, it is important to accurately estimate the toilet flushing demand and to understand its variability due to factors such as climate, culture, water tariffs, individual preferences, status and gender. In residences, toilet flushing demand is usually estimated by multiplying the number of people using a facility by the estimated number of flushes per person per unit of time (Jacobs, 2004; Wong, 2005; Ghisi et al., 2007). This conventional and crude approach can however lead to the over- or under-design of plumbing infrastructure. In commercial or public buildings, toilet flushing demand is even more difficult to estimate due to the diversity of factors influencing demand and the varying number of people using the facility at any given time.

Some studies (e.g. Froukh, 2001; Zhou et al., 2002; and van Zyl et al., 2008) show that water use can be estimated by using multiple regression analysis. In regression models, water use relationships are expressed in the form of mathematical equations showing water use as a mathematical function of one or more independent variables. The factors commonly assumed to influence water use include temperature, precipitation, marginal price, and median income. Considering the fact that non–residential buildings are a different category to residential buildings, other factors such as academic calendar (for an education institution), educational status, and gender may have an influence on toilet flushing demand. In order therefore to estimate toilet flushing demand for GWR, modelling and estimation of toilet flushing demand is imperative.

b) Evaluating the suitability of available greywater reuse technologies

Despite the general successes achieved in treating sewage at a large scale (i.e. centralised sewage treatment plants), treatment generally tends to be less effective as the volume treated decreases. Small scale treatment plants ranging in capacity from 4PE to 1000PE (PE = Population Equivalent = ±120l/day) typically fail to successfully treat sewage influent as a result of (i) small buffering capacities (ii) small plants are much more prone to treatment problems due to changes in the quality of their influent, and (iii) their small capacities, and often treatment range inflexibilities, results in them being subjected to a far greater range of hydraulic loads during a normal diurnal fluctuation inflow than do their larger counterparts (Gaydon et al., 2006). The heterogeneity of greywater composition further complicates treatment processes (Rose et al, 1991).

Three factors significantly affect greywater composition (Eriksson et al., 2002): (i) the potable water supply quality; (ii) the type of pipe materials within the piped distribution network which determine the potential for pipe leaching, and the chemical and biological processes within the biofilm on the piping walls; and (iii) the water use activities within the building generating the wastewater.

With the growth of on-site greywater reuse, the evaluation of available and appropriate greywater treatment package plants is imperative, especially with the increasing availability of novel, emerging or imported package plants for which little information and experience under local conditions are known. There are a number of decision support systems (DSS) in the field of water and wastewater treatment such as WASDA (Sairan, 2004) which assesses the technical suitability of a treatment system, and WADO and WTRNet (Hamouda et al., 2009) which assess only the technical and economical aspects of selecting treatment technologies. These DSS are limited in holistically addressing the complex dimensions of determining a suitable technology. Hence, the need for sustainability based assessment approaches (Balkema et al., 2001; Loetscher and Keller, 2002; Comas et al., 2003, Memon et al., 2007) that will incorporate technical and economic, social, and environmental criteria in the determination of appropriate package plants for specific end uses.

c) Determining the economic viability of greywater reuse

Cost benefit analysis is an economic assessment tool that can be used to assess whether an investment will provide satisfactory returns. It forms a major part of feasibility studies and provides decision makers with a tool to guide judgment on the implementation of reuse projects by evaluating the benefits and costs of a project over a determined planning horizon (Biagtan 2008, Adewumi 2011). Faruqui and Al-jayyousi (2002) published a benefit–cost ratio ranging from 2.8 to 9.4 for four household irrigation with greywater projects in Jordan. Booker (2000) demonstrated that the cost of reclaiming greywater is about 30-40% cheaper than potable water supplied to houses in Melbourne, Australia. Surendran and Wheatley (1999), March et al. (2004), and Ghisi and Ferreira (2007) determined payback periods ranging from 8 to 14years based on greywater reuse for toilet flushing in hotels and high rise buildings. Some reasons for these results include the high price of potable water and incentives from government.

In South Africa, the economic viability of GWR for toilet flushing in high density residential and non-residential buildings has not been studied. It is therefore an important area to be investigated. The economic viability of GWR depends on the costs of the treatment required to generate an effluent that is fit for use, the pipe and associated infrastructure, pumping/operations and externalities (e.g. greenhouse gas production). A detailed cost benefit analysis which includes different toilet flushing arrangements will provide a proper estimate of economic viability.

1.2.3 The environmental aspects of sustainability requiring investigation

Predicting human exposure to greywater contaminants in potable water reticulation.

With the increase in urban water reuse using dual reticulation systems, there is potential for accidental (or deliberate) injection of contaminants into potable water distribution systems. This could occur from a cross-connection between a grey and potable water pipe or from a broken or leaking greywater pipe, pinhole or gasket. For this reason, understanding the transport of specific contaminants (which pose a hazard to human health) within potable water distribution systems, so as to predict human exposure to these contaminants, is critical. Contaminant transport is complex because different contaminants display different characteristics under different conditions and contaminant transport is dependent on the potable water end uses at the time of and shortly after contamination. Contaminant transport is therefore dependent on variables such as day of contamination (weekday versus weekend), time of contamination (peak versus off-peak periods), and the number, type and volume of end-uses (e.g. toilet and shower) within the building.

Several models have been developed that address the chemical and biological reactions of contaminants in potable water distribution systems e.g. SANCHO, PICCOBIO and Chloramine Decomposition models which is also referred to as the Comprehensive Disinfection and Water Quality Model (CDWQ). The SANCHO model (Servais et al., 1995) contains a mass balance equation incorporating microbial synthesis, biodegradable organic matter utilization and the reaction of organic matters with chlorine. It predicts steady-state concentrations of heterotrophic plate count (HPC), chlorine, biodegradable organic carbon (BDOC), and fixed bacteria as a function of water residence time in pipes and reservoirs. It can also calculate biomass concentration in bulk water and service pipes. It is however limited to the analysis of straight pipes of decreasing diameter and it is not commercially available. PICCOBIO (Dukan et al.,

1996) addresses the re-growth of bacteria and is based on well-known concepts in biofilm modelling of water and wastewater treatment processes. PICCOBIO is similar to SANCHO except that it contains a multi-level biofilm growth and disinfection sub-model. It accounts for chlorine loss through reaction with the pipe and it is commercially available with a user friendly graphical interface. The CDWQ was developed to address special issues within treatment systems where chloramines are used for disinfection. CDWQ contains detailed chloramine and free chlorine chemistry that accurately model chloramines, chlorine decay and heterotrophic and nitrifying bacterial processes (Woolschlager et al., 2000). CDWQ is a complex chemical reaction system involving both kinetic rate expressions and nonlinear equilibrium relationships and it addresses the auto decomposition of monochloramine to ammonia in the presence of natural organic matter (Vikesland et al., 2001; Duirk et al., 2005; and Shang et al., 2008). The general limitation of SANCHO, PICCOBIO and CDWQ is that they study the reaction of chlorine/chloramine with organic matters in drinking water. None of the above can model the interaction of chemical contaminants in greywater such as nitrates and phosphorus within drinking water. Also, earlier models could not be modified to suit other purposes as they were developed solely to solve a specified problem. This is unlike the EPANET_MSX model which is a platform for writing codes that be used to solve different problems relating to water quality in distribution systems.

At present, the transport of chemical contaminants such as nitrates and total phosphorus in dual grey and potable water distribution systems has not been studied. The study of these two water quality parameters are critical considering the negative impact they pose on health if ingested i.e. nitrates may cause methaemoglobinaemia in infants while high levels of phosphorus may result in algae growth within the pipe network leading to unpleasant smells. These contaminants could occur through the chemical degradation of greywater introduced into a potable water supply system. It is therefore imperative that such contaminant transport and the associated risks to human health be studied.

1.3 Research Aim and Objectives

Based on the above areas of investigation, the aim of this study is to develop and implement integrated risk management in the implementation of dual grey and potable water reticulation systems in South Africa.

Specific objectives are:

1. To monitor the evolving perceptions of users towards GWR for toilet flushing in high-density urban buildings before and after the implementation of GWR.
2. To estimate toilet flushing water consumption in high density urban buildings and consequently, develop a model for this purpose.
3. To develop and apply a robust framework for evaluating available package plants for GWR for toilet flushing.
4. To investigate the economic viability of the implemented pilot GWR systems.
5. To model and simulate the transport of contaminants (specifically nitrates and phosphorus) within a dual grey and potable water reticulation system. In doing so, to investigate the degree of human exposure to these contaminants at various times of the day, due to varying contaminant quantities, and at different injection points.

1.4 Layout of thesis

This thesis contains 7 chapters. Figure 1.1 depicts the layout of the thesis.

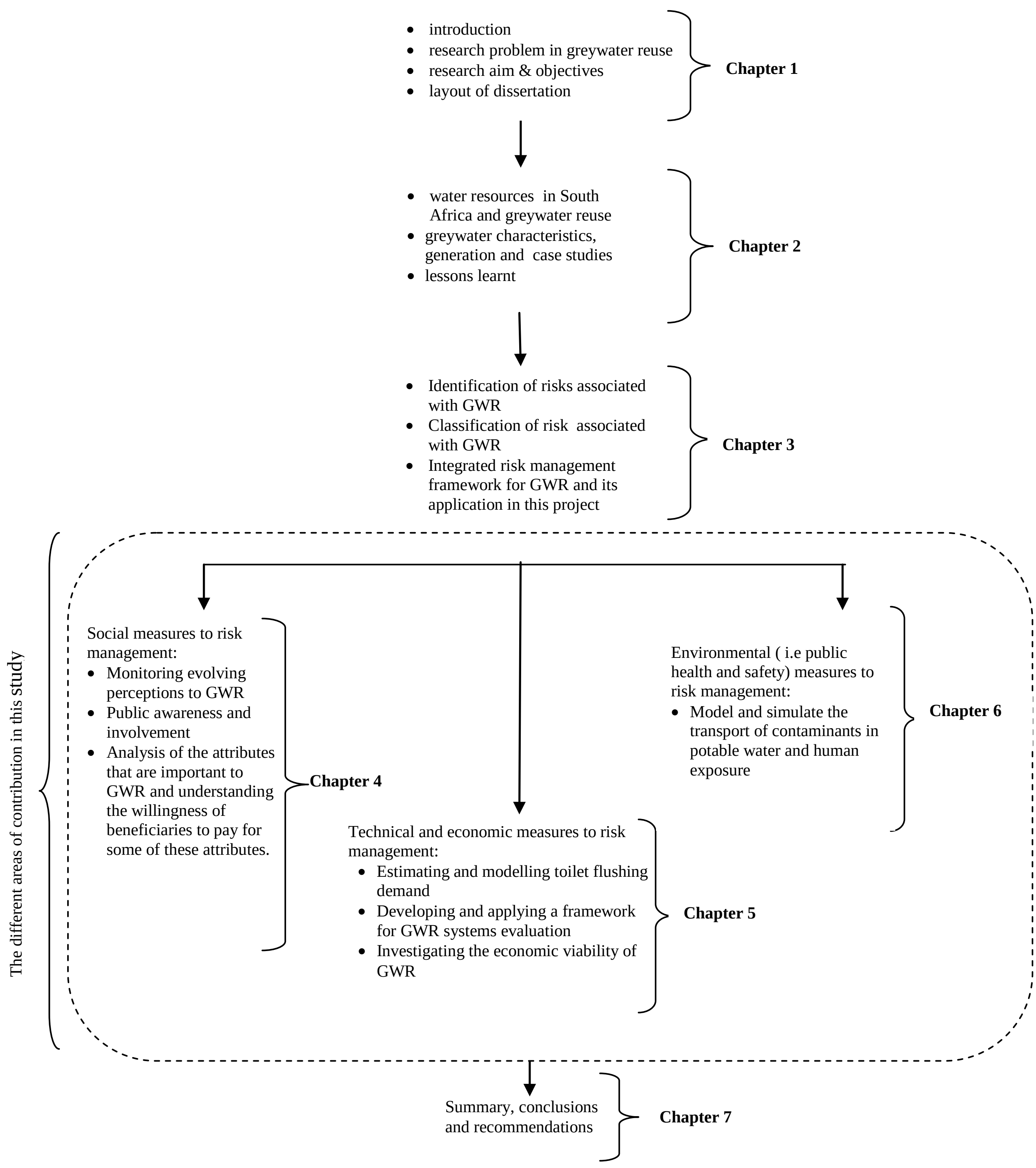


Figure 1.1: Flow chart of the thesis layout

The first chapter contains the introduction and background to the study, risks/barriers associated with GWR, and objectives addressed in this thesis. The second chapter expatiates on the current South African water resources situation and motivation/need for GWR. It provides a literature survey of greywater generation and characteristics. Success and controversial case studies of GWR around the world, and lessons learnt about some of the GWR projects are discussed in this chapter.

The third chapter focuses on the technical and economic, social and environmental risks of and objectives for sustainable wastewater reuse. The chapter also provides an integrated management framework for managing the risks identified above and other risk management frameworks as reported by the World Health Organisation, Canada Health and the Australian guidelines.

Chapter four discusses the social measures that were implemented within the pilot projects. The chapter reports on the factors that affected users perceptions to GWR; the process involved in designing, administering, collecting and coding the questionnaires used to determine perceptions; a review of the analytical methods available to analyse perceptions;, and justification for the method chosen. Lastly, factors that influence the attitudes of respondents to some attributes of greywater are modelled using conjoint analysis.

Chapter five focuses on the technical and economic risks of GWR. The chapter documents the development a framework for evaluating locally available GWR systems using sustainability criteria and thus mitigating the risk of choosing the wrong system for a specific reuse application. The chapter also documents the process of estimating and modelling toilet flushing demand, and the analysis of the economical viability of the pilot GWR systems using cost benefit analysis.

Chapter six reports on the measure employed to mitigate risks associated with public health and safety i.e. the hydraulic and water quality modelling of greywater contaminate transport within potable water networks due to accidental or deliberate ingress. Chapter seven summarises the highlights and contributions of this thesis and provides recommendations for future research.

CHAPTER 2

WATER RESOURCES IN SOUTH AFRICA AND GREYWATER REUSE

2.1 Background and motivation

South Africa is an arid to semi-arid country with its climate varying from desert and semi-desert in the west to sub-humid along the eastern coastal area. The country is highly water stressed (Figure 2.1) due to its low mean annual precipitation of about 450 mm per year, which is significantly below the world average of about 860 mm per year with evaporation comparatively high (approximately 85 percent of mean annual precipitation). The highly variable and spatial distribution of rainfall across the country as shown in Figure 2.2, adds to the sparse availability of fresh water. This is compounded by the seasonality of rainfall over virtually the entire country as well as the high within-season variability of rainfall and consequently runoff (DWAF 2004).

Groundwater plays an important role in most rural water supplies in the country. However, due to the predominant rocky nature of the South African geology, few major groundwater aquifers exist that could be utilised on a large scale (Mukheibir and Sparks, 2005). Stream flows in most South African rivers are at relatively low levels for most of the year, and the infrequent high flows that do occur, happen over limited and often, unpredictable periods. The country has no navigable rivers, and the combined flow of all the rivers in the country amounts to approximately 49 000 million m^3 per year (DWAF, 2004, Adewumi 2011). Also with several rivers already exceeding their natural availability, it was projected in 1996 that the water resources supply in South Africa may be unable to cater for anticipated overall demands by 2030 if unchecked (Basson et al., 1997, Ilemobade et al., 2008).

South Africa depends on surface water for most of its urban, industrial, and agricultural requirements with about 320 dams providing a total capacity of approximately 1 000, 000 m^3 (DWAF, 2004). To manage existing water resources, the country's hydrological basins are divided into 19 water management areas with mean annual runoff of approximately 49 000 million m^3/a. This includes water inflows of about 4 800 million m^3/a and 700 million m^3/a originating from Lesotho and Swaziland respectively (DWAF, 2004). The available yield from each water management area is shown in Table 1.1.

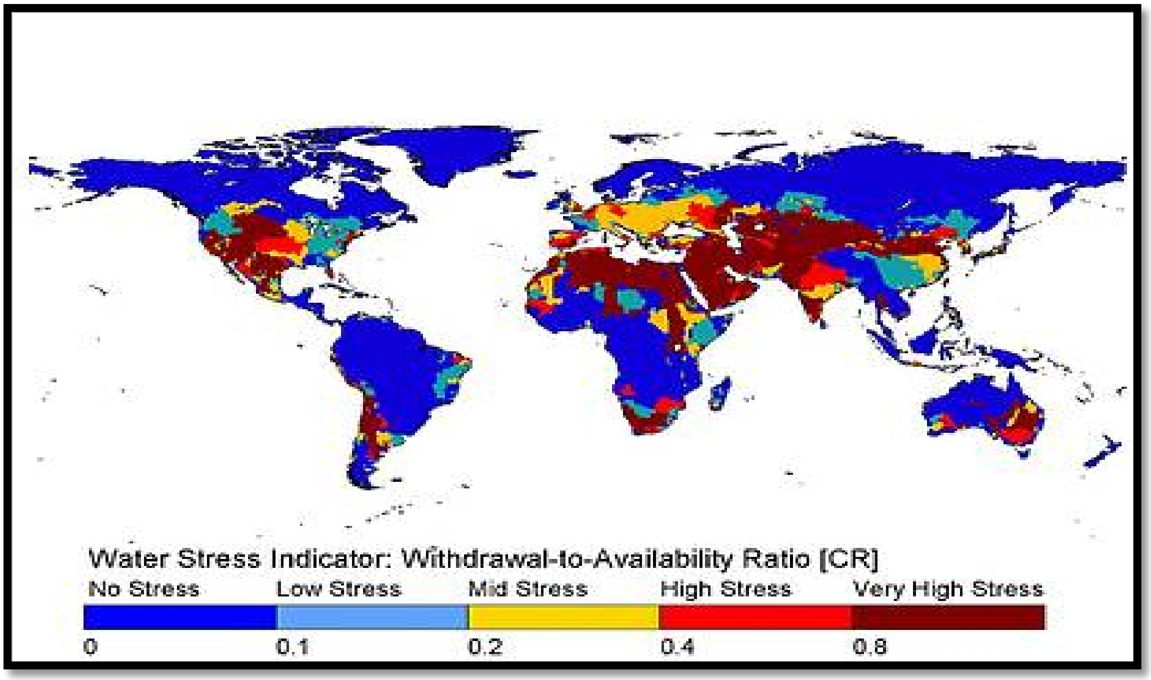


Figure 2.1: Map showing the water stress level of countries in the world. (Source: Alcamo et al. 2000).

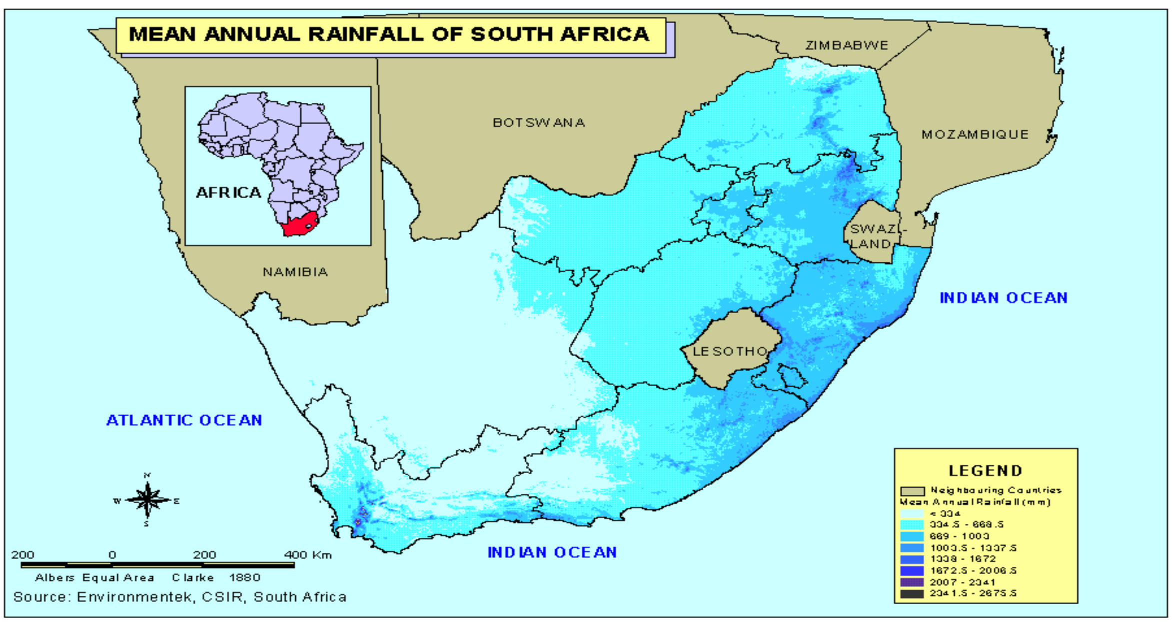


Figure 2.2: Map of South Africa showing its mean annual rainfall distribution. Source: http:// www. gis.mapsofworld.com/government/government-agencies/csir-environmentek-south-africa.html.

According to Ilemobade et al. (2008), many of the metropolitan and industrial centres of South Africa (e.g. Johannesburg, Kimberley, Rustenburg, Mokopane, Durban and Cape Town) developed around mineral deposits and harbour sites, and are located a significant distance away from major freshwater sources. Some irrigation developments in the country are also located in sub-optimal regions with respect to water use efficiency, having been established in times of relative water abundance and lower demand for water in upstream reaches. Thus, the location of several South African metropolis, industrial and agricultural areas has added to the challenges of freshwater availability.

Going by the above water situation, it is therefore important that supply and demand be efficiently managed in areas of surplus as well as deficit. Consideration has in the past, been given to other options and less conventional sources in order to augment water supplies in South Africa. These include the importation of water from the Zambezi River; rainfall augmentation by cloud seeding; shipping of fresh water from the mouths of large rivers; and towing of ice bergs. Although most are technically feasible, there are various degrees of environmental, political and legal considerations attached to them (DWAF 2004). Some water demand management initiatives have also been implemented such as leakage management, metering management, use of efficient plumbing fittings and non-potable water reuse.

The use of appropriate qualities of non potable water (i.e. greywater, rainwater, and sewage) has become an area of interest in recent times. Non-potable water may be suitable after undergoing some level of treatment for some water requirements (e.g. toilet and urinal flushing, car washing, fire-fighting, landscape irrigation, dust suppression and a variety of industrial and commercial water requirements). This process is called water reuse. Non-potable water conveyed within dual water reticulation systems presents a viable option for supplementing existing water supplies. This option is promising especially for South African settlements with limited access to freshwater sources (Mukheibir, 2005).

2.2 What is Greywater?

Domestic wastewater can be characteristically divided into three sub-categories relating to the organic strength or level of contaminants typically contained in the water i.e. (i) black water (ii) light greywater and (iii) dark greywater. Table 2.1 highlights some of the characteristics of the different wastewater types.

i. Black water is effluent from toilets and urinals and contains high concentrations of bacteria (including disease causing microorganisms), organic contaminants and ingested chemicals (e.g. pharmaceuticals).
ii. Light greywater is effluent from bathroom sinks, bath tubs, showers, and laundry. Light greywater generally has lower concentrations of contaminants than black water and dark greywater.
iii. Dark greywater includes both light greywater sources plus effluent from kitchen sinks, dishwashers, or other sinks involving food preparation. Food waste, grease/oils and cleaning products contribute to increased contaminant loading, including disease causing microorganisms.

Thus, greywater can be defined as urban wastewater that proceeds from baths tubs, showers, bathroom sinks, washing machines, dishwashers and kitchen sinks, but excludes effluent from toilets (Al-jayyousi, 2003, Ilemobade et al., 2009b). Some communities exclude kitchen effluent from its definition of greywater e.g. Jordan (Al-Joyyousi, 2003); Australia (Christova-Boal et al., 1996); Arizona, US (Little, 2002); Germany (Wilderer, 2004).

Greywater constitutes 50–80% of total household wastewater (Eriksson et al., 2002; Friedler and Hadari, 2006).

Table 2.1: Characteristics of different wastewaters

Parameter	**Metcalf and Eddy(1991)**	**Lazarova (2001)**	**Smith et al (2001)**	**Surrendran and Wheatley (1998)**	**Rose et al (1991)**	**Laine (2001)**	**Christova-Boal et al (1996)**
Wastewater type	**Black**	**Dark**	**V.light[1]**	**Light and dark**	**Light**	**Light**	**Light**
BOD^5 (mg/L)	110-400	275-530	33	216-252(light) 472-536(dark)	*	129-155	76-200
COD (mg/L)	250-1000	471-915	95	424-433(light) 725-936(dark)	*	367-587	*
SS (mg/L)	100-350	71-215	36	40-78(light) 8.8(dark)	*	58-153	48-120
NH_3H (mg/L)	12-50	0.6-18.8	*	0.5-1.6(light) 4.6-10-7(dark)	0.15-3.2	*	<0.1-15
TKN (mg/L)	*	8.9-22.8	4	*	0.6-5.2	6.6-10.4	4.6-20
TP (mg/L)	4-15	5-26.7	*	1.6-45.5(light) 15.6-101(dark)	4-35	*	0.11-1.8
TC (CFU/100ml)	10^4-10^5	$1.8x10^3$ $1.8x10^8$	$2.4x10^3$ $2.4x10^8$	$5x10^4$-$6x10^6$ $7x10^5$	$6.1x10^8$	$6.8x10^3$ $9.4x10^3$	$500-24x10^7$
FC (CFU/100ml)	*	$3.0x10^5$ $1.6x10^8$	*	32-600(light) 728(dark)	$1.8x10^4$ $7.9x10^8$	*	$170-33x10^3$
E coli (CFU/100ml)	*	$7.6x10^5$ $2.04x10^7$	0 $2.4x10^8$	*	*	$10-15x10^3$	*
*=not stated in the study; [1]=collected only from "bathroom sinks" or "hand basins"							

Source: Lazarova et al., (2003)

2.3. Greywater generation

The amount of greywater generated varies and is dependent on the unique dynamics of each household. Greywater generation is influenced by factors such as existing water supply service and infrastructure, number of household members, age distribution of household members, lifestyle characteristics, and water use pattern (Morel and Diener, 2006). Greywater volume in low-income areas with water scarcity and rudimentary forms of water supply (e.g. community taps or wells) can be as low as 20-30 litres per person while high-income households with piped reticulation may generate several hundred litres per day (see Table 2.2). Greywater volumes are even lower in regions where rivers or lakes are used for personal hygiene. Literature indicates a typical greywater generation of 90-120 l/p/d in houses with piped water (Morel and Diener, 2006, Li et al., 2009). This range corresponds with a recent report by Mandal (2011) which states an average greywater generation of 110 l/p/d, out of which 80 l/p/d was generated from bathing, cloth washing and wash basins, and 30 l/p/d from kitchen greywater.

Table 2.2: Domestic greywater generation in selected countries.

	Vietnam [1]	Mali [2]	South Africa [3]	Jordan [4]	Isreal [5]	Nepal [6]	Switzerland [7]	Australia [8]	Malaysia [9]
	l/p/d	l/p/d	l/p/d	l/p/d	l/p/d	l/p/d	l/p/d	l/p/d	l/p/d
Total	80-110	30	20	50	98	72	110	113	225
Kitchen	15-20				30		28	17	
Shower, bath	30-60				55		52	62	
Laundry	15-30				13		30	34	
Water source	In house taps	Single taps	Community tap/well	In house taps	In house taps	In house taps	In house taps	In house taps	In house taps

Note: These figures do not reflect national averages but relates to specific cases with specific settings. Type of water supply and living standards appears to be more decisive that the location.
1: Bussser(2006); 2:Aderlieste and langeveld (2005); 3: Adendorff and Stimie(2005); 4: Faruqui and Al-jayyousi (2002); 5:Friedler (200); 6:Sresha (1999) 7:helvetas (2005); 8: www.greenhouse.gov.au; 9:martin(2005)

Source: Morel and Diener, (2006)

Research on domestic wastewater inflows (Butler, 1991: Butler et al., 1995; Edwards and Martin, 1995; Surrendran and Wheatley, 1998) has shown that a morning peak discharge is followed by two other major peaks, one in the afternoon and the other in the late evening. A minimum flow period of 4 hours occurs late at night, corresponding to occupants' sleeping hours. The distribution of appliance greywater discharges shows that the smallest contribution comes from the bathroom sinks (Butler et al., 1995). In the south east of England (Butler, 1993), appliance usage patterns were more frequent in households with more occupants than in those with less occupants. On weekends, the morning appliance usage peak is extended but lesser than during the week. Butler et al. (1995) noted that the discharge from the bath and shower constitutes about 66% of the total instantaneous discharge in the morning (4-8 am) and evening periods (6-10 pm). The most significant single wastewater generating appliance of the day is the toilet and this contributes about 40% to the total instantaneous flow during the day and up to 90% at nights.

2.4. Characteristics of Greywater

The characteristics of greywater vary considerably over time and space. Three factors influence greywater composition i.e. (i) the potable water supply quality, (ii) the type of distribution network for both non-potable and potable water, and (iii) the water related activities within the building generating the wastewater (Eriksson et al. 2002). Cooking habits (if kitchen effluent is included in the greywater), as well as the amount and type of soaps and detergents used, significantly determine the level of greywater quality. The heterogeneity of greywater and the effect of storage therefore complicate both its treatment and the risks associated with its reuse (Rose et al, 1991; Liu et al, 2010). There have been several studies conducted on the characteristics of greywater owing to the fact that there is increasing interest in reuse in industrialised and developing countries. However, it is only recently that some data has emerged on the typical characteristics of greywater in low and middle income communities of South Africa.

In confirmation of the heterogeneity of greywater, Carden et al. (2007a), Engelbrecht and Murphy (2006), Salukazana et al. (2005) and Jackson et al. (2006) identify a high variability in greywater quality as can be seen in Table 2.3. Carden et al., (2007a) assessed the quality of greywater from 39 settlements in 6 of the 9 provinces of South Africa using field test kits for water quality analysis in most cases. Results from the limited testing reveal a varying concentration of total nitrogen, TKN (ranging between 0.6-488 mg/l), ortho phosphate (ranging between 0.7-769 mg/l) and COD (ranging between 32-11451 mg/l). In the study, Carden et al., (2007a) documented the different relationships between source water qualities, cleaning habits, and detergent use. For example, the temperature and hardness of the wash water affected the amount of soap or detergent required for laundry and in the absence of hot water, residents of low-income settlements tended to leave their detergent bars in the laundry water for long periods, thus resulting in large amounts of detergent dissolving in the greywater.

Engelbrecht & Murphy (2006) studied different greywater qualities from different residential locations in the Cape Peninsula area (Table 2.3). The study showed no significant difference in quality amongst the different types of greywater generated as well as amongst the different locations where greywater was generated. The variation in quality between source water and dish greywater resulted from faecal bacteria contamination during food preparation and the washing of used dishes/utensils. Household greywater was found to have high concentrations of chlorine, sodium (Na) and potassium (K) with variable levels of nitrogen (N) and phosphorous (P). The study also reported that greywater was generally alkaline and had a reasonably high sodium adsorption ratio (SAR).

Salukazana et al, (2005) also studied the characteristics of greywater in Cato Crest, Kwazulu-Natal. The results provided in Table 2.3 were obtained from eight households, selected based on the number of people per household, age, gender and washing applications (bath, bathroom sink, laundry and dish washing). The study originated from the need to address the worrying situation of inappropriate greywater management, especially in peri-urban areas. Problems related to the pooling of wastewater, which typically led to unpleasant smells, potential risks of ground water pollution and soil erosion were reported.

2.4.1. Physical characteristics

Physical parameters of relevance to GWR are temperature, colour, turbidity and suspended solids. Greywater temperature is often higher than that of the municipal potable water supply and often varies within a range of 18–30^{o}C. These temperatures are attributed to the use of warm water for personal hygiene and cooking. These temperatures are not suitable for biological treatment processes (aerobic and anaerobic digestion occurs within an optimal range of 25–35^{o}C) (Crites and Tchobanoglous, 1998). Temperatures within the typical greywater range can cause increased bacterial growth and decreased $CaCO_3$ solubility, causing precipitation in storage tanks or piping systems. Suspended solids concentrations in greywater typically range from 50–300 mg/l, but can be as high as 1,500 mg/l in isolated cases (Del Porto and Seinfeld, 1999). The highest concentrations of suspended solids are typically found in kitchen and laundry greywater. Observations in Nepal, Malaysia, Israel, Vietnam, and the United States reveal that an average suspended solids loads of 10–30 g/p/d in domestic water contributes 25–35% of the total daily suspended solids load in domestic wastewater which includes toilet wastewater (Ledin et al., 2001).

Table 2.3: Domestic greywater characteristics in selected communities of South Africa

Parameter	Unit	Salukazana (2006)		Engelbrecht and Murphy (2006)		Carden et al. (2007)
		Range for 1st trial	**Range for 2nd trial**	**Dishwater**	**Bathwater**	**All GW Source[1]**
Alkalinity	(mg/L)	300-334	300-334	10-572	14-453	*
NH_3H	(mg/L)	20	157	0.3-3	<0.1-57	0.2-44.7
BOD_5	(mg/L)	280-310	300-320	*	*	*
Cadmium	(mg/L)	<0.05	<0.05	*	*	*
Calcium	(mg/L)	<0.5	7.5	4.4-20	3.5-21	*
Chrome	(mg/L)	210	220	*	*	*
Chloride	(mg/L)	0.11	0.14	17-144	6.8-127	*
COD (mg/L)	(mg/L)	1135	1140	713-7821	70-8619	32-11451
Conductivity	(mS/m)	144-148	267	19-265	8-145	28-1763
Copper	(mg/L)	0.1	0.1	*	*	*
Lead	(mg/L)	0.2	<0.05	*	*	*
Magnesium	(mg/L)	5.6	7.1	0.5-4.9	*	*
Nickel	(mg/L)	<0.1	<0.10		*	*
Boron	(mg/L)	*	*	<0.1-9.5	<0.1-0.16	*
Nitrate+Nitrate	(mg/L)	<0.1-1.2	<0.10	<0.1-0.35	<0.1-0.6	*
Ortho Phospate	(mg/L)	11	40	0.87-131	<0.1-11	0.7-769
PH	(mg/L)	5.8-6.3	8.1	5.5-9.5	6.7-9.9	3-3-10.9
Selenium	(mg/L)	<0.05	<0.05	*	*	*
Sulphate	(mg/L)	113	137	2.7-483	2.9-51	*
TKN	(mg/L)	24-30	206	15-62	1.1-224	0.6-488
TP	(mg/L)	13	69	0.87-131	<0.1-14	*
Zinc	(mg/L)	0.22	0.22	*	*	*
Sodium	(mg/L)	*	*	25-655	6.6-192	96-1700
Potassium	(mg/L)	*	*	2.5-28	0.58-30	*
SS	(mg/L)	*	*	36-1173	0-1553	*
TC	(CFU/100ml)	$4x10^5$	$4x10^9$			*
FC	(CFU/100ml)	*	*	$0-1.0x10^8$	0-296000	*
E coli	(CFU/100ml)	$4x10^5$	$4x10^9$	$0-1.0x10^8$	0-20000	*
Oil and Grease	(mg/L)	*	*	*	*	96-1700

*=not stated in the study, [1]= greywater from all source in a non sewered settlement.

2.4.2. Chemical characteristics

The chemical parameters of relevance to greywater reuse are hydro-chemical e.g. biological and chemical oxygen demand (BOD, COD), nutrient content (nitrogen, phosphorous), pH, alkalinity, electrical conductivity, sodium adsorption ratio (SAR), heavy metals, disinfectants, bleach, surfactants and organic pollutants in detergents (Morel and Diener, 2006).

Biological and chemical oxygen demand (BOD, COD) measure organic pollution in water. COD describes the amount of oxygen required to oxidise all organic matter found in greywater while BOD describes biological oxidation through bacteria within a certain time span (typically 5 days) (Morel and Diener, 2006). The COD and BOD parameters in greywater are always dependent on the quantity of water or products used within the household (especially detergents, soaps, oils and fats) (Mourad et al., 2011). Dallas et al. (2004) observed an average BOD_5 of 167 mg/l in mixed greywater in Costa Rica with a 107 l/p/d water consumption. In Palestine, where the greywater flow from bath, kitchen and laundry averages 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). Eriksson et al. (2002) observed COD and BOD concentrations for laundry greywater ranging between 700-1800 and 50-500 mg/l respectively. However, for dark greywater, the values may range between about 10-8000 and 90-350 mg/l for COD and BOD, respectively. According to Pidou et al. (2008), BOD and COD concentrations in shower water in England are about 130-200 and 470-670 mg/l respectively. Halalsheh et al. (2008) studied greywater characteristics in Mafraq-Jordan. They found that the average COD, BOD and TSS values were 2568 mg/l, 1056 mg/l and 845 mg/l respectively.

The COD/BOD ratio is a good indicator of greywater biodegradability. A COD/BOD ratio below 2–2.5 indicates easily degradable wastewater. 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 indicate low dark greywater biodegradability with COD/BOD ratios of 2.9–3.6 (see Table 2.1) (Al-Jayyousi, 2003; Jefferson et al., 2004). This, as expected, can be attributed to the fact that biodegradability of dark greywater depends primarily on the 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 (e.g. Alcohol ether sulphate replaced Linear alkylbenzene sulfonate) (Tchobanoglous, 1991), such resistant products may still be used (e.g. in powdered laundry detergents) in low and middle-income countries.

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 in plants (Morel and Diener, 2006). High phosphorous content is sometimes observed to cause problems such as algae growth in receiving waters or within a piped distribution system. The levels of nitrogen in greywater are relatively low (urine being the main nitrogen contributor to domestic wastewater) but it is known to cause methaemoglobinaemia in infants if ingested. Kitchen wastewater is the main source of nitrogen in domestic greywater while the lowest nitrogen levels are generally observed in bathroom and laundry greywater. Nitrogen in greywater originates from ammonia and ammonia-based 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, the municipal potable water supplied can be a significant 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 the mineralisation of peat, an abundant organic material in Hanoi's groundwater aquifers (Hong Anh et al., 2003). Typical values of nitrogen in household dark greywater were found to be within a range of 5–50 mg/l. Dishwashing and laundry detergents are the main sources of phosphorous in greywater. Average phosphorous concentrations typically range from 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 in Thailand (Schouw et al., 2002) or Israel (Friedler, 2004).

There have been a few reported cases of the presence of micronutrients and other ground elements in greywater. Laundry wastewater was found to contain elevated sodium levels compared to other types of greywater. The sodium in the laundry wastewater was said to have been caused by the use of sodium such as counterion and several anionic surfactants in powder laundry detergent (Jeppesen, 1996) and the use of sodium chloride in ion-exchangers. Another study by Christova Boal et al.,(1996) reported notably high levels of zinc in the greywater. Laundry and bathroom wastewater contained 0.09–0.34 and 0.2–6.3 mg/l of Zinc respectively. The reason for the high values of zinc in bathroom wastewater was related to chlorine tablets that were used for disinfecting. These tablets were said to be acidic and may cause the leaching of zinc from the plumbing. As a result, it was suggested that systems associated with greywater collection, storage and reuse should be constructed from non-corrosive materials, for instance plastic or fibreglass (Christova Boal et al., 1996).

For easier treatment, the pH level of greywater is expected to be in the range of 6.5–8.4 (FAO, 1985; USEPA, 2004). The pH indicates whether a liquid is acidic or basic. The pH value of greywater, which strongly depends on the pH value of the water supply, usually lies within this optimal range. 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. Observations from Carden et al. (2007a) and Salukazana et al. (2005) in South Africa show that the lower limit of the pH level range may be as low as 3.3 and as high as 8.8 (see Table 2.3)

Greywater also contains salts indicated as electrical conductivity (EC, in μS/cm or ds/m). EC measures salinity of all the ions dissolved in greywater including negatively charged ions (e.g. Cl-, NO3-) and positively charged ions (e.g. Ca^{++}, Na^{+}). The most common salt is sodium chloride – the conventional table salt. Other important sources of salts are sodium-based soaps, nitrates and phosphates present in detergents and washing powders (Morel and Diener, 2006). The electrical conductivity (EC) of greywater is typically in the range of 300-1500 μS/cm, but can be as high as 2,700 μS/cm, as observed in Palestine (Burnat and Mahmoud, 2005). 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), with SAR exceeding 100 for some powder detergents (Petterson, 2001). Sodium is of special concern when applied to loamy soils poor in calcite or calcium/magnesium. High SAR may result in the degradation of well-structured soils (dispersion of soil clay minerals), thus limiting aeration and water permeability. The sodium hazard 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 (1994) observed hydraulic conductivity problems in Australian soils irrigated with wastewater containing a SAR > 3.

Greywater may contain significant amounts of fat such as oil and grease (O&G) originating mainly from kitchen sinks and dishwashers (e.g. cooking grease, vegetable oil, food grease etc.). Important O&G concentrations can also be observed in bathroom and laundry greywater, with O&G concentrations ranging between 37 and 78 mg/l and 8–35 mg/l, respectively (Christova

Boal et al., 1996). The O&G content of kitchen greywater strongly depends on the cooking and disposal habits of households. No data was found on O&G concentration specific to kitchen greywater, but values as high as 230 mg/l were observed in Jordan for mixed greywater (Al-Jayyousi, 2003), while Crites and Tchobanglous (1998) observed 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. Surfactants, also called surface-active agents, are organic chemicals altering 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 have been banned since the 1960s, these environmentally problematic organic chemicals are still used in many developing countries, e.g. Pakistan (Siddiq, 2005) and Jordan (Bino, 2004). 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. Studies conducted by Friedler (2004), Gross et al. (2005), and Shafran et al. (2005) reveal 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 greywater. A per capita production of mixed surfactants of 3.5–10 g MBAS/p/d seems realistic (Friedler, 2004; Garland et al., 2004).

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

2.4.3. Microbiological characteristics

Both direct and indirect risks of human infection arise from the presence of pathogens in greywater. These risks are affected by a number of factors including the type and infectiousness of the pathogen, amount of faecal contamination, nature and levels of treatment, potential for human exposure to the effluent, method of irrigation and types of plants grown (Myers, 1999). Pathogens such as viruses, bacteria, protozoa, and intestinal parasites are often present in greywater. These pathogens may originate from the faeces of infected persons. They can end up in greywater through hand washing after toilet use, washing of babies and children after defecation, diaper changes or diaper washing. Some pathogens may also enter the greywater system through the washing of vegetables and raw meat. Pathogens of faecal origin pose the main health risk causing diseases such as vomiting, diarrhoea, respiratory illness, anaemia, hepatitis, meningitis, paralysis and eye and skin infections (Ledin et al., 2001).

Faecal contamination of greywater, traditionally expressed by faecal indicators such as faecal coliforms, strongly depends on the age distribution of the household members. High contamination must be expected where babies and young children are present. Average concentrations are reported to be around 103–106 cfu/100 ml (see Table 2.1). Contamination can range between 107–108 cfu/100 ml in laundry or shower greywater, as observed in Costa Rica or Jordan (Al-Jayyousi, 2003; Dallas et al., 2004). Since greywater may contain high loads of easily degradable organic compounds, re-growth of enteric bacteria, such as the faecal indicators, are favoured in greywater systems (Ottoson and Stenstrom, 2003b; WHO, 2006). Hence, bacterial indicator numbers may lead to an overestimation of faecal loads and thus risk.

2.5. Cases studies of greywater reuse around the world

2.5.1. Success stories

(a) 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) and 9 floors. It is mostly occupied by foreign visitors (most of them from Scandinavia) who go 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 average hotel occupancy of 85%.

In terms of perceptions, an informative pamphlet was left in all rooms. The pamphlet included a short introduction on the importance of water management, a description of the GWR 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 (e.g. opinion on the system and the quality of water in the toilet cistern). Data from residents indicated a general satisfaction with the system. A deficiency in odour was mentioned by one customer who also gave a "fair" overall impression of his holiday period. No complaints about the system were reported to the hotel administration. The system was 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).

(b) Florianopolis, Southern Brazil

(Ghisi and Ferreira, 2007)

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

In order to estimate potable water end-use 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 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 rain water and greywater either separately or jointly. Results show that the average potential for potable water savings (using non-potable water for toilet flushing, cloth washing and cleaning) range from 39.2% to 42.7%. By using rain water alone, potable water savings ranged from 14.7% to 17.7%. When greywater alone was used, potable water savings were higher, ranging from 28.7% to 34.8%. As for the joint use of rain water and greywater, potable water savings ranged from 36.7% to 42.0%. One of the conclusions that was 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 rain water, the greywater option proved more cost effective.

(c) Institute Agronomique et Veterinaire, Rabat, Morocco

(Hamouri et al., 2007)

This pilot study was conducted in 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 produced in the showers and the toilets of the ACSA club gym was segregated thus allowing the collection of 8 m^3/d of greywater. A reservoir outside the gym collects greywater which is 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 treated in a two-step gravel/sand filtration unit. Step 1 consists of 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 (Figure 2.3) and has the following characteristics: length = 2.25 m, width = 2.0 m depth = 0.8 m, and cross sectional area = 1.6 m^2. After passing through the filters, greywater is disinfected in an Ultra Violet Tspa Teflon system (Figure 2.3). 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. Four other toilets, located on the first floor of the DRE building, were flushed with potable water and used as control toilets during comparison studies.

Figure 2.3: The reinforce concrete horizontal-flow gravel filter and UV disinfection unit

Figure 2.4: Dual piping supplies for toilet flushing

The performance of the two-step unit was satisfactory. The effluent turbidity was reduced from 28 to 2 NTU. Removal rates of COD and BOD5 were 75% and 80% respectively. Half of the nitrogen was nitrified during the filtration process. Removal rate of phosphorus was almost 50% while anionic surfactants were removed at a rate of 97%. On the contrary, the gravel/sand filter performance in Faecal Coliform removal was low and did not exceed one log Unit.

(d) Berlin, Germany

(Nolde, 1999)

Nolde (1999) presented his 10 year experiences on GWR for toilet flushing in multi –storey buildings. One of the buildings was a 400-bed hotel. The first greywater treatment plant (GW 1) was installed in a 15 m^2 basement (Berlin-Kreuzberg, Manteuelstraße 41) and it treated the greywater from showers, bathtubs and hand-wash basins for 70 persons. At the beginning of these investigations in 1989, the pilot plant had not been optimized and the biological stage consisted of a two-stage rotating bio-contactor (RBC) which was replaced in 1997 with a four-stage RBC (Fig.2.5) (Zeisel, 1999). The second greywater treatment plant (GW 2) is a two-stage Fluidized-bed reactor (Berlin-Wedding, Bornemannstraße 4) treating the greywater from a shower and bathtub of a two-person household. The system has a total volume of 165 litres (stage 1 is 105 litres and stage 2 is 60 litres) and placed above the toilet in the bathroom. Cube shaped polyurethane material was used as biofilm carrier in both stages.

Samples were taken as 24-hour quantity proportional mixed samples (GW1) or as random samples (GW 2), immediately stored without preservation at 4°C and processed within 24 hours. Influent samples were taken from the sedimentation tank (or bathtub in GW 2), and the effluent samples from the service water reservoir. For all microbiological parameters, random samples were taken, stored at 4°C and processed immediately. Testing for faecal and total coliforms followed in triplicate serial dilutions and was quantified using the Most Probable Number (MPN) method (APHA, 1980). Settled samples were taken for all parameters.

Results from RBC (GW1) showed that the effluents' BOD 7 concentration were always below the 5mg/l control limit. Although the water samples did not meet the microbiological standards of 100 cfu/ml and 1000 cfu/ml for the total bacterial count, it showed that the faecal coliforms and faecal streptococci were even below the detection limit of 0.03 bacter/ml limits. Also results from the Fluidized-bed reactor (GW2) showed that a good service water quality can be achieved with a smaller greywater system (TOC = 4-8mg/l and BOD = 5 mg/l). In addition, the water standard was achieved following the UV disinfection of the water.

Nolde (1999) concluded that biological treatment of the greywater is indispensable in order to guarantee risk-free service water for reuse applications other than potable water. The process shown in Figure 2.6 was proposed by Nolde 1999. The treatment process consisted of a sedimentation stage, biological treatment, a clearing stage and eventual UV disinfection.

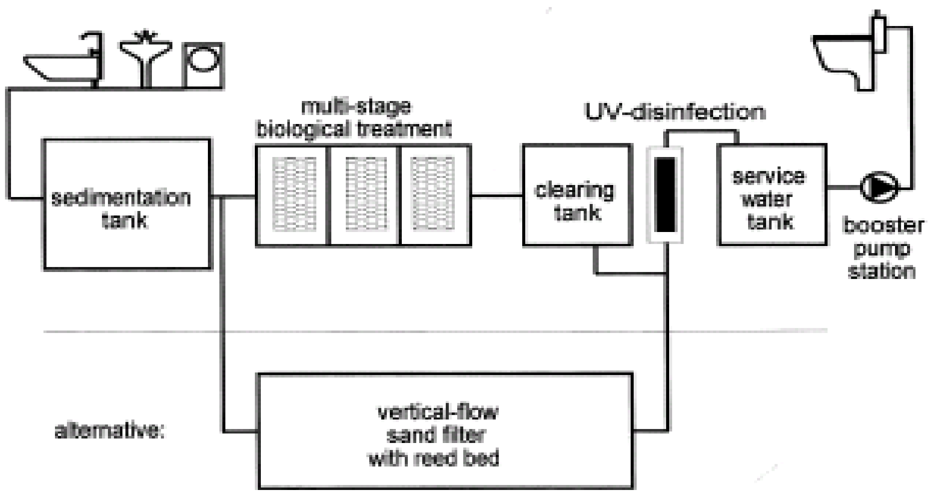


Figure 2.5: Recommended concept for greywater treatment (Nolde, 1999a).

(e) Nicosia, Cyprus

(Kambanellas, 2007)

The recycling of greywater started on an experimental basis in 1997 and continued right through 1998 by the Cyprus Water Development Department, with the support of Ministry of Agriculture, Natural Resources and Environment and Planning Bureau. The study involved the recycling of greywater in a hotel, a stadium and five houses (Kambanellas, 2004). Cyprus has a population of around 700,000 people but is visited by over 2.5 million tourists a year. The water resources in the area are almost fully developed and the greywater scheme was started as part of an initiative to conserve water at the household level.

During the experimental work, measurements were taken and it was determined that only 50% of the water supply needed to be of drinking water quality, and a plan was developed to use 'processed water' to reduce potable water demand. The first systems were installed in 1997, and seven units were installed by the end of 1998.

Greywater from laundry, baths, showers, hand-wash basins, and laundry was collected from five households and amounted to 36 litres per day or 33% of the total daily consumption. This greywater was treated, and then used to irrigate garden or stored for use in flushing toilets. The small amount of settled material accumulated was discharged into the septic system.

The cost of the household greywater recycling system with a capacity to treat 1 cubic metre per day was approximately €1400 with the government subsidizing over 50% of this cost. The decision to subsidize the greywater system was taken after the government realised that the cost saved on the quantity of water was about a quarter than if the same amount of water were supplied from a new project. A conservation of drinking water from 35% to 40% of the per capita water consumption was realized in this project.

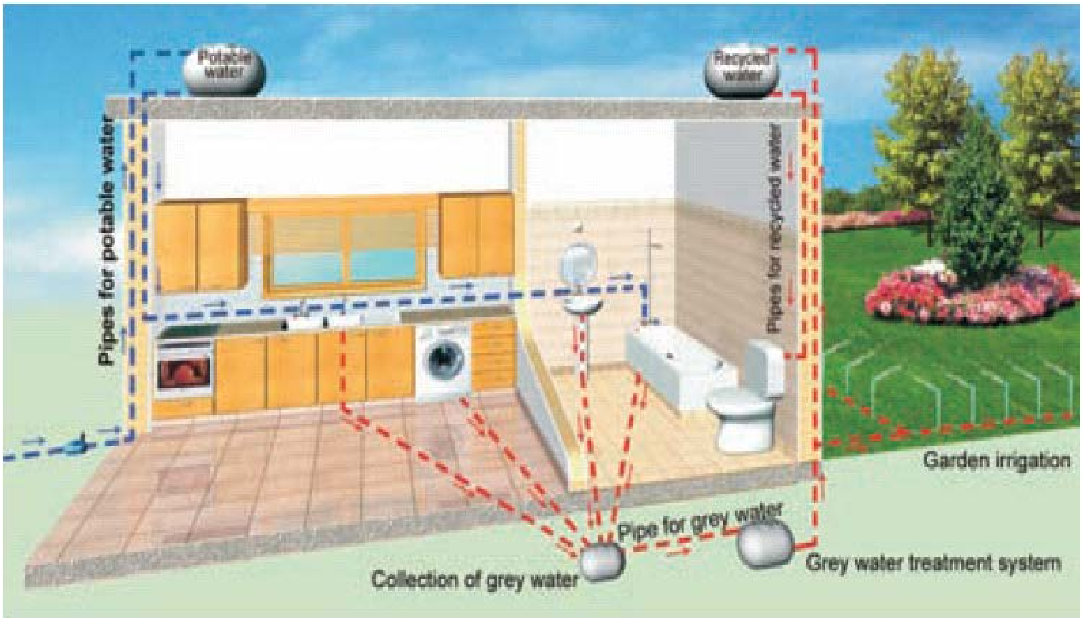


Figure 2.6: Recycling of Greywater at Household level in Nicosia, Cyprus.

(f) Loughborough University, United Kingdom

(Surendran and Wheatley, 1999)

A laboratory scale greywater treatment system and a full sized greywater system for University residences were constructed to examine the feasibility of greywater reuse at Loughborough University (Surendran and Wheatley, 1999; Surendran, 2004). The laboratory scale system had a capacity of 75 litres and consisted of four stages: 1) balancing flow and buffering peak mass loads, 2) solid separation and digestion 3) aerated bio-filter to remove organics, and 4) deep bed slow filtration to generate near potable quality. It operated for 200 days without any maintenance or disinfection. Prior to the lab scale treatment, a survey was conducted to determine people's perceptions and the survey revealed that as many as 96% of customers would accept greywater use for toilet flushing and 70% of the respondents would invest an additional 9.8% of the water bill-equivalent for long-term benefits. The dissenting respondents (4%) expressed concern about the purity and safety of recycled water. During the demonstration stage, the cost of full-scale system emerged as the major concern.

The full-scale system was built to flush toilets using greywater and rainwater. This was implemented at the university halls of residence, which house about 40 students. The full-scale system was based on the laboratory scale design with a few modifications. This system was subsequently changed to incorporate a second greywater recycling system that served 6 of the 33 students. The second full-scale system was implemented in order to test a variation of the original methods employed at the lab/full scale. The full-scale system collected greywater from 16 sinks, 2 baths, 2 showers and about $^{2}/_{3}{}^{rd}$ of the washing machine water for GWR in 4 toilets. The five treatment processes are illustrated in Figure 2.8, with the fifth being optional. These include:

1. 1400-litre raw greywater buffering tank with a filter.
2. anaerobic solids treatment tank with large pore size.
3. aerated bioreactor with large pore size foam and beads
4. active slow filter with small pore size reticulated foam, and
5. activated carbon stage (optional if potable water quality is required).

The aeration used 2.4 l/min of coarse air bubbles .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. 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 toilets. The low-level tank was equipped with a timer to initiate pumping of treated water to the high-level tank. Excess water was returned to 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 water 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, BOD5, faecal coliforms. Odour problems or sludge blockages were not experienced (Surendran and Wheatley, 1999). The unit has been evaluated to have a payback period of 8-9 years and life-span of 20years.

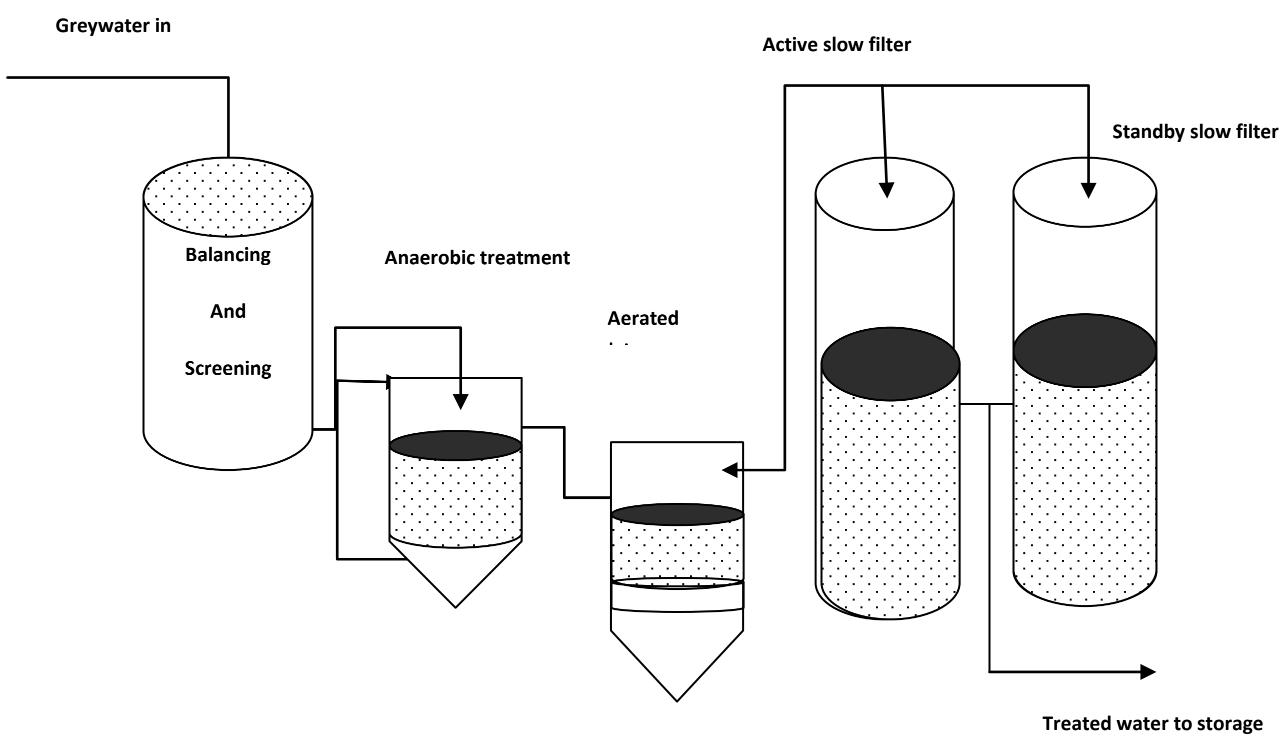


Figure 2.8: Schematic diagram of greywater treatment plant

(g) Annecy Residential Building, France

(Lazarova, 2001)

A full-scale greywater recycling scheme was set-up in a residential complex with 64 apartments (i.e. 40 buildings with approximately 120 users) in Annecy, France (Lazarova, 2001; Savoye et al., 2001). Light and dark greywater were collected from washing machines, baths, showers, washbasins, kitchen sinks and dishwashers and were treated using a membrane bioreactor (MBR) (biological treatment followed by ultra-filtration) from Ondeo Degremont. The collected greywater accounted for approximately 50–70% of the total water use within the apartments, which appeared to be more than the requirement for toilet flushing, even accounting for losses within the treatment process. The excess recycled water was discharged into the sewer or used for landscape irrigation.

Water quality monitoring demonstrated 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 TC, FC, streptococci and *E. coli*. Consequently, MBR treatment appeared to be a highly appropriate technical solution for greywater recycling, particularly in residential complexes and individual homes, 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 installations below 75 m^3/d. The annualised capital and operational cost has been estimated at 3 €/m^3 (Lazarova, 2001). This cost drops to 1.7 €/m^3 for plants of up to 300 m^3/d capacity (for installations serving more than 500 inhabitants).

(h) The Millennium Dome, London

(Hills et al., 2001)

The largest in-building recycling scheme in the UK and known as “Watercycle” 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 sufficient volumes of greywater, rain water and groundwater from site to flush all of the WCs and urinals on site (646 WCs and 191 urinals). The plant has a capacity of 500 m^3/d and served 6.5 million visitors in the year 2000.

Rain water from the Dome roof was collected in specially designed hoppers directing the roof run-off into the surface water drainage system and treated through a reed-bed system. Greywater from washbasins inside the Dome was treated using a biologically aerated filter (BAF), followed by membrane filtration. Rising groundwater from an aquifer beneath the Dome made up the required flushing volume. Preliminary tests revealed that the groundwater under the Dome was heavily contaminated and brackish, so Granular Activated Carbon (GAC) and membrane filtration were used to remove the organic contaminants and salt from the groundwater.

The BAF provided a compact and reliable treatment system for the reduction of BOD, SS and microbiological contaminants from the greywater throughout the year. Rain water was the least polluted of the 3 water sources and the reed beds and lagoon treatment process produced a high quality effluent. The ultrafiltration membranes removed particulate matter and bacteria from the mixed feed stream very effectively. Microbial analysis showed 100% removal of both TC and *E. Coli*. The reverse osmosis plant worked efficiently throughout the year and no cleaning of the membranes was necessary due to the efficiency of the UF pre-treatment (Smith et al., 2001). Overall, the scheme provided recycled water for 55% of the Dome 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 rain water contributing 19% (Hills et al., 2002). A survey carried out on a sample of Dome visitors showed that they were very positive about the use of recycled water for toilet flushing (Hills et al., 2001).

(i) Irvine Ranch Water District, California, USA

(Lewinger and Young, 1988)

Irvine was the first city recorded to use its reclaimed water for toilet-flushing on a large scale (Young et al 1994). The Irvine Ranch Water District, IRWD, is a full service water and sewer agency serving approximately 120 square miles and an existing population of 138,000 in California.

In 1987, with the planned intense 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). The project estimated that 80% of the total water used could be reclaimed water employed for toilet and urinal flushing, and landscape irrigation (Holliman, 1992; Young et al., 1994). A significant quantity of the remaining 20% could be directed to cooling tower operations. It was estimated that a 10% savings in potable water could be realised if the cooling tower supply was switched to reclaimed water.

A 66 000 m^3/d reclamation plant was constructed to provide effluent for all the targeted uses within the district (Young et al., 1994). Greywater was treated by biological oxidation, in-line chemical coagulation and dual media filtration followed by disinfection, with all the processes meeting the California State Department of Health services' Wastewater Reclamation Criteria (Holliman, 1992; Lewinger and Young,1998).

The reclaimed water contained less than 2.2 coliforms in 100 ml and was classified as type 1 or Class A of Title 22 of the California Administrative Code (Holliman, 1992). In 1991, the district was the first in the USA to obtain health department permits for the use of reclaimed water in interior spaces such as for toilet flushing (Young et al., 1998). Initially, reclaimed water was used in two high-rise buildings. By the late 1990's, the scheme was extended by connecting two 20-strorey high-rise and two low-rise buildings to dual water supply with five additional high-rise towers awaiting service.

Analyses showed that there were no noticeable difference in colour, corrosivity and odour between the reclaimed water and fresh water. The maximum measured value of COD, which was used as an indicator of the odour generation propensity, was 50mg/l.

Early results of the operation showed that fresh water demand in high-rise buildings dropped by 75 % because of the installation and use of the recycling system (Holliman, 1992). The life-cycle cost of supplying reclaimed water to at least half of the high-rise tower in the districts was less than purchasing and distributing domestic water over a 50 year period (Lewinger and young, 1988).

(j) Casa del Agua (Tucson, Arizona)
(Karpiscak et al., 1993)

Casa del Agua represents residences in Tucson that were retrofitted in 1985 with water-conserving fixtures and reuse technologies, and landscaped with drought tolerant plants. Casa del Agua is an occupied domestic residence that is also an educational project designed to facilitate research and to test domestic water use and condensation strategies, and is open to the public during scheduled hours. Modifications included retrofitting existing landscapes and enlarging the rooftop to collect and harvest rain water; separating black water and greywater disposal lines; installing meters, low-water-use appliances and fixtures, underground storage tanks for rainwater and greywater; and creating a public information center. The construction of Casa del Agua's greywater treatment and distribution system in 1985 was about US$1,500.

The Casa del Agua greywater system drains greywater from households' water–using appliances into a 55-gallon sump surge tank. A filter is fitted over the greywater drain line where it enters the sump to remove lint and hair before the water is pumped to other components of the recycling system. The sump fills to a level that activates a float switch and then greywater is pumped through an underground drip irrigation system to the landscape or for use in toilet flushing

Over the 13-plus years of actual operation, both the interior and exterior water use research results indicated that large reductions in drinking water use can be effected using water-saving devices and/or harvesting and reusing rainwater and greywater respectively. Casa del Agua achieved over 30% in municipal water used compared to the typical Tucson residence. Overall water used at Casa del Agua comprised harvested rainwater (10%), recycled greywater (20%), and municipal water (70%).

2.5.2. Controversial/failed case studies

(a) Victoria University of Technology, Melbourne, Australia

(Christova-Boal et al., 1996)

This research was conducted through the Victoria University of Technology (VUT), Australia as a Master's degree project. Technical support was given by Melbourne Water (MW), the Department of Health and Community Services (HCS) and Victoria's Environment Protection Authority (EPA). A social survey was conducted in Melbourne and showed that people were interested in reusing greywater from the bathroom and laundry. The surveyed respondents indicated a strong preference for using greywater on gardens. However, they would only consider a greywater reuse system if the pay-back period was short (2-4 years). A sampling and testing program was developed to analyze a number of typical physical, chemical and microbiological characteristics of greywater from bathroom and laundry.

Four experimental sites were selected to provide a variety of conditions in terms of topography, soil characteristics, housing type and size of family. Three houses were retrofitted to reuse greywater for garden watering and toilet flushing and one house was designed from the start with a greywater system. At the experimental sites, the removal of the suspended material was achieved by using a three-stage filter system:

- Stage 1 - a strainer (pre-filter) in the laundry trough, shower or bath outlet to remove large sized materials
- Stage 2 - a mesh filter installed in the collection tanks to collect hair, soap particles, lint and some entrapped body fats.

- 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 to the existing houses. These included insufficient hydraulic head and the consequent need to use a pump. This was because the floor level drainage outlets were near to ground level, resulting in the collection tanks being installed below ground level and the need for ground anchoring.

Lessons Learnt

Many of the difficulties encountered could have been avoided if the greywater reuse systems were included in the initial design of a house prior to its construction. The operating cost of treating the greywater was considered very high because a lot of money was spent on disposable filters. In addition, the analyses of greywater taken from the bathroom and laundry indicated that the use of detergent resulted in the greywater having high levels of sodium, zinc, aluminium and (by inference) carbonate which could be detrimental to soil conditions. The initial trials with mesh filters and disc filters using 0.1 mm mesh or 0.11 mm disc spacing clogged almost immediately. A more satisfactory performance was achieved using a larger size of filter (0.2 mm mesh and 0.17 mm disc spacing). This meant that more filtrate was collected through filters with larger surface areas. However, the incorporation of collection and storage tanks was undesirable.

(b) Linacre College, Oxford

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

The first scheme comprising a bag filter and a depth filter was built and operated by a contractor (Read, 1997). Due to severe problems, the plant was on-line only for two days. Consequently, the local water company was contacted in order to have the plant fully operational. Anglian water services Ltd, Huntigdon, undertook a series of process selection trialsls (Murrer and Wards, 1997) to identify a suitable system for the scheme, and a number of sand filters and membranes were tested. A trial house with a selected process was evaluated at a small-scale experiment to investigate the effectiveness of the treatment unit and this led to the second stage of the Linacre scheme where greywater was treated by a depth filter and a membrane.

The physical process used at Linacre was situated in an underground chamber. Greywater from baths, showers and hand basins was collected in a storage tank and filtered through a 4 inch diameter sand filter (Murrer and Ward, 1997). This was followed by a hollow fibre ultra-filtration membrane with a pore size of 0.01μm. The effluent was collected into a header tank in the loft and topped up with mains water when necessary to supply enough water for toilet flushing. The effluent was disinfected with chlorine prior to use. Some of the effluent from the ultra-filtration membrane was used for backwashing the sand filter. A 5 log reduction in bacteria was attained by treatment. Viruses were not detected in the effluent.

However, after few months of operation, it suffered some operational difficulties. The operating 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 subsequently comprised a bioreactor followed by a sand filter, an activated carbon column and chemical disinfection. Further development of the membrane cleaning procedure was done to reduce membrane fouling from fats and other organic material in the greywater treatment system.

Lessons Learnt

The failure of the first scheme was as result of the project manager not following the proper procedure in the selection of the treatment unit and due to the fact that no trial was carried out before the unit was installed. This led to the continuous breakdown of the treatment unit. The failure of the second scheme which was due to operational problems was attributed to inadequate knowledge about the operational and maintenance costs of running the treatment unit. A recommendation to proceed from this experience is that the selection of treatment units should be based on available guidelines or a framework designed to optimally guide selection. Also, a thorough cost benefit analysis should be conducted in other to understand the cost effectiveness of a GWR project.

(c) Water Dynamics systems, UK

(Sayers, 1988)

A two-year project was carried out by the UK 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 a 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 <8mg/l, but on occasions, rose to 40mg/l thus resulting in odour problems (Sayers, 1988). The following operational concerns were raised during the study:

- The need for frequent cleaning of filters due to blocking
- Pump failures occurred often times due to replacement or maintenance hence, the mains potable water 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

Improvements to 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 recycling unit and the appearance of the treated greywater aesthetically acceptable though the retrofitted 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 economic payback period was 13 years in case of a 4 person household and the most uneconomic at 138 years in case of single person household.

Lessons Learnt

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

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 economic aspects of implementing a greywater reuse project is a critical parameter that should be investigated when considering GWR.

iv.

(d) Quayside Village Vancouver, British Columbia, Canada

(Canada Mortgage and Housing Corporation (CMHC), 1998)

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:

- 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 has since been replaced by chlorination;

- A slow sand filter for automated back-washing, and
- A storage tank.

Although the system had operated for a prolonged period since implementation (>3years), there were a number of equipment failures that interfered with being able to meet the regulatory operational requirement of six continuous months. 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 thus 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.

(e) Toronto Healthy House, Toronto, Ontario, Canada

(Canada Mortgage and Housing Corporation (CMHC), 1998)

The Toronto Healthy House project resulted from a Canada wide Health Housing Design Competition. Two residences located next to one another, have no connection to the municipal potable water or sewage infrastructure, and are situated on small stands (approximately 6m by 22m of area). The dwellings rely on harvesting rain water for potable water supply, and reuse water for all other domestic water needs (i.e. toilet flushing, laundry, bath/showers and irrigation).

Black water and greywater are collected and treated for reuse as illustrated in Figure 7. The treatment process employed in the residences consisted of the following components:

- A 3 000 litre septic tank which was divided into two unequal (2/3,1/3) compartments. The first compartment was intended 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 using a venture-style aspirator, followed by a contact tank
- Storage tank

Any wastewater that was in excess of the reuse requirement of the household was discharged to a gravel bed in the front yard. A three component filter (roughing filter, slow sand filter and activated carbon filter) was originally installed but 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. Analytical parameters monitored included: microbiological (Total coliforms, E.coli and background bacteria) and chemicals for reuse (nitrate, BOD, TSS, TDS, sodium, chlorides, phosphate and ammonia). Although some reuse water qualities (i.e. BOD ,TSS and turbidity) were consistently met, the total Coliform bacteria were have not met at times and heterotrophic plate counts were often times 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 in using reuse water for showers/baths. 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 to the growth of Legion Ella. Another concern with the existing treatment system was that ozone was being released into the residence and this posed 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 treatment system:

- An ozone sensor and alarm could 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 structure.

  Either a secondary chlorination or ultraviolet disinfection could be added to both the potable and reuse water treatment systems to inhabit bacterial regrowth within the storage and distribution systems. The provincial health agency prefers to have a minimum 1mg/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.

(f) Conservation Coop, Ottawa, Ontario

(Canada Mortgage and Housing Corporation (CMHC), 1998)

Conservation co-op 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 in 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 has resulted in a normalized water use per apartment of 390 l/day compared to a typical apartment’s water consumption of 530 l/day in the Ottawa area. Bathrooms in 8 of the 84 apartments were constructed with dual plumbing systems. The plumbing systems allow 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, 1, 300 l for bath/shower water and 700 l/day for other uses (there were no laundry facilities in individual apartments).

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

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

2.6. Lessons Learnt from the Case Studies

Based on the above and Ilemobade et al., (2009a), some of the factors that hindered uptake of GWR projects were:

2.6.1. Economical issues

i. Cost is a significant barrier to a wider uptake of water recycling systems (Mustows et al., 1998). Several investigations regarding water recycling have shown that the requirements to treat greywater to prescribed standards, as is the case with sewage, will usually result in higher costs (Minh, 2005)

ii. Costs associated with greywater recycling in different locations are difficult to compare. They depend on the quality of the recycled water and the use to which it may be put. They also depend on whether the costs include infrastructure, pumping/operations and externalities (e.g. greenhouse gas production).

iii. Long payback periods tend to infer non profitability, and thus are likely to reduce interest amongst potential beneficiaries. The most cost-effective of the GWR systems reviewed had a payback period of between 5-10 years. Large housing developments seem to provide more tangible economic benefits than smaller developments or individual homes..

v. The most economic application for each GWR system reviewed scheme was in combination with rain water, with a payback of less than 6 years. However, in a survey conducted by Christova-Boal et al., (1996), most people preferred a payback period of 2-4 years. In order to implement GWR in high density urban residential dwellings in South Africa, a careful life cycle cost-benefit analysis should be carried out. Also governments must encourage individuals or communities by subsidizing the cost of providing such facilities, as is done in Cyprus (Kambanellas et al., 2007).

2.6.2. Technical issues

i. The recycling of greywater would need to be done in such a way as to avoid the build up of impurities within the system. The use of a final, polishing filter in the treatment system would therefore be an essential component of the system.

ii. Simple technologies and sand filters have been shown to have only a limited effect on greywater quality, whereas membranes have been reported to provide good solids removal but cannot efficiently tackle the organic fraction.

iii. Biological schemes achieve good general treatment of greywater with particularly good removal of organics. Micro-organism removal was found to be sufficient to meet the standards only in schemes including a disinfection stage; Membrane bioreactors were the only systems reported to achieve good microbial removal without the need for disinfection.

iv. It is difficult to give general recommendations regarding the design of greywater treatment plants, since different variables such as the type and location of the building, cost issues, government policies and legislation are some of the factors which make GWR variable to be considered. However the selected treatment plant should be capable of treating greywater to the recommended standards.

2.6.3. Social issues

i. Public perceptions are recognised as key elements of the success of GWR. The factors to consider when evaluating perceptions to GWR include information and context, communication and dialogue, trust and trust building, perceptions of fairness, and motivation and commitment to participate in decision-making (Hartley (2001).

ii. According to Po et al, (2004), people expressed their greatest opposition to the reuse of water for potable purposes but seem to accept other purposes in which the level of human contact with the reclaimed water is low e.g. toilet flushing and garden irrigation.

iii. Perception to GWR may change as consumers develop trust in the relevant water authority.

iv. Communities that have experienced water scarcity or about to, are more favourably disposed to the concept of reuse than communities in areas of water resource abundance (Ilemobade et al, 2009a).

v. Even though perceptions are linked to the success of reuse projects, one of the reasons why most reuse projects fail is because of the “fit and forget” attitude. Most surveys are conducted prior to or immediately after the implementation of the reuse system. Subsequently, complaints may not be received and attended to after the implementation, leading to the breakdown of the project. To this end, the constant involvement of the users and relevant authorities is vital and can help to build trust between authorities and consumers. This will assist in implementing quick remedies before a possible system failure. Constant dialogue and engagement will also assist in studying consumers’ attitudes to certain variables which need to be constantly monitored.

2.6.4. Institutional issues

i. Government policies can promote or mar greywater reuse. The introduction of stringent laws, policies and guidelines may reduce the interest of people who are willing to participate in greywater reuse projects. It is believed that as governments change hands, policies may also change based on the attitude of the person at the helm of affairs (Radcliffe, 2003).

ii. In South Africa, non-potable water reuse is often driven by private sector initiatives, with irrigation, mining and industry being the main uses for the non-potable water (especially treated sewage effluent) (Ilemobade et al, 2009a). As a result, many of the implemented schemes are currently being operated, maintained and/or driven by the private sector, have no formal agreements in place, do not comply with anticipated norms and standards, often not fit for use; and have no formal tariff agreements in place (i.e. no payments are being made in many instances) (Ilemobade et al, 2009a

iii. There is urgent need to develop a national regulatory document that sets out government’s policies on non-potable water use, dual systems, non-potable water licenses, and tariff structures. The DNHPD (1978) guideline document and the City of Cape Town (CCT, 2006) bye-laws may provide good starting points for this process. Also, uniform plumbing codes for dual systems should be adopted in order to present a consistent technical guide for infrastructure implementation nationwide (Ilemobade et al, 2009a).

2.6.5. Environmental and public health and safety issues

i. Most of studies conducted on health issues express a strong concern about the safety of children if exposed to non-potable water. As a result, the level of acceptance of dual systems may be based on the assurances of safety given by the service providers. Colour coding and clear identification/labelling of the non-potable pipes (in order to avoid potential cross-contamination problems) played a significant role in encouraging the acceptance of dual systems amongst some respondents previously negative to the technology (Ilemobade et al, 2009).

ii. Disinfection of greywater to a higher standard for utilization in toilet and urinal flushing is very important. Distinction of the non-potable pipe network from the potable network and extensive education about this distinction is therefore critical for system feasibility and sustainability (Ilemobade et al, 2009). This involves, interacting with and educating communities from inception about different non-potable water qualities and their potential to satisfy certain non-potable water requirements.

CHAPTER 3
RISK-BASED APPROACH TO GREYWATER REUSE

3.1 Introduction

Risk is the likelihood of an identified hazard or hazardous event that may cause harm to an exposed population. It includes the magnitude of the harm and the consequences. A risk-based approach incorporates three components i.e risk assessment, risk management, and risk communication (Haas et al, 1999). Risk assessment is the qualitative or quantitative characterization, and estimation of potential adverse health effects associated with exposure of individuals or populations to hazards. Risk management is the process of controlling risks, weighing alternatives and selecting appropriate action while, risk communication is the communication of risks to managers, stakeholders, public officials and the public (WHO, 2006).

The objectives of this chapter are as follows:

- To identify and quantify potential health risks associated with the implementation of GWR for toilet flushing. This was achieved by employing the elements of risk assessment discussed in the next section.
- To develop an integrated risk management framework using various frameworks that have been proposed (i.e. The World Health Organisation, 2006; The United States Environmental Protection Agency, USEPA, 2005; Canada Health, 2010 and the Australian guidelines, NRMMC-EPHC, 2006) in order to mitigate the risks relating to GWR within the pilot studies implemented in this study. Developing this framework involved documenting the different risk management frameworks listed above and identifying the similar measures employed which would be applicable to this study.

3.2 Risk assessment of greywater reuse for toilet flushing

The process of risk assessment comprises four components (Figure 3.1) (Metcalf and Eddy, 2004):

- Hazard identification
- Exposure assessment
- Hazard characterization
- Risk characterization

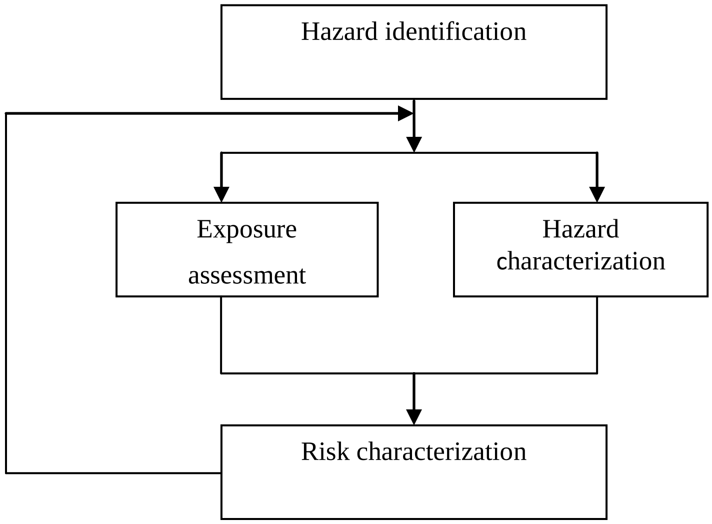


Figure 3.1: The risk assessment process (Metcalf and Eddy, 2004)

3.2.1 Hazard identification

The first step in risk assessment is hazard identification (Health Canada, 2010). This component involves defining the hazards or finding the index hazard agents that present the most prominent risks and assessing their prevalence in the relevant environment. This is a qualitative process of identifying microorganisms, toxins or chemicals of concern in the water. Greywater may contain less faecal matter than sewage; it however contains chemical and pathogenic agents that may pose a serious risk to human health. It is therefore necessary to establish the quality (physical, chemical and microbiological) and quantity of greywater that is generated from various domestic activities and that is available for treatment and reuse.

3.2.1.1 Hazard identification — microbiological

It is practically impossible to identify and account for all pathogens in greywater. The microbial quality of greywater depends on the quantity of faecal material that enters the greywater through activities such as washing of feacally contaminated laundry (i.e. diapers) anal cleansing and bathing (Jeppesen and Solley, 1994; Dixon et al., 1999a; Casanova et al., 2001; Ottoson and Stenstrom. 2003a; WHO 2006). Tables 3.1 and 3.2 present a wide range of microorganism counts that may be found in greywater and wastewater.

Faecal coliform is the most common indicator of the possible presence of other faecal pathogens. Therefore, faecal contamination has been used as a central parameter in wastewater quality monitoring (Ottoson and Stenstrom, 2003a). Household greywater has been reported to contain high levels of indicator organisms such as Total coliforms or *E. coli*. Ottoson and Stenstrom (2003a) estimated the faecal load in household greywater to be 0.04 g/day per person. As seen in Table 3.2, a single gram of feaces can contain a large number of pathogens (NRMMC-EPHC, 2006). Viruses constitute a key component of such faecal pathogens because of the high rate of excretion from infected persons, the low dosages needed for potential infection, and their high survival rate in the environment (Gerba et al., 1996; Ottoson et al., 2003; WHO, 2006). Rotaviruses are a common cause of gastroenteritis in humans (Gerba, 1995), for which a dose-response model has been established. In a risk assessment conducted by Ottoson and Stenstrom (2003), rotaviruses were found to pose the most significant risk to human health from greywater. For these reasons, rotaviruses were chosen as the reference pathogens for risk assessment in this study. Opportunistic bacteria such as Pseudomonas spp., Mycobacteria and Legionella spp. are also known to grow in hot water systems and could pose a threat depending on reuse options and technical solutions (Ottoson and Stenstrom, 2003a).

Table 3.1: Ranges of indicator bacteria reported in untreated greywater and wastewater

Concentrations (CFU/100mL)				
Source of greywater	Total coliforms	Thermotolerant coliforms	Escherichia coli	Faecal enterococci
Hand basin	2.4×10^2 - 2.4×10^6	N/A[b]	0 -2.4 X 10^6	0-2 x 10^4
Bath shower	N/A	N/A	N/A	6.3 x10^4
Bath/showers and hand basins	25 x10^{2}- 1.8 x 10^8	0-5.0 X 10^3	10 -10^5	10 -10^5
Laundry, Kitchen Sick	7 x 10^5	7.3 X 10^2	N/A	N/A
Greywater[c]	10^2-10^6	10^2-10^6	10 -10^5	N/A
Wastewater	10^6-10^8	10^6-10^8	10^6-10^8	10^4-10^6

[a] From Gardner (2003), Koivunen et al. (2003), Lazarova et al. (2003), Ottoson and Stenstrom(2003), Birks et al.(2004), Gardner (2003), and FBR(2005). [b] N/A= not available; [c] Wastewater from all domestic source excluding the toilet and kitchen sink.

Source: Health Canada (2010)

Table 3.2: Enteric pathogens and indicators reported in faeces and raw sewage[a]

Organism	Numbers in faeces(per gram)	Numbers in sewage(per litre)
Bacteria		
Coliforms (indicator)	10^7 -10^9	
EstehERichia		10^5 -10^{10}
Pathogenic E coli		Low
Enterroccoi (indicator)		10^5 -10^7
shigella	10^5 -10^9	10 -10^4
Salmonella spp	10^4 -10^{11}	10^3 -10^5
clostridum perfringens(pathogen and indicators)		10^4 -10^6
Virus		
Enterovirus	10^3 -10^7[b]	10^2 -10^6
Adenoviruses	10^{10}[c]	10 -10^4
Norovirues	10^{12}[c]	10 -10^4
Rotaviruses		10^2 -10^5
Somatic coliphages(indicator)		10^5 -10^9
F-RNA coliphages (indicators)		10^5 -10^7
Protozoa		
Cyptosporriduim	10^5 -10^7	0-10^4
Giardia	10^5 -10^7	
Helminths		
Helminth ova		0-10^4

[a] From Chappel et al. (1996). Chauret. (1999), Haas et al. (1999) and EPHC/NRMMC (2005). [b] Cell culture essays. [c] Electron microscopic observation of viral particles.

Source: Health Canada (2010)

3.2.1.2. Hazard identification — chemical

Chemical hazards pose a greater risk to the environment than to human health, though long term exposure to some chemicals may adversely affect human health in the long run (NRMMC-EPHC, 2006). The aim of identifying chemical hazards is to safeguard the welfare of future generations, protect biological diversity and maintain essential ecological processes and life-support systems. Chemical hazards may be caused by inorganic and organic chemicals, pesticides, potential endocrine disruptors, pharmaceuticals and disinfection by-products (NRMMC-EPHC, 2006).

Greywater may contain salts and the most common salt is sodium chloride – conventional table salt. The salinity of greywater is normally not problematic but can become harmful when greywater is reused for irrigation. High salinity in greywater can considerably reduce the yield potential of irrigated crops. Greywater also contains low levels of nutrients such as nitrogen and phosphorous and these are important parameters considering their nutrient value for plants, their relevance for natural treatment processes and their potential negative impact on the aquatic environment (NRMMC-EPHC, 2006). Nitrogen is widely believed to cause methemoglobinemia in infants who are exposed to nitrates in drinking water. Phosphorus discharges into water bodies is believed to cause eutrophication_resulting in oxygen deprivation and fish deaths (Cantor et al. 2000). Other chemical parameters of importance are grouped under the categories below (Morel and Diener, 2006):

- endocrine disrupting chemicals;
- pharmaceutically active compounds (drug residuals) and personal care products; and
- complex mixtures

An Australian draft of the National Guidelines for Water Recycling (NRMMC-EPHC, 2006) identified nine environmental hazards that should be prioritized when assessing the environmental risks associated with specific uses of recycled water (e.g. including agricultural, municipal, residential and fire control). The nine hazards are boron, cadmium, chlorine disinfection residuals, hydraulic loading (water), nitrogen, phosphorus, salinity, chloride and sodium.A screening-level risk assessment identified another set of nine hazards associated with the use of recycled water for environmental allocation for water bodies — ammonia, aluminium, arsenic, copper, lead, mercury, nickel, surfactants (i.e. linear alkyl benzene sulfonates and alcohol ethoxylated surfactants) and zinc (NRMMC-EPHC, 2006). In properly designed and managed recycled water systems where reclaimed water is limited to toilet and urinal flushing, health hazards from these chemicals are not expected to be high because of the relatively low exposure to human and environment (Health Canada, 2010). However, in instances where a failure occurs (e.g via a cross-connection between different quality pipes) and there is direct ingestion of the above chemicals, the negative impact can be significant (see next section)

3.2.2. Exposure assessment

This component of risk assessment involves assessing the routes, magnitude (e.g quantity ingested per exposure event), frequency and duration of exposure to the hazard, and the exposed population, the size and nature of the exposed population (Health Canada, 2010). A complete exposure assessment must consider both planned and unintended uses. Unintended uses can take two forms:

- deliberate misuse — for example, filling a swimming pool with recycled water supplied for non-drinking residential use; and
- accidental misuse — for example, mistakenly cross-connecting different water quality supply pipes.

Unintended uses can be reduced by educating stakeholders (users, plumbers, etc.) and by ensuring effective management processes. However, it is difficult to completely eliminate all forms of misuse especially accidental misuse (NRMMC-EPHC, 2006 and Health Canada, 2010).

Usually, the main route of exposure to microbial and chemical hazards from recycled water is ingestion, including ingestion of droplets produced by sprays. Some microorganisms found in recycled water have the potential to cause respiratory illness (e.g. certain types of adenoviruses and enteroviruses) and, for these organisms, inhalation of fine aerosols (rather than droplets) may be a source of infection (NRMMC-EPHC, 2006). In the case of greywater used for toilet flushing, aerosols and droplets may also be deposited on surfaces (e.g. toilet seats) which may in turn be touched by users, and who may subsequently ingest through hand-to-mouth contact. There is also the possibility of dermal exposure. There is however a lack of evidence of the health impacts through this route, and it is considered unlikely to cause significant levels of infection or illness in users. It is reasonable to also assume that children will take less care to avoid hand-to-mouth contact after touching contaminated surfaces, but there is little information available to quantify this potential route of exposure (Trevett et al., 2005).

The Australian Guidelines (NRMMC-EPHC, 2006) suggests an average exposure from toilet flushing of 11 ml per person per year from aerosols. The estimated exposure volumes and frequencies presented in Table 3.3 were those published by the NRMMC-EPHC, (2006) and are considered to be conservative. Ottoson (2002) estimated water intake from inhalation of aerosols as a log-normal distribution (dependent on time and droplet size). York and Walker-Coleman (2000) suggested that for a residential irrigation scheme, average consumption can be based on the accidental ingestion of 1 ml of reclaimed water per person per day, while maximum limits can be based on the accidental ingestion of 100 ml on one occasion per year.

Table 3.3: Different exposures to recycled water

Source of exposure	Route of exposure	Exposure volume (mL)	Exposure frequency per person per year	Comment
Toilet flushing	Aerosol	0.01	1100	Frequency is based on three toilet flushes per day. Aerosol volumes are less than those produced by garden irrigation.
Cross-connection with drinking water supply	Ingestion	1000/day	1/1000 houses	Total consumption is estimated to be 1.5 L per day of which 1L is expected to be consumed cold (unboiled). Affected individuals may consume water 365 days per year; however, only about 1/1000 houses will be affected. This is likely to be a conservative estimate.

Two recent reviews of drinking water consumption (Westrell et al., 2004; Mons et al., 2005) calculated volumes of cold (eg. unboiled) tap water consumption to be about 870ml per person per day; therefore, 1t is considered to be conservative.

Source: NRMMC-EPHC (2006)

3.2.3. Hazard characterization

This component of risk assessment is sometimes referred to as the dose-response characterization. It describes the adverse health effects that may result from exposure to a microorganism, toxin or chemical. When data is available, the characterization should present quantitative information e.g. dose–response relationship, and probability of adverse outcomes. In hazard characterization, exposure and health effects are described with background information on the pathogens existing within the specific environment (WHO, 2006). It also includes the range of human diseases associated with the identified pathogens (Haas et al., 1999). It focuses on the adverse health effects that may result from the ingestion of pathogenic microorganisms. This health effect varies from asymptomatic illness to different levels of acute and chronic disease and potential death. This relationships between doses of organisms and responses, in the form of incidence or likelihood of infection or illness, are obtained either from epidemiological investigations of outbreaks or from experimental human feeding studies (Rose et al., 1991; Haas et al., 1999; Haas, 2000; Teunis et al., 2004; WHO, 2006). In general, the doses associated with illness are much lower for viruses and protozoa than for bacteria. Ingestion of 1–10 virus particles or protozoan cysts can result in illness. In contrast, ingestion of 10^3 to more than 10^6 of bacteria (depending on the type of bacterial pathogen) might be required to cause illness. *Shigella* spp, typhoid salmonellae and enterohaemorrhagic *E. coli* are notable exceptions to these, requiring fewer organisms to cause disease (Haas et al., 1999; Hunter, 2003; Teunis et al., 2004; WHO, 2006). An investigation of one outbreak found that average doses of E. coli Serotype (O157:H7) in affected people were 30–35 organisms (Teunis et al., 2004). Other investigations have estimated a dose of 75 organisms ingested in a swimming-related outbreak in the United States and an average of 23 organisms consumed in a food borne outbreak in the United States (Strachan et al., 2005). Dose–response models developed from human-feeding studies are common components of risk assessments (Haas et al., 1999). Table 3.4 provides dose–response information and lists the models that may be used to determine probabilities of infection following exposure to the reference organisms discussed above.

Table 3.4: Dose-response relationships for different microorganisms

Organism type	Distribution	Model	Parameter
Enteric virus (rotavirius)	Beta-Poisson	$P_{inf}=1-(1+d/\beta)^{-\alpha}$	$\alpha=0.253$
			$\beta=0.426$
Bacterium (campylobacter jejum)	Beta-Poisson	$P_{inf}=1-(1+d/\beta)^{-\alpha}$	$\alpha=0.145$
			$\beta=7.58$
Protozoan Cryptosporiduim parvum	Exponential		r=0.059

α and rare parameters describing probability of infection ; d=dose; β=median infective dose $(N_{50})\div(2^{1/\alpha}-1)$;$P_{inf}$ = probability of infection model parameters as described in Table 9.15 of Haas et al(1999), except for cryptosporidium, where the data of Messner et al (2001) have been used.

Source: Health Canada (2010)

3.2.4. Risk characterization

The risk characterization component of risk assessment is an integration of the three previous steps in order to derive a risk estimate i.e. an estimate of the likelihood and severity of the adverse health effects that would occur in a given population, with associated uncertainties. It is an integration of the information from the hazard identification, dose–response and exposure assessments to estimate the magnitude of risk and to evaluate variability and uncertainty (WHO, 2006). Utilization of wastewater or greywater involves risk. Accordingly, there is a need to set a maximum acceptable risk level. Such thresholds involve ethical decisions and are a function of societal benefit-cost equations i.e. balancing the benefits of saving water versus the costs of infectious disease. The variables in determining the magnitude of risk for the reference pathogens are the concentrations of the organisms and the exposures. It is expected that the magnitude of risk can be assessed on two levels:

- Maximum risk- risk in the absence of preventive measures; and
- Tolerable or Residual risk- risk that remains after consideration of existing preventive measures.

Maximum risk is useful for identifying high-priority risks, appropriate preventive measures, calculating performance targets and preparing for emergencies should preventive measures fail. One simple definition of tolerable risk is that it is a risk that has been widely accepted in environmental regulation (Hunter and Fewtrell, 2001). Tolerable risk provides an indication of safety and the sustainability of a recycled water scheme or the need for additional preventive measures. After the consideration of preventive measures, tolerable risks are expected to be less than 10^{-6} Disability Adjusted Life Years (DALYs) per person per year (NRMMC-EPHC, 2006). This means that, a person's chance of developing a disease in a year is one in a million or less (Hunter and Fewtrell, 2001).

The DALY concept calculates both the number of years of life lost due to death (YLL) and the years lived with disability (YLD), and it is used to measure the healthiness of a society (Homedes, 1996). DALY is commonly used by the WHO and other countries (e.g. Australia) as an important tool to assess maximum tolerable risks by which health targets and public health management are decided. The WHO has set 10^{-6} DALYs per person-year as the maximum tolerable risk for water borne disease (WHO, 2006). In other words, a risk is deemed tolerable if one year of healthy life is lost due to water borne disease in a population of 1 million people. The tolerable infection risk for rotavirus was calculated according to the 10^{-6} target and the severity of the diseases it causes and it was set as 1.4×10^{-3} infections per person per year (WHO, 2006). This in turn means that, of the entire population, it is tolerable for about one person out of 1000 to become infected with a rotavirus, once a year.

A sample risk characterization is shown in Table 3.5. Same value estimates, which are assumed to be conservative, are used for exposure per event (L) and number of exposure events per year. The formulae used in the calculations are shown in Box B1 and the result is summarized in Table 3.6. This example demonstrates that even with a very conservative assumption, effective water treatment should reduce the risk of illness and the associated disease burden to a very low level on an annual basis. The information from the hazard identification, dose–response and exposure assessments was used to estimate the magnitude of risk. A deterministic approach was used to calculate a health-based target for the reference pathogens in the reclaimed water.

Table 3.5: Potential disease burdens for aerosols from toilet flushing with greywater

	Cryptosporiduim	*Rotavirus*	*E coli 0157:H7*
Organisms per liter in source water[a,b]	2000	8000	$1.2X10^5$
Log reduction provided by treatment[c]	5	6	6
Exposure per event(L)	$1 x 10^{-5}$	$1 x 10^{-5}$	$1 x 10^{-5}$
Dose per event (L)	$2 x 10^{-7}$	$8.0 x 10^{-5}$	$1.2 X10^{-5}$
Number of events per year	1100	1100	1100
Dose-response constants[d] (α)	$1.8 x 10^{-2}$	$2.7 x 10^{-1}$	$2.1 x 10^{-1}$
			N=1120
Probability of infection per organism	$1.8 x 10^{-2}$	$2.7 x 10^{-1}$	$4.8 x 10^{-3}$
Risk of infection(P_{inf}) (Probability of infection per event)	$3.6 x 10^{-9}$	$4.6 x 10^{-8}$	$6.0 X10^{-9}$
Ratio of illness /infection[e]	0.7	0.88	0.53
Risk of illness (P_{ill}) per event	$2.5x 10^{-9}$	$4.0 x 10^{-8}$	$3.2 x 10^{-9}$
Risk of illness (per year, i.e, 1100 events)	$2.8 x 10^{-6}$	$4.4 x 10^{-5}$	$3.5 X10^{-6}$
Disease burden[f] (DALY per case)	$1.5 x 10^{-3}$	$1.3 x 10^{-2}$	$1 x 5.5^{-2}$
Susceptibility fraction (%)[g]	100	6	100
DALY per year	$4.2 x 10^{-9}$	$3.5 x 10^{-8}$	$1.7 x 10^{-8}$

[a] Concentrations of Cryptosporidium and rotavirus in raw sewage are taken from NRMMC-EPHC (2006); numbers of adenovirus are used as an indication of rotaviruses because of lack of enumeration methods for rotavirus

[b] Concentration of E.coli O157:H7 is calculated assuming the 2% of the maximum number of generic E.coli enumerated in raw wastewater samples from Canadian cities are pathogenic ($6.2 x 10^6$; Payment et al., 2001). More information is needed to refine this estimate.

[c] Based on log reductions shown in tables D1 and D2 (see Appendix D); hazard concentrations reduced by secondary treatment, coagulation, filtration and disinfection.

[d] Models used to calculate risk of infection are shown in Table 3.4

[e] Havelaar and Melse (2003)

[f] DALY per case based on Havelaar and Melse (2003)

[g] The proportion of the population susceptible to developing disease following infection. The figure of 6% for rotavirus is based on the fact that infection is common in very young children. The 6% equates to the percentage of population aged less than five years.

Source: Health Canada (2010)

BOX B1

1	Dose per event =	Source water concentration x log reduction x exposure
2	P_{inf} =	Dose -response models and parameters are shown in Table 3.4
3	$P_{inf\ per\ year}$ =	$1-(1-P_{inf})N$
		where N=number of exposures per year
		For lower levels of risk, this can be approximated to:
		P_{inf} per year = P_{inf} x N
4	$P_{ill\ per\ year}$ =	P_{inf} per year x ratio of illness to infection
5	DALY per year =	P_{ill} per year x DALY per case x susceptibility fraction

Source: Health Canada (2010)

Health-based targets are the ‘goal-posts’ or ‘benchmarks’ that have to be met by each recycled water scheme to ensure that the maximum risk of 10^{-6} DALYs per person per year is not exceeded (NRMMC-EPHC, 2006). In many countries, the common forms of health-based targets are numerical guideline values and/or performance targets for chemical and microbiological hazards. In relation to chemicals, a guideline value is generally the concentration or measure of a water quality parameter that, based on present knowledge, does not pose any significant risk to the health of the consumer over a lifetime of consumption. A health based target uses the tolerable risk of diseases as a baseline to set specific performance targets that will reduce the risk of disease level. Reducing this risk thus involves reducing the levels of exposure or concentration of pathogens/chemicals. Health-based targets can be specified in terms of combinations of different components or single parameters including:

- Health outcome: as determined by epidemiological studies, public health surveillance or quantitative microbiological risk assessment (QMRA):
- Excreta or greywater quality: e.g. concentrations of viable intestinal nematode eggs and /or E coli;
- Performance e.g. a performance target for removal of pathogens through a combination of treatment requirements, handling practices and quality standards. Performances may be approximated by other parameters such as storage time and temperature; and
- Specified technology: specified treatment process, either in general or with reference to specific circumstances of use.

Table 3.6: Tolerable risk of illness and disease burden calculated for reference pathogens

	Cryptospordium	***Rotavirus***	***E. coli 0157:H7***
Risk of illness (per year, i.e 1100 events)	7.2×10^{-7}	4.5×10^{-5}	3.5×10^{-6}
DALY per year[a]	11×10^{-9}	3.5×10^{-8}	1.7×10^{-8}

Source: Health Canada (2010)

3.3. Integrated Risk Management Frameworks

Integrated risk management (IRM) involves managing risks in a proactive way, rather than simply reacting when problems arise. This includes identifying preventive measures to control a hazard, the establishment of monitoring programmes to ensure that preventive measures operate effectively, and the verification of the management system as it consistently provides quality recycled water that is fit for the intended use (i.e 'fit for purpose') (NRMMC-EPHC, 2006). The management strategies may involve all aspect of sustainability which may include social, engineering, economics, legal and political issues.

An IRM framework is a generic risk assessment and protective management tool that can be applied to any form of wastewater recycling (NRMMC-EPHC, 2006). The development of IRM management frameworks are often dependent on many factors, including enabling legislation, available resources and the need or desire of the individual or community to pursue water recycling. Authorities in different regions have to determine the IRM framework that will best suit the needs of their communities. Examples of some of these frameworks are outlined in The WHO guidelines for *Safe Use of Wastewater, Excreta and Greywater: Volume IV, Excreta and Greywater in Agriculture* (WHO, 2006) and have been published within guidelines in Canada (Health Canada 2010); United States (USEPA, 2005); and Australia (NRMMC-EPHC, 2006).

3.3.1 The Stockholm IRM framework

The WHO 2006 publication titled: *Water Quality — Guidelines, Standards and Health: Assessment of Risk and Risk Management for Water-related Infectious Disease*, presents a harmonized IRM framework for the development of guidelines and standards for water related microbial hazards and involves (1) the assessment of health risks prior to setting of health targets; (ii) defining basic control approaches; and (iii) evaluating the impact of these combined approaches on public health status (Bartram et al., 2001; WHO, 2006). The framework encourages countries to adjust the guidelines to suit local social, cultural, economic and environmental circumstances and to compare the associated health risks with the risks that may result from microbial exposures through wastewater use, drinking-water and recreational or occupational water contact. This approach requires that diseases be managed as a whole package and not in isolation. Disease outcomes from one exposure pathway, or from one illness to another, can be compared by using a common measure, such as disability adjusted life years (DALYs). The framework contains four major components which are:

- Assessment of health risk (discussed extensively in section 3.2)
- Tolerable health/health based targets (discussed extensively in section 3.2.4)
- Health risk managements
- Public health status.

The assessment of health risk can be carried out directly via epidemiology studies or indirectly through quantitative microbiological risk assessment (QMRA). Epidemiology studies aim to assess health risks by comparing the level of diseases in exposed population (e.g a population using excreta/greywater in agriculture) with that in an unexposed or control population. QMRA is an indirect approach of risk assessment usually done in four steps (see section 3.2) which includes (1) Hazard identification, (2) Exposure assessment, (3) Hazard characterization, and (iv) risk characterization (WHO, 2006).

Tolerable risks are described as the risk that remains after consideration of existing preventive measures while health base targets are the ‘goal-posts’ or ‘benchmarks’ that have to be met by each recycled water scheme to ensure that the maximum risk of 10^{-6} DALYs per person per year is not exceeded (NRMMC-EPHC, 2006). Health-based targets are numerical guideline values and/or performance targets for chemical and microbiological hazards. A health based target uses the tolerable risk of diseases as a baseline to set specific performance targets that will reduce the risk of disease level. Reducing this risk thus involves reducing the levels of exposure or concentration of pathogens/chemicals (see section 3.2.4)

The Stockholm IRM framework emphasised two basic control approaches to achieving health-based targets i.e (wastewater quality and other management objectives) in the management of risks associated with the use of greywater and excreta. These objectives are the basis for many of the frameworks developed in several countries. The different elements of the Stockholm framework are presented in Figure 3.2.

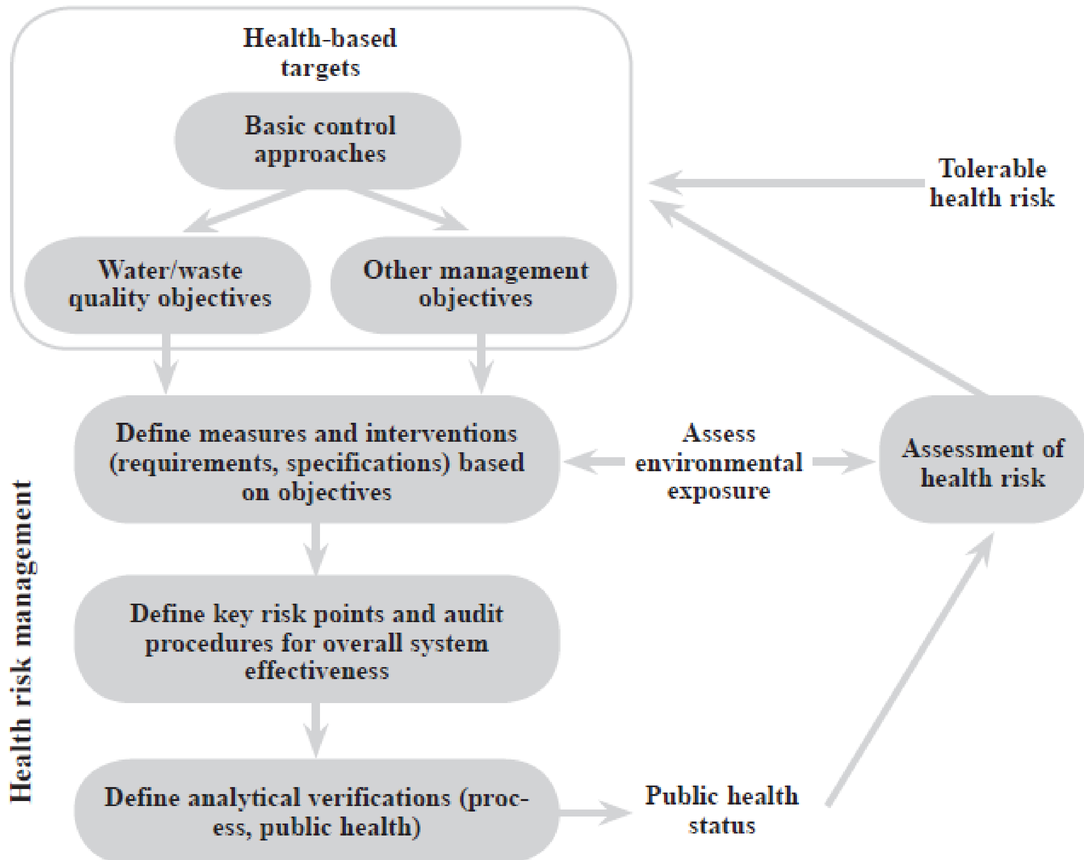


Figure 3.2: The Stockholm framework for developing harmonized guidelines for management of water-related infectious diseases (Bartam et al., 2001)

Health risk management is an aspect of risk management which may include identifying preventive measures to control a hazard and the establishment of monitoring programmes to ensure that preventive measures operate effectively. It may also include the verification of the management system as it consistently provides quality recycled water that is fit for the intended use (NRMMC-EPHC, 2006). Risk management strategies may include combinations of the following (WHO, 2006):

- Addressing behaviour (e.g. hand washing with soap);
- On-site storage treatment technologies to reduce pathogens to a level that presents a tolerable risk
- Off-site additional treatment to further reduce pathogens;
- Efficient operational processes e.g. during irrigation with greywater, and during operation and maintenance of facilities;

- Exposure control methods e.g. limiting public access to the resource through the wearing of protective clothing such as gloves or masks when coming in contact with the resource.

Public health status assists in evaluating the effectiveness of risk management interventions on specific health outcomes through both investigation of disease out-breaks and evaluation of background disease levels (WHO, 2006). Public health status can be regarded as a health indicator for certain communities so as to encourage dialogue about actions that can be taken to improve a community's health. These indicators are not designed only for the public health professionals but also for members of the community who are interested in the health of their community. The outcome report may have indicators like death rate due to heart disease and cancer.

3.3.2 The Canadian IRM framework

In Canada, the IRM framework outlined in the Position Paper *From source to tap: The multi-barrier approach to safe drinking water* has been used as framework for the management of drinking water (FPTCDW/CCME, 2004). The report contains 9 section/chapters. The document begins with the introduction which is followed by the discussion of the multi- barrier approach as a way of ensuring drinking water supplies are kept clean, safe and reliable. It recognises that the drinking water system contains three main elements: the source water, the drinking water treatment plant, and the distribution system (Figure 3.3).

Section 3 looks at the commitment to responsible use of water and the obligation of all parties involved in the management of drinking water. These commitments include legislative and policy tools, resources for research and development, financial support for infrastructure programs and staff training. Section 4 gives general information about risk management process which leads into a discussion in section 5 of hazards that can compromise a drinking water system.

Section 6 talks about source water protection and is divided into two sections: source water assessments and the development of watershed/aquifer management plans. Section 7 builds on the information given in Section 6 to deal with the design of drinking water treatment plants and distribution systems based on the quality of the source water.

Section 8 is entitled "Total Quality Management" and focuses on how best to manage and operate the components of the water supply once the elements are in place. This section includes discussions on monitoring, record-keeping and reporting; laboratory selection and sampling protocols; operating procedures; automated systems; facility classifications and operator training; incident and emergency response plans; program evaluations and audits; as well as abatement and enforcement programs.

The document ends with a discussion in Section 9 of public awareness and involvement in the drinking water program. It emphasis that public awareness is key to the success of any drinking water program (FPTCDW/CCME, 2004).

According to Health Canada (2010), the above framework can also be adjusted to apply to reclaimed water (Health Canada 2010). The elements of the framework also centred on the two objectives of water quality management and other management objectives as earlier mentioned in the Stockholm IRM framework. The elements of this framework can be grouped under the following objectives:

- Water quality (inner circle): this involves water quality monitoring and management of water supplies from source to tap.
- Other management (outer circle): this involves legislative and policy frameworks, public involvement and awareness, guidelines, standards and objectives, and research, science and technology solutions.

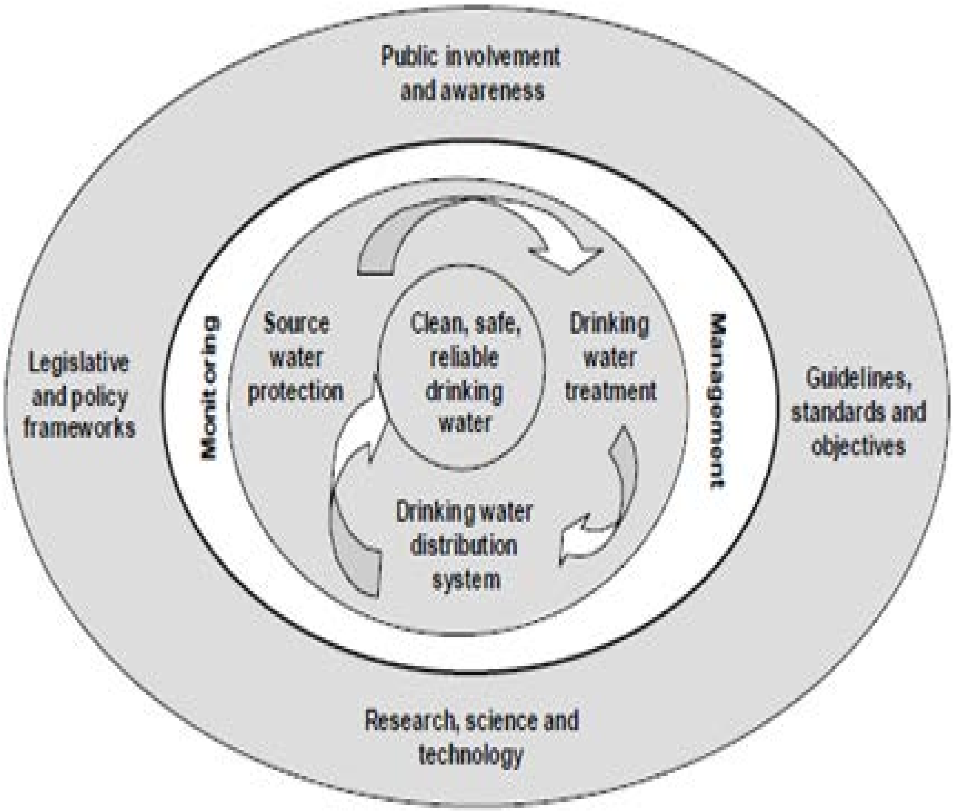


Figure 3.3: Components of the multi-barrier approach (FPTCDW/CCME, 2004)

The key strength of multiple barrier systems is that the limitations or failure of one or more barriers may be compensated for by the effective operation of the remaining barriers. This compensation minimizes the likelihood of contaminants passing through the entire system and being present in sufficient amounts to cause illness to consumers (FPTCDW/CCME, 2004).

3.3.3. The Australian IRM framework

In Australia, the IRM framework used was based on the *Australian Drinking Water Guidelines* (NRMMC-EPHC, 2006). The Australian management framework consists of twelve elements of which nine are interrelated. An important feature of the framework is that if one measure fails, other measures continue to provide control. For example, in order to irrigate commercial crops with recycled water from a metropolitan sewage treatment plant, preventive measures designed to protect human health might include restrictions on the type of waste entering the plant, a range of treatment processes, cross-connection control at all irrigation sites and an education programme on irrigation practices for those using the water or working on the scheme. Also essential to the approach are critical control activities, procedures or processes where control can be applied, and that are essential for either preventing or reducing to acceptable levels, those hazards that pose high risks.

The 12 elements are organised within four general areas, as illustrated in Figure 3.4 and listed below (NRMMC-EPHC, 2006):

- Commitment to responsible use and management of recycled water. This requires the development of a commitment to responsible use of recycled water, and to the 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 area 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: This area includes 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.

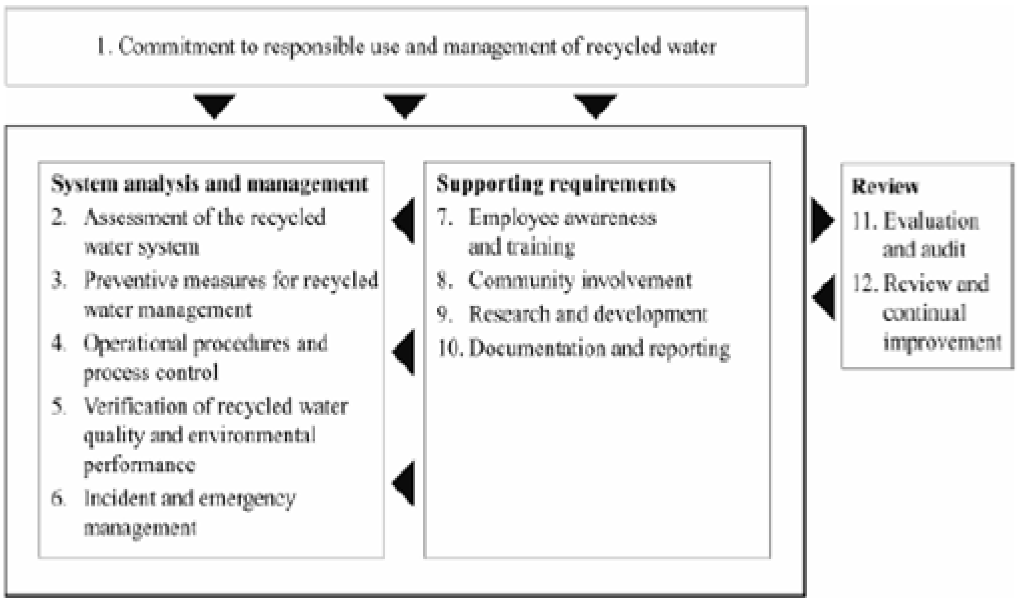


Figure 3.4: Elements of the Australian IRM framework for the management of recycled water quality and use (NHMRC-NRMMC, 2006)

Looking at the 4 areas of the framework, the Australia framework can be categorized under the two basic objectives of water quality management and other management as categorised by the Stockholm IRM framework. The Australian IRM frameworks elements under system analysis and management may easily be categorised under Stockholm's water quality objectives while the other three areas under the Australian IRM framework i.e. commitment to responsible use and management of recycled water, supporting requirements and review may easily be categorised under other management objectives.

3.3.4 The USA IRM framework

In the USA, The United States Environmental Protection Agency (U.S. EPA, 2005) developed a handbook that outlines a useful process for developing a decentralized wastewater IRM programme (USEPA, 2005). It provides an overview of key considerations for developing or enhancing management programs for decentralized wastewater treatment systems. Chapter 1 of the document outlines some of the benefits of decentralized systems and the management program. Information-gathering and public outreaches are reviewed as critical factors in this phase to help communities identify management options that are technically feasible, cost-effective, and protective of public health and the environment. Chapter 2 discusses the important role of formal leadership in the program development process. During this phase, key stakeholders are identified, convened, and tasked with setting program goals. Various leadership options are reviewed.

Chapter 3 reviews necessary risk assessment and analytical work that must be undertaken to characterize the current situation and identify existing gaps in wastewater system management. Chapter 4 considers the authority needed to implement various program elements, such as operation and maintenance, enforcement, and permitting. Chapter 5 offers options for implementing a management program, including the adoption of the model programs developed by EPA. Integrated wastewater planning, linkages between wastewater management activities, and compliance with state, tribal, and federal water resource protection programs are also reviewed.

Appendix A contains EPA decentralized wastewater treatment fact sheets. The one page fact sheets summarize each of the 13 principal programme elements that make up an onsite management program (Figure 3.5) which are: (i) public education and participation, (ii) planning, (iii) performance requirement, (iv) record keeping, inventories, and reporting (v) financial assistance (vi) site evaluation, (vii) system design (viii) construction and installation (ix) operation and maintenance (x) residuals management, (xi) training and certification/licensing (xii) inspections and monitoring (xiii) corrective action and enforcement.
These one-page fact sheets describe various levels of management based on community needs along with real life examples to help guide decision-makers and are applicable to the management of reclaimed water systems. Each element of the programme is explained in detail in Table 3.7.

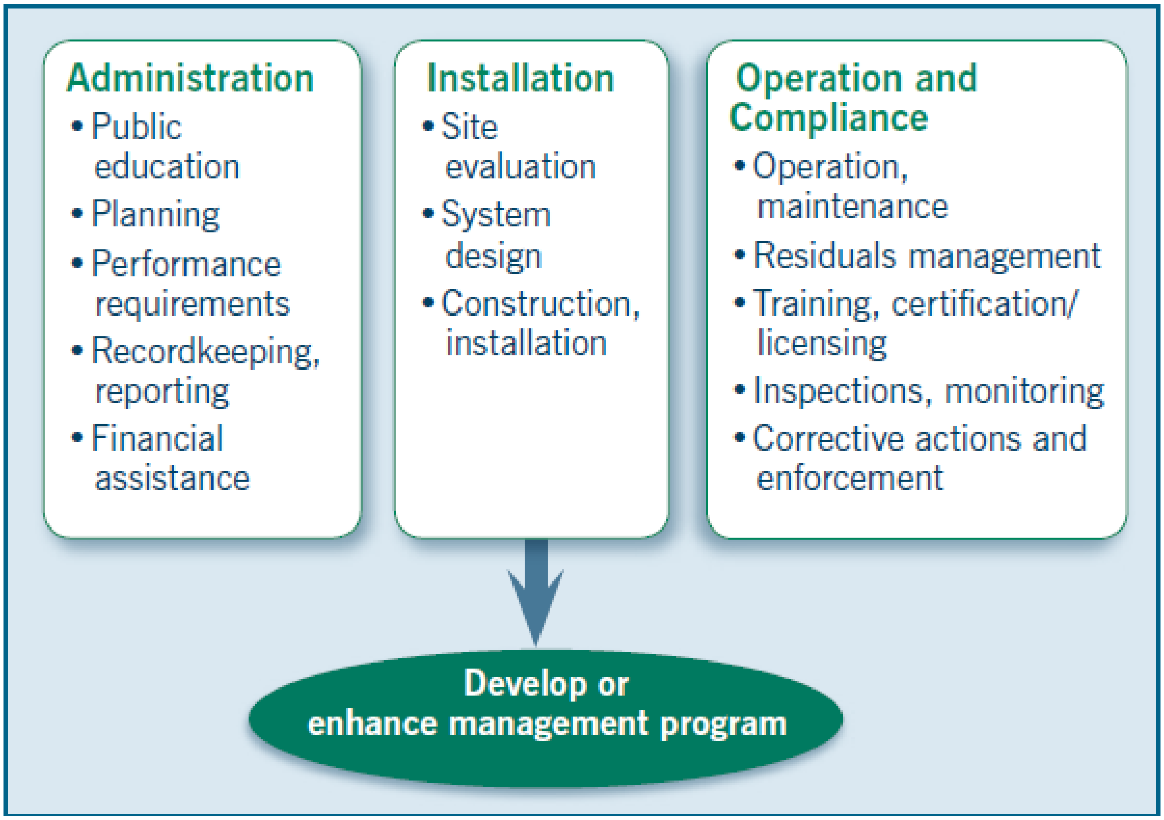


Figure 3.5: Decentralized reclaimed water management programme elements (USEPA, 2005)

Based on the figure above, this IRM programme also supports the twin goals of protecting human health and environmental resources. They are also intended at influencing future growth and community character, promoting water recycling and reuse, protecting and enhancing private property values, and protecting against water resource diversions. Depending on the type of reuse activity, risks are classified into high, moderate or low in order to be able to select the appropriate management programme. The elements of the framework can be grouped based on the two Stockholm objectives of water quality and other management. The USEPA (2005) elements of risk management on the administration and installation of a decentralized water reclamation programme mostly relate to the Stockholm's other management objective while the elements under operation and compliance mostly relate to Stockholm's water quality objective.

Table 3.7: Decentralized wastewater management programme elements (USEPA 2005)

Elements	Purpose	Basic activities	Advanced activities	Application to this study
Administration				
Performance requirements	Link treatment standards and relative risk to health and water resource goals	Prescribe acceptable site characteristics and system types allowed.	Stipulate that system performance must meet defined standards that consider water resource values, vulnerabilities and risks	Prior perception survey to determine the pilot project site
Planning	Consider site and regional conditions and effects on long term watershed and public health.	Identify minimum lot sizes surface water/ground water separation distances, and critical areas requiring protection	Monitoring and model regional pollutants loads; tailor development patterns based on environmental and physical limitations; require clustering for large developments	Estimating toilet flushing water consumption in high density urban buildings and develop a model for estimating this demand
Record keeping, inventory and reporting	Create inventory of systems and O & M logs, planning and reporting to oversight agencies	Provide inventory information on all systems; submit performance reports to health agency	Provide GIS-based comprehensive inventories including web-based monitoring and O & M data input for administrative reporting and watershed assessment studies.	Investigating the economic viability of the implemented greywater system
Financial assistance and funding	Provide financial and legal support for management program.	Implement basic powers, revenue-generation fees and legal backup for a sustainable program.	Initiate monthly or quarterly service fees; cost-share or other repairs/replacement program full financial and legal support for management program; equitable revenue base and assistance programs; regular reviews and modifications.	
Public education and participation	Maximize public involvement while developing a management program	Sponsor public meetings forums, updates and education programs	Maintain public advisory review groups and other involvement opportunities in the program; distribute educational and other materials.	Monitoring users perceptions and awareness sessions
Installation				
Site evaluation	Assess system site and relationship to other features(groundwater and surface water).	Characterize landscape soils, ground and surface water location, lot size and other conditions	asses site and cumulative watershed impacts groundwater mounding potential, long-term specific potential, long-term specific pollutant trends, and cluster system needs	
System design	Ensure that system is appropriate for site watershed and wastewater characteristics.	Prescribe a limited number of design for specific site condition	Implement codes for developing designs that meet performance requirements for each site: address wastewater, reuse and dispersal options	Framework for the evaluation of locally available greywater treatment plants

Elements	Purpose	Basic activities	Advanced activities	Application to this study
Construction	Ensure installation as design: record as built drawings.	Inspect installation prior to covering with soil and enter as built information into the file record.	Provide supplemental training certification and licensing programs; provide as-built information into record more comprehensive inspection of installations; verify and enter as-built information into the record.	
Operation and Compliance				
Operation and maintenance	Ensure that systems perform as designed	Initiate homeowner education and reminder programs that promote O&M	Require service contracts or renewable revocable operating permits with periodic reporting; log service reports in database; ensure responsibility for O &M activities	Monitoring users perceptions and awareness sessions
Inspections and monitoring	Documents provider performance, functioning of systems, and impacts	Perform inspection prior to cover-up and property title transfer; provide complaint response.	Conduct regional surface water and groundwater monitoring; web-based reporting and inspections.	
Residual management	Remove and treat residual; minimize health or environmental risks from residuals handling use, and dispersal	nsure compliance with federal and state codes for residuals dispersal	Conduct analysis and oversight of residuals program. Web-based reporting and inspection of pumping and dispersal facility activities; assistance in locating or developing residuals handling facilities.	Modelling and simulation of contaminant transport in potable water distribution network
Training and certification/licensing	Promote excellence in site evaluation, design installation, O&M and other service provider areas	Recommend use of only state-licensed/certified service providers	Provide supplemental training certification and licensing programs; offer continuing education opportunities; monitor performance through inspections; sponsor mentoring programs	
Corrective actions and enforcement	Ensure timely compliance with applicable codes and performance requirements.	Provide for complaint reporting under nuisance laws; inspection and prompt response procedures and penalties	Deny or revoke operating permit until compliance measures are satisfied; set violation response protocol and legal response actions, including correction and liens against property by RME	

3.3.5 Finding similarities and the development of a proposed IRM framework

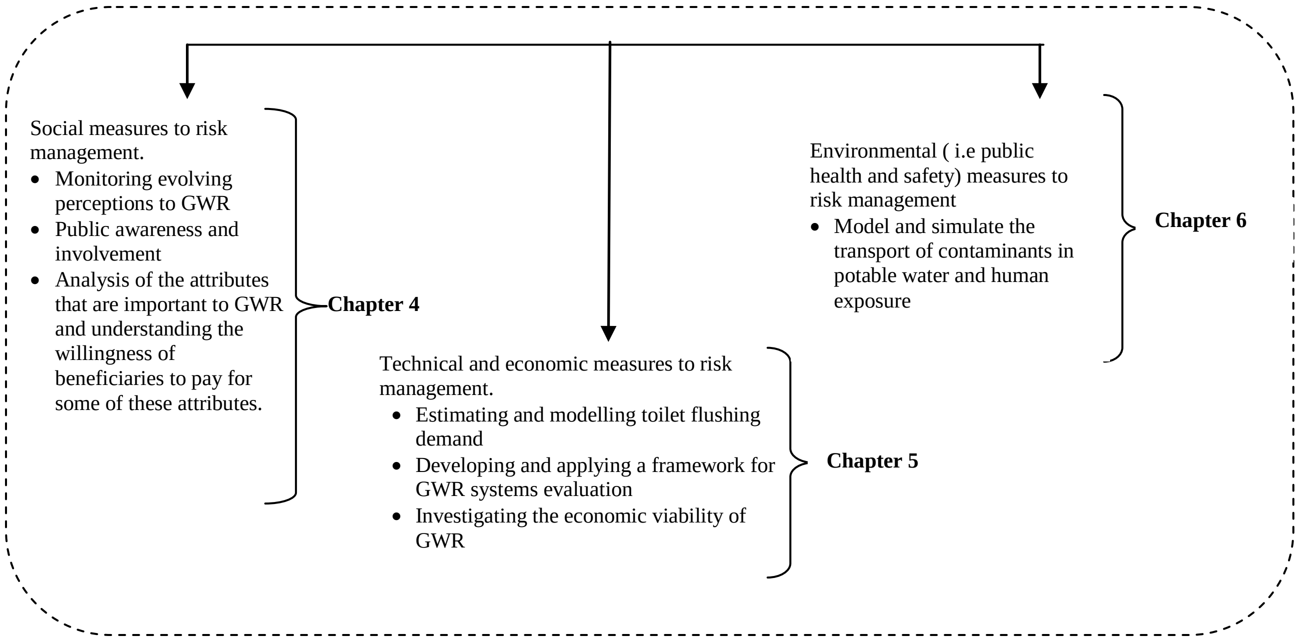
The development of an IRM framework is dependent on many factors, including enabling legislation, available resources and the need or desire of the individual or community to pursue water recycling (NRMMC-EPHC, 2006). According to the Stockholm's IRM framework, the basis for selecting IRM strategies should be based on the combination of other management practices and appropriate water quality objectives. As shown in the immediate previous sections, these objectives to a large extent relate quite well with the elements and structures of various frameworks developed by different organizations and countries (i.e NRMMC-EPHC, 2006; USEPA, 2005; FPTCDW/CCME, 2004). Thus, the development of the proposed IRM framework in this study was based on these two objectives.

The Stockholm's water quality objective requires an understanding of hazards in GWR and the implementation of preventive measures and operational control for assuring safety and reliable use of greywater. This objective thus relates reasonably with the technical and environmental attributes of sustainability in this study. A detailed discussion and analysis of these attributes as they relate to the GWR implemented in this study is presented in chapters 5 and 6.

The second Stockholm objective involves the implementation of other management (i.e. good management) practices which involves public awareness and education about GWR, building trust between stakeholders, and understanding the economic viability of GWR. This objective thus relates to the social and economic attributes of sustainability in this study. A detailed discussion and analysis of these attributes as they relate to GWR implemented in this study is presented in chapter 4 and 5.

Thus, the IRM framework developed for this study comprised the following measures (see extract of Figure 1.1 below):

- Social measures of risk management (Chapter 4).
- Technical and economic measures of risk management (Chapter 5).
- Environmental (i.e. public health and safety) measures of risk management (Chapter 6).


Social measures to risk management.
Monitoring evolving perceptions to GWR
Public awareness and involvement
Analysis of the attributes that are important to GWR and understanding the willingness of beneficiaries to pay for some of these attributes.
Chapter 4
Technical and economic measures to risk management.
Estimating and modelling toilet flushing demand
Developing and applying a framework for GWR systems evaluation
Investigating the economic viability of GWR
Chapter 5
Environmental (i.e public health and safety) measures to risk management
Model and simulate the transport of contaminants in potable water and human exposure
Chapter 6

CHAPTER 4
SOCIAL MEASURES TO RISK MANAGEMENT

4.1 Introduction

Public perceptions and acceptance are recognised as key elements of the success of any developmental scheme that has the potential to change a community's way of life (May-Le, 2004; World Bank, 2003). Po et al. (2004) ascribes the successes in the implementation of dual water reticulation systems to several factors including positive attitudes of communities towards reuse, and community participation in the planning and implementation of the reuse project. Lundqvist and Gleick (1997) indicate that major decisions made without involving local communities and those affected by the decisions made, are more likely to fail. Therefore in order to facilitate the success of a reuse project, perceptions of potential and actual respondents need to be investigated.

This chapter reports on the social measures implemented to manage, and therefore mitigate, the risks associated with the implementation of GWR for toilet flushing at the pilot sites. The social measures carried out were the following:

- The evaluation of perception surveys carried out on potential and actual beneficiaries of GWR for toilet flushing;
- Public awareness and involvement; and
- An analysis of the attributes that are of importance to GWR and understanding the willingness of beneficiaries to pay for some of these attributes.

4.2 Perception survey

4.2.1 Background

The successful implementation of any reuse project is hinged on public acceptance (Po et al., 2004). Numerous reuse projects have failed in the past despite initially having received favourable support from potential users Po et al. (2004). The California Bay water recycling programme in the USA had to be redesigned after strong opposition from the local community (Okun, 2002).

In many of the perception studies conducted, several factors have emerged as affecting public attitudes and willingness to accept water reuse schemes: Hartley (2003) identifies factors influencing public participation and perceptions towards recycled water use as the information and context, communication and dialogue, trust and trust building, perceptions of fairness, motivation and commitment to participate in decision-making. Surveys carried out in Australia and California indicate that the foremost reasons for public willingness to use reclaimed water is based on their overall environmental attitude and level of trust in the local water authority (Khan & Gerrard, 2006; Po et al., 2004). Erickson (2004) identified health risks, psychological repugnance, and religion as some of the factors that have affected the acceptance of reuse. Table 4.1 shows the levels of opposition to reclaimed water reuse from different surveys. These studies show how the acceptance of recycled water is dependent on its proposed uses, with minimum to no human contact uses (e.g. toilet flushing and irrigation) being preferred.

Recent research conducted in South Africa shows that acceptance is a function of cost and the extent of the aridity of an area (Ilemobade et al., 2009a); the awareness about sustainability (Wilson and Pfaff, 2008); and trust in the service provider (Adewumi et al., 2008).

Many of the above factors are confirmed by Po et al. (2004) who identified the following factors as influencing the acceptance of a water reuse project. (i) disgust or "Yuck"; (ii) perceptions of risk associated with using recycled water; (iii) the specific uses of the recycled water; (iv) the sources of water to be recycled; (v) the issue of choice; (vi) trust and knowledge; (vii) attitudes towards the environment; (viii) environmental justice issues; (ix) the cost of recycled water; and (x) socio-demographic factors.

This section documents the evaluation of perception surveys carried out on potential and actual beneficiaries of GWR for toilet flushing. To achieve this, the following tasks were carried out:

i. Perception and demographic surveys were carried out using the (Po et al., 2004) factors on potential beneficiaries of GWR
ii. From the above perception surveys, the preferred locations for the pilot system were identified.

iii. After the GWR for toilet flushing system were implemented at the preferred locations, perception and demographic surveys were carried out on actual beneficiaries.

iv. The perception and demographic surveys were analysed for trends highlights.

Table 4.1: Opposition to different uses of recycled water in different surveys (Po et al., 2004)

	ARCWIS (2002) N=665 (%)	Lehman, Milliken (1985) N=403 (%)	Milliken, Lowman (1983) N= 399 (%)	Bruvold (1981) N=140 (%)	Olsson *al.* (1979) N=244 (%)	Kasperon *et al.*(Po et al. (2004) 1974) N=400 (%)	Stone & Kable (1974) N=1000 (%)	Bruvold (1972)* N=972 (%)
Drinking	74	67	63	58	54	44	46	56
Cooking at home	-	55	55	-	52	42	38	55
Bathing at home	52	38	40	-	37	-	22	37
Washing clothes	30	30	24	-	19	15	-	23
Toilet flushing	4	4	3	-	7	-	5	23
Swimming	-	-	-	-	25	15	20	24
Irrigated dairy	-	-	-	-	15	-	-	14
Irrigated vegetable	-	9	7	21	15	16	-	14
Irrigated vines	-	-	-	-	15	-	-	13
Orchard irrigation	-	-	-	-	10	-	-	10
Irrigation of alfalfa hay	-	-	-	-	8	-	9	8
Home garden	4	3	1	5	6	-	6	3
Irrigated park	-	-	-	4	5	-	-	3
Golf course irrigation	2	-	-	4	3	2	5	2

***cited in Bruvold (1988) –this study was conducted in the US**

4.2.2. Structure for the perception questionnaires

The questionnaires were developed using the factors influencing perceptions as identified by Po et al. (2004). The first questionnaire, which solicited respondents' perceptions to reusing greywater for toilet/urinal flushing prior to the greywater systems being implemented, was administered to the following respondents: students registered at three South African Universities (the universities of the Witwatersrand, Johannesburg and Cape Town). After identification of the pilot sites at the Universities of the Witwatersrand and Johannesburg, and the implementation of the GWR system, the first questionnaire was also administered to the beneficiaries of the systems. Thereafter, three site-specific questionnaires were designed and administered (see Table 4.2). The sampling size in table 4.2 was based on the minimum acceptable sample sizes (continuous and categorical data) presented by the following authors – (Krejcie and Morgan, 1970, Bartlett et al., 2001).

- Questionnaire 2 followed up on some items in Questionnaire 1 and solicited respondents' perceptions as regards their levels of satisfaction with the system about 3 months after implementation;
- Questionnaire 3 followed up on some items in Questionnaires 1 and 2 and required that respondents evaluate the system about 7 months after implementation.
- Questionnaire 4 followed up on some items in Questionnaires 1, 2 and 3 and required respondents to assess the system about 14 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* (See Table 4.3). The succeeding section is open-ended and requests respondents to provide reasons (personal, cultural, religious or otherwise) why they may not use treated greywater for toilet/urinal flushing or garden watering, and also to make whatever comments they wish to make. The third section solicits socio-demographic data such as age and status at university.

Table 4.2: Profile of respondents

Year	Questionnaire	Respondents	Number
2008	Questionnaire 1 (prior to the implementation of the greywater system)	WITS (students and staff at the School of Civil and Environmental Engineering, University of the Witwatersrand)	253
		UJ (a random sample of students at the University of Johannesburg)	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 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
2011	Questionnaire 4 (about 14 months after implementation of greywater system)	UJ (beneficiaries of the greywater reuse system)	12

Table 4.3. Extract of Questionnaire 1 showing section 1

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.

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.

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

4.2.3. Analysis of perceptions

Data from the questionnaires were entered into a Microsoft Excel worksheet with coding based on that shown in Appendix A5. Frequencies of responses were calculated in Microsoft Excel, while Statistical Package for the Social Sciences (SPSS) was used to analyse socio-demographic patterns and some other aspects. Open-ended responses were tabulated and grouped according to similarities and differences

To understand patterns in the responses to the statements addressing perceptions to GWR, *Strongly (dis)agree* and (*Dis*) *Agree* responses are often merged in the results section to further simplify the results generated. A principal components exploratory factor analysis was carried out using the extraction method to examine the correlation between each statement. This was achieved by determining the Cronbach's alpha (α) value amongst the statements. Cronbach's alpha is commonly used to measure the extent to which multiple items of a construct belong together and varies from 0.0 to 1.0. It is generally accepted that a Cronbach's alpha value above 0.7 is an indication of good internal consistency between items (Vicente and Reis, 2008).

4.2.4 Results from perception surveys

4.2.4.1 Location of Pilot Sites

During the administration of the first questionnaire, relevant officials decided that the University of Cape Town (UCT) should not participate in the implementation of the GWR systems. This was due to some other water saving interventions which had recently been carried out in their University. Therefore subsequent questionnaires were not administered after the identification of the location for the pilot sites. The University of Witwatersrand (WITS) and University of Johannesburg (UJ) were on the other hand, excited to participate and therefore, selected to host the GWR systems. The specific locations were the WITS School of Civil and Environmental Engineering (representive of a non-residential/public building), and Unit 51A, a residence unit within Student Town, UJ (representive of a residential building).

Figure 4.1 shows the building housing the School of Civil and Environmental Engineering, WITS. On a peak working-day of the academic calendar, the building typically houses about 36 staff (academic and support services) and approximately 450 students. There are 12 toilets within the building: 2 male and 3 female toilets (mostly used by students) are located at the south wing of the building, while 5 male and 2 female toilets (mostly used by staff) are located at the north wing of the building. In each of the male bathrooms, there are 2 urinals. Unit 51A, UJ (Figure 4.2) houses the second pilot greywater reuse system. Unit 51A, which houses 16 students, comprises of 2 floors with 2 toilets, 1 shower, 1 bath tub and 3 hand wash basins on each floor.

Figure 4.1: The entrance into the School of Civil and Environmental Engineering at WITS (left)
Figure 4.2: The rear view of Unit 51A, Student Town, UJ(right)

4.2.4.2 Socio-demographic survey

For the 2008 cohort of respondents, principal components exploratory factor analysis of the data generated from responses to the 12 statements in Table 4.3 produced 3 broad categories of responses: '*Comfort levels*' (statements 1, 2, 3, 5, 10, 11, 12), '*Concern levels*' (statements 6, 7, 8 and 9) and '*Other*'(statement 4). The discussion below is based on the first 2 categories. The '*Other*' category did not statistically present any significant difference from the '*Comfort levels*' category and is hence omitted from the highlighted results presented below:

- ***Age groups***: In relation to '*Comfort levels*', the average response of the median of the '*15-21 yrs*' category of respondents (1.83) was slightly lower than that for the '*22 yrs and older*' category (2.00) (Figure 4.3 left). This implied that 50% of the '*15-21 yrs*' were generally less comfortable about greywater reuse than the same percentage of the '*22 yrs and older*'. Thus the '*Concern levels*' expressed by the '*15-21 yrs*' (median of 2.50) was less than that expressed by the '*22 yrs and older*' (median of 2.75) (Figure 4.3 right).

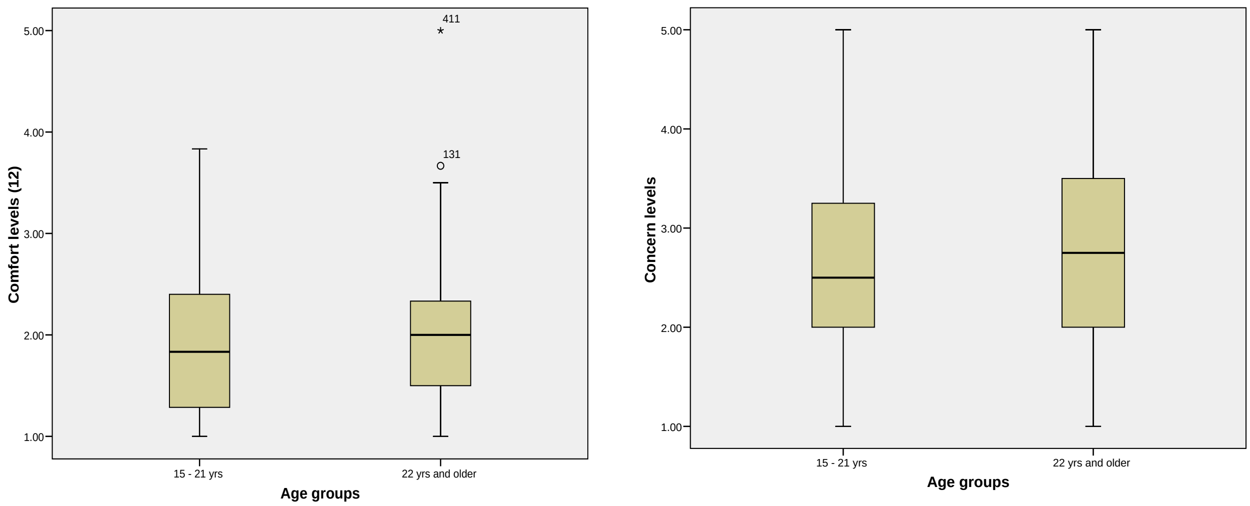


Figure 4.3: Response due to age- levels of comfort (left) and levels of concern (right)

- ***Gender***: In relation to '*Comfort levels*', the average responses of the 75th percentile of '*Male*' and '*Female*' respondents were the same (1.86). A marginal difference did however exist between the genders in terms of '*Concern levels*' – the average response of the median for '*Female*' (2.50) was less than for the '*Male*' (2.75). This indicated that females may be generally less concerned about greywater reuse than males (Figure 4.4);

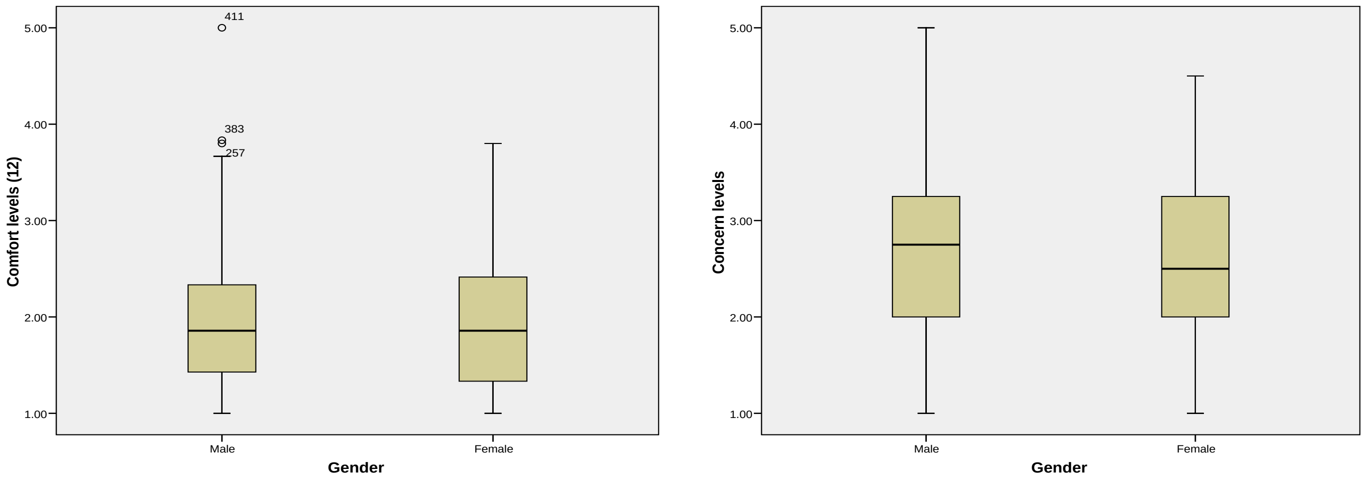
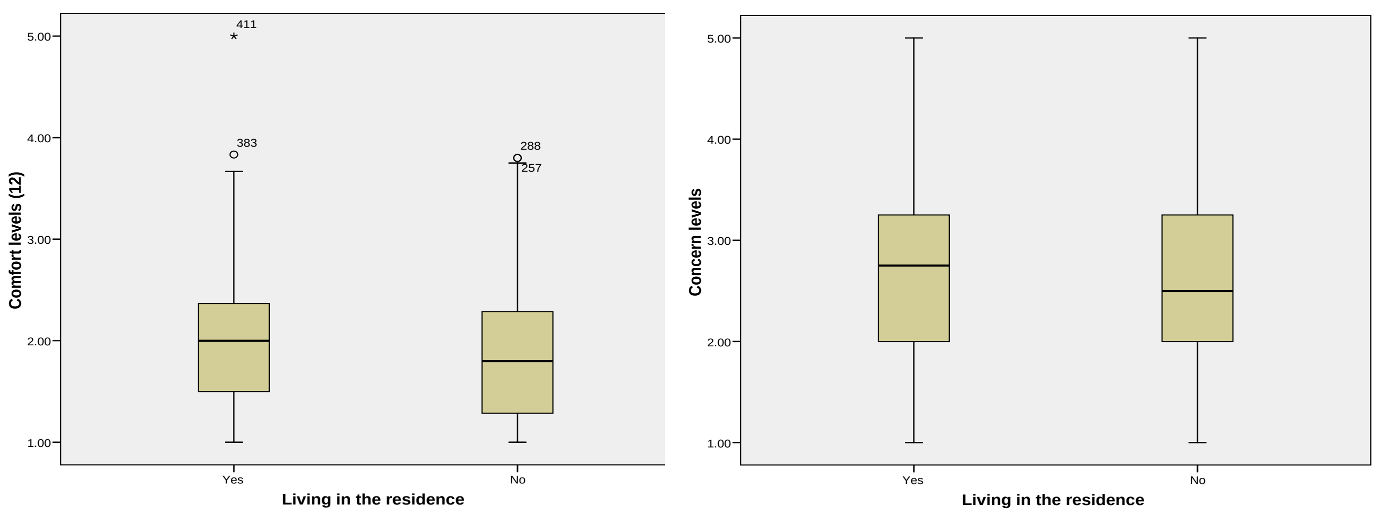


Figure 4.4: Responses due to gender-levels of comfort (left) and levels of concern (right)

- ***Residence***: In relation to '*Comfort levels*', the average responses of the medians of those living in university residence (2.00) were higher than that for those not living in university residence (1.80). This was converse for '*Concern levels*'. These results showed that those not living in university residence were in general, more comfortable about greywater reuse than those living in university residence (Figure 4.5);



- **Figure 4.5. Responses due to residence status-levels of comfort (left) and levels of concern (right)**

- ***Status***: In relation to '*Comfort levels*', the average response of the 75th percentile for the '*Undergrad*' category (1.86) was lower than that for the '*postgraduate students*, *academics and support staff*' category (2.14). This result which correlates positively with the age groups in the bullet point above, shows that the '*Undergrad*' category of respondents who are typically within the age group 15-21 years, are more comfortable about greywater reuse than the older age groups (Figure 4.6);

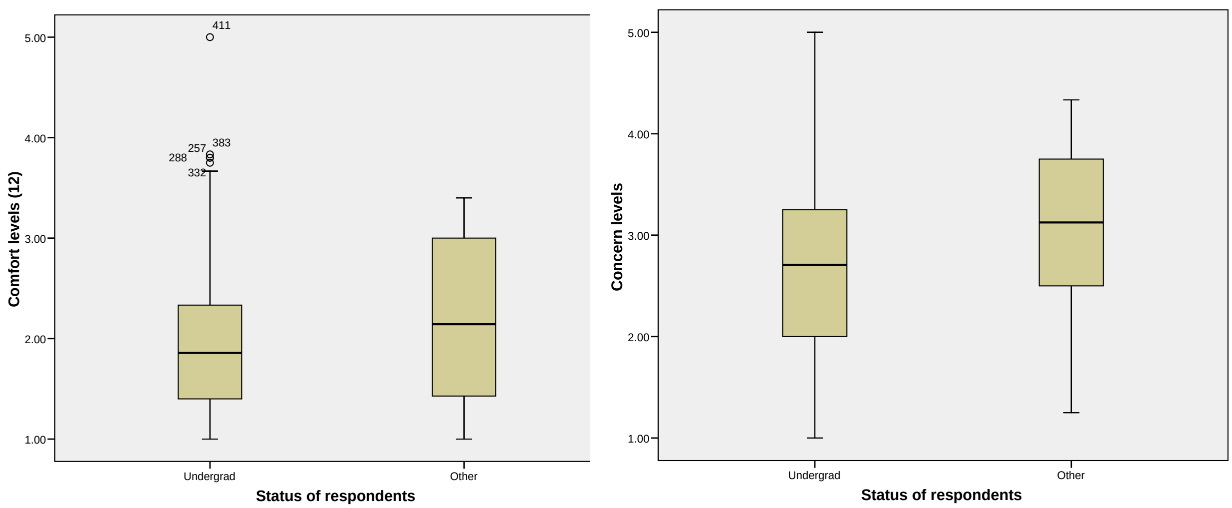


Figure 4.6. Responses due to status-levels of comfort (left) and levels of concern(right)

- ***Race***: In relation to '*Comfort levels*', the '*White*' racial category were generally more comfortable (median of 1.50) about greywater reuse than the '*Asian and Coloured*' (median of 2.00) and '*Black*' (median of 2.00) race groups. The '*Black*' race group expressed more concern (median of 3.00) about greywater reuse than either of the other groups (Figure 4.7).

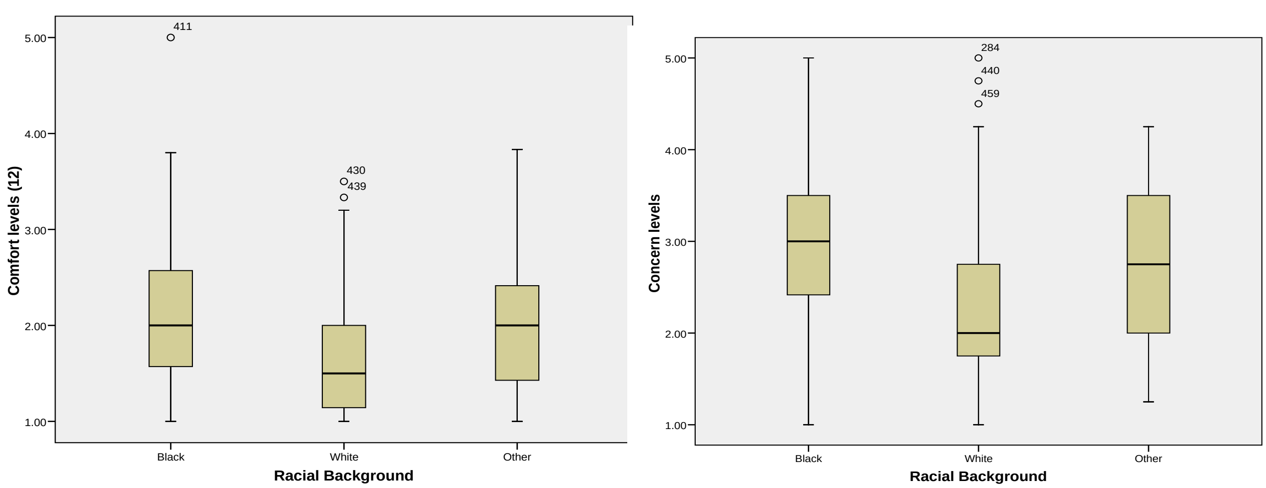


Figure 4.7. Responses due to racial background-levels of comfort (left) and levels of concern(right)

4.2.4.3 Evolution of perceptions

Questionnaires administered were analysed in order to observe the evolution of certain respondent perceptions. The responses of “strongly agree” and “agree” were merged together to become the “agreement response”, while the responses of “disagree” and “strongly disagree” were merged together to become the “disagreement response”. The mergers were carried out in order to simplify the analysis below.

- **Trust**

Respondents were asked the following questions: “I trust that the authorities will ensure that the treated greywater is safe for toilet/urinal flushing? Prior to the implementation of the GWR system at WITS (Figure 4.7a), 88% of respondents were in agreement that the relevant authorities will ensure that greywater is safe. Immediately after implementation 84% were in agreement; while the figure was 76%, 3 months after implementation. A marginal percentage decline is noticed in respondents’ trust from prior to implementation to 3 months after implementation. The perceptions at UJ (Figure 4.7b) shows 64% of respondent were in agreement with the above statement prior to implementation, 86% just after implementation, 69% 3 months after implementation, and 83% 14 months after implementation. The distinct declines in the UJ response 3 months after implementation were due to certain operation problems experienced with the GWR system and which was immediately resolved by the project team. Overall, the level of trust in authorities at both universities was high (above 64%).

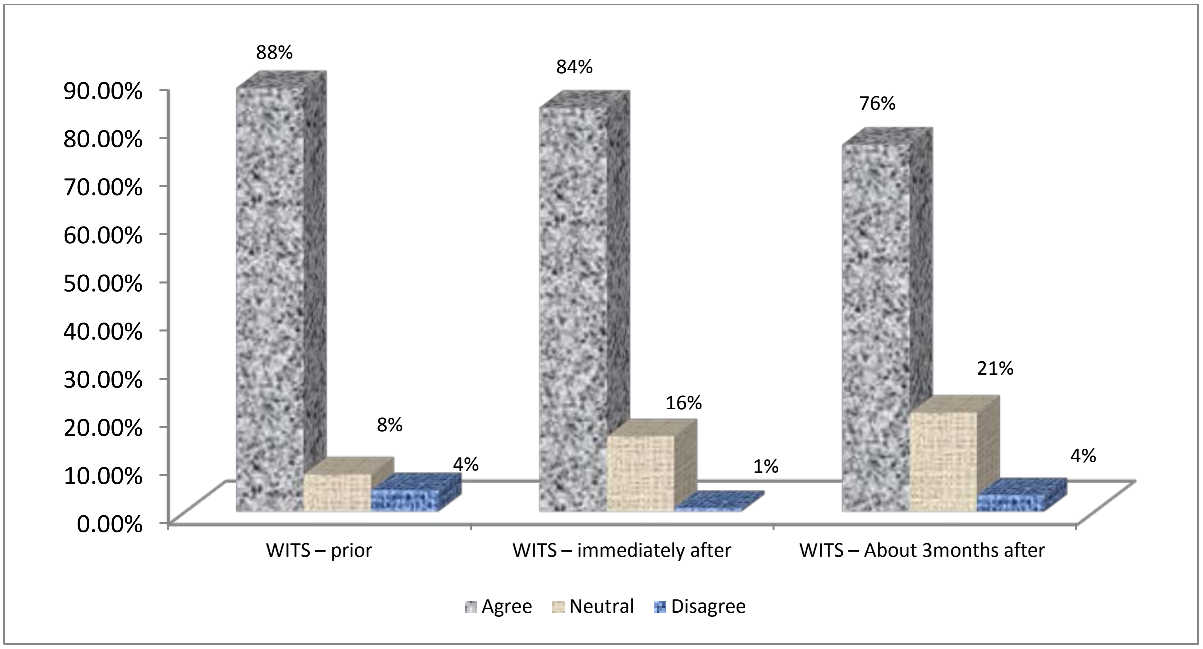


Figure 4.7a: I trust the authorities will ensure that the treated greywater is safe for toilet/urinal flushing (WITS)

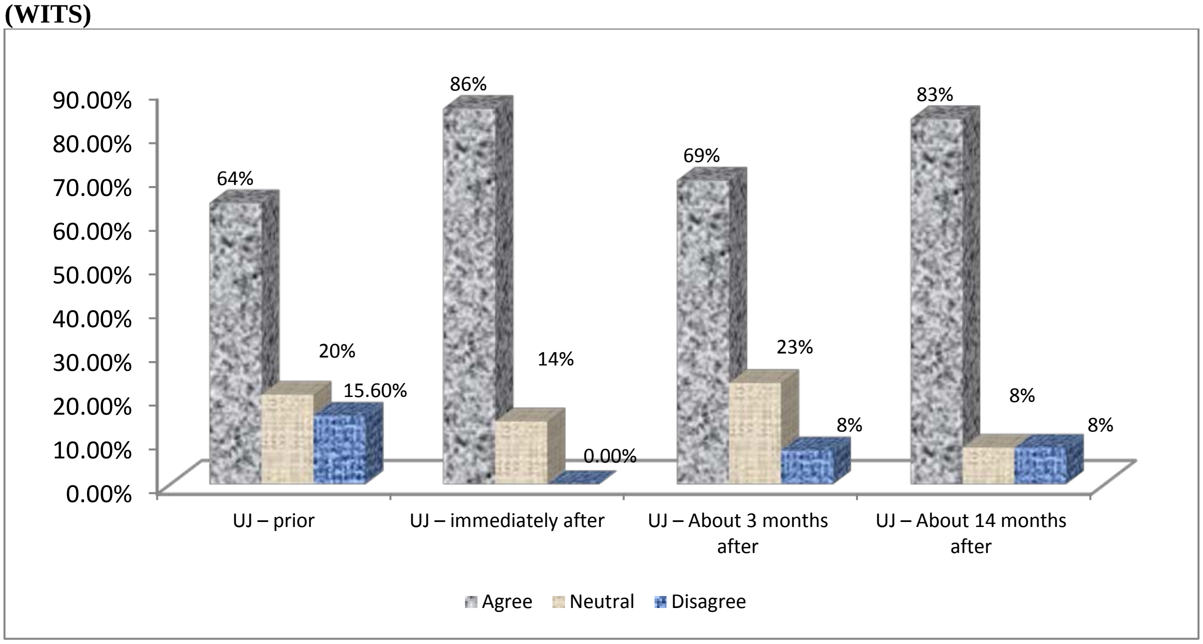


Figure 4.7b: I trust the authorities will ensure that the treated greywater is safe for toilet/urinal flushing (UJ)

- **Perceptions of risk associated with using recycled greywater**

Perceptions of risk are often related to public health issues from reusing waste water. 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) 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 presented below. At WITS (Figure 4.8a), 33% of respondents were concerned and 41% unconcerned about greywater reuse for toilet flushing prior to implementation. The respondent concern level from WITS was also reduced to 40% and 21% immediately after implementation, and 3 months after implementation respectively. At UJ however (Figure 4.8b), the percentages of the concerned, were much higher (average of 65% prior to the implementation than at WITS). Immediately after implementation at UJ in 2010, the female residents recorded a percentage of concern of 50% which was significantly lower than the results prior to implementation and it was later reduced to 39%, 3 months after implementation The reduction in concern levels at both universities may have resulted from an increased level of confidence in the project team who regularly held awareness sessions with the respondents, routine maintenance and random water quality tests to ensure that the greywater system was safe and hygienic for their use. Overall, the results above highlight the impact regular community engagement and awareness by the project team and regular maintenance and hygiene had on respondents trust.

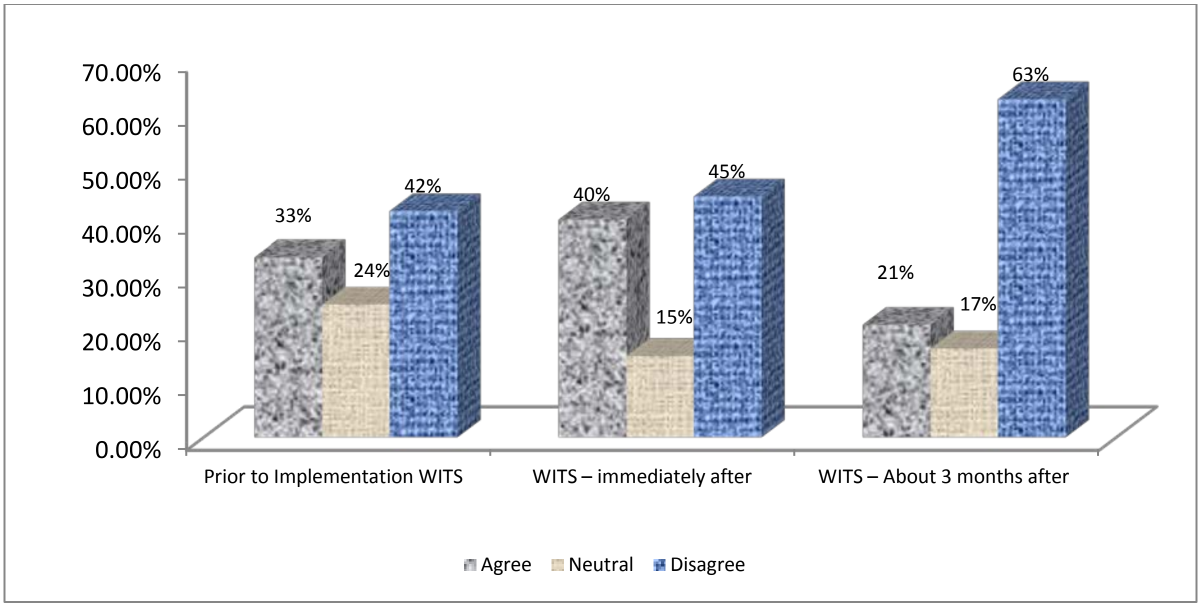


Figure 4.8a: I am concerned about people getting sick from using treated greywater for toilet/urinal flushing (WITS)

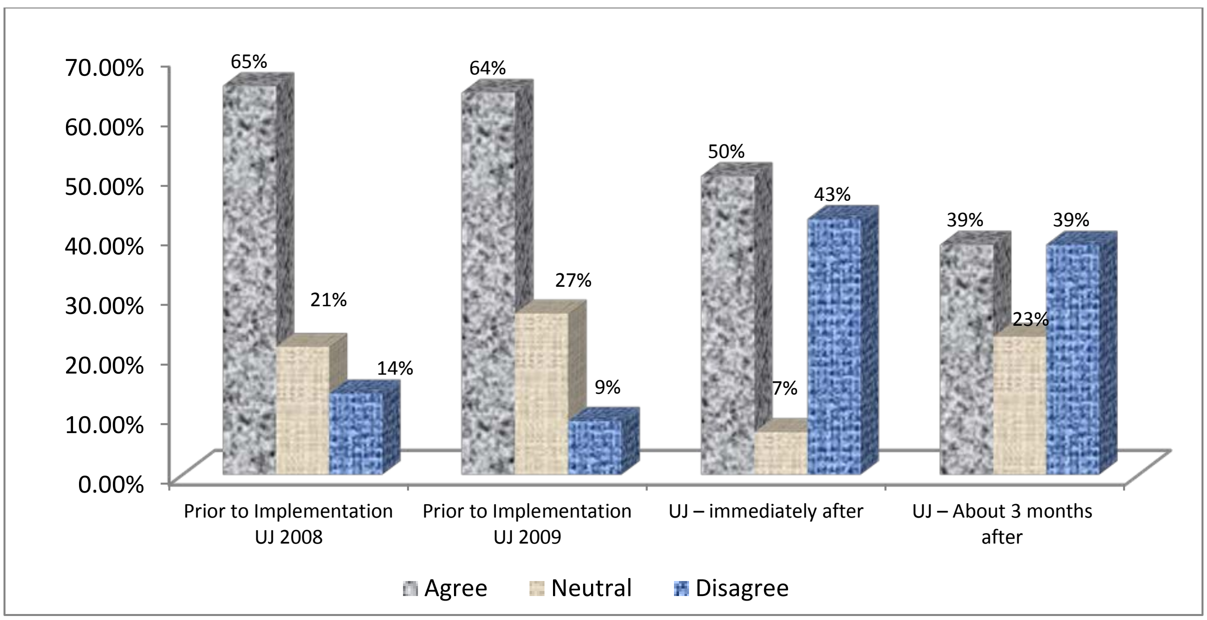


Figure 4.8b: I am concerned about people getting sick from using treated greywater for toilet/urinal flushing (UJ)

- **Perceptions regarding the colour of the greywater**

Respondents were asked the following question *"I am satisfied with the improvement in the colour of the greywater"*. At WITS (Figure 4.9a), the results show an increase (from 56% to 71% in the level of satisfaction with regards to colour of the greywater from 3 months after implementation to 7 months after implementation. At UJ (Figure 4.9b), the result also shows an increase from 62% to 67% in the level of satisfaction from 3 months after implementation to 7 months after implementation. After 14 months of implementation, there was a drastic reduction in respondent's satisfaction to 17%. What was noticed is that most of the respondents that were initially satisfied with the colour were now "neutral" about the colour issue. The latest response at UJ was likely due to the fact that the maintenance of the system may not have been as effectively carried out in comparison to when the system was initially installed.

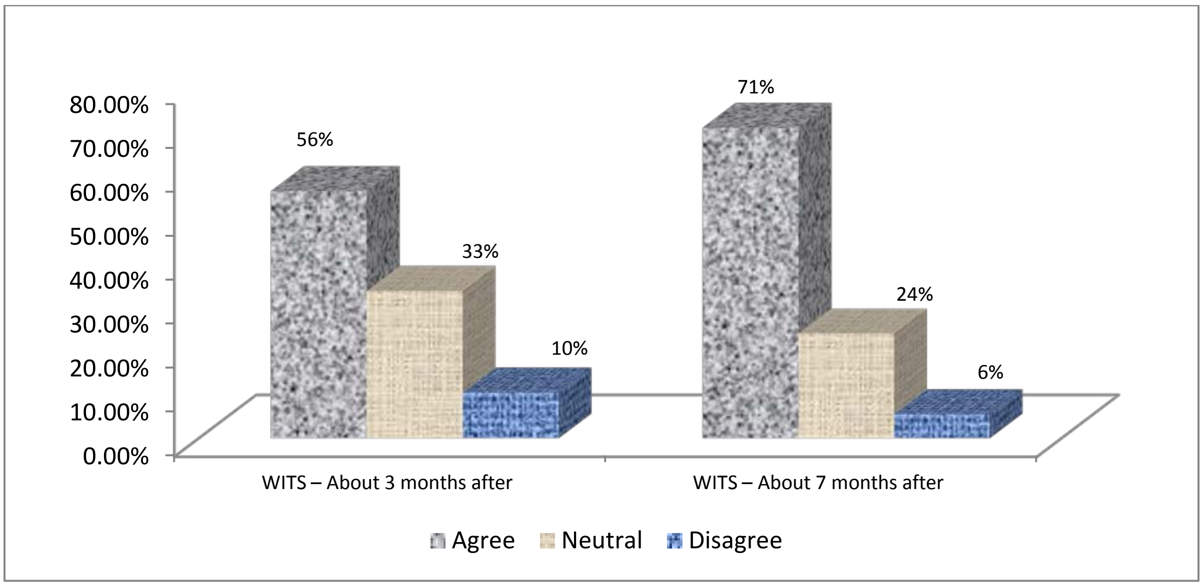


Figure 4.9a: I am satisfied with the improvement in the colour of the greywater (WITS).

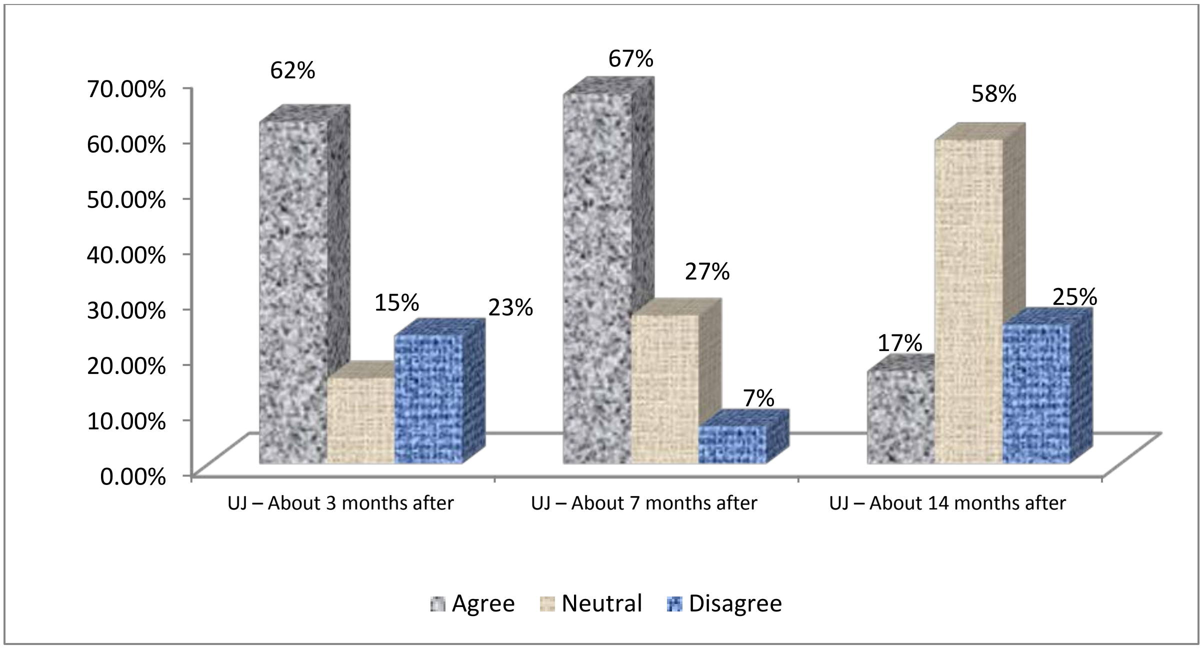


Figure 4.9b: I am satisfied with the improvement in the colour of the greywater (UJ).

- **Perceptions regarding the smell of the greywater**

Respondents were asked the following question: *"I am satisfied with the reduction of unpleasant smells emanating from the greywater toilet while flushing"*. At WITS (Figure 4.10a), the responses show an increase from 55% to 78% in the level of satisfaction with regards to smell from 3 months after implementation to 7 months after implementation. At UJ (Figure 4.10b), the responses show an increase from 46% (3 month after implementation) to 80% (7 month after implementation) and a decline to 25% about 14 month after implementation. Two issues likely resulted in this situation firstly, the ineffective maintenance mentioned in the previous section between months 7 and 14 after implementation and secondly, the smell of chlorine which was used as the disinfectant and which many of the respondents deemed to be a persistent and unpleasant smell.

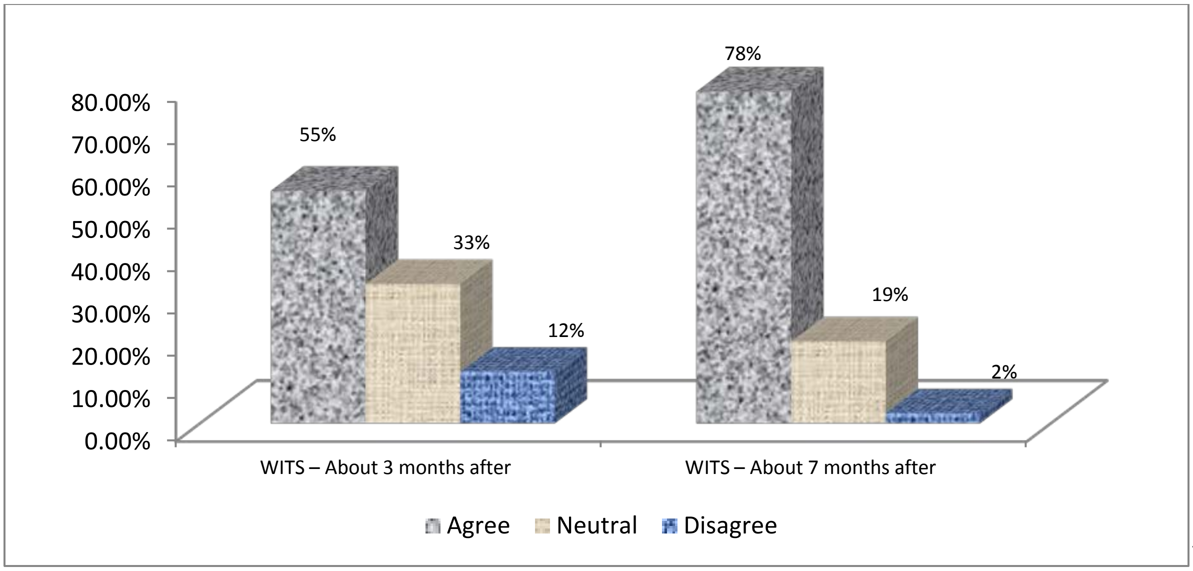


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Figure 4.10a: I am satisfied with the reduction in unpleasant smells emanating from the greywater toilet while flushing (WITS)

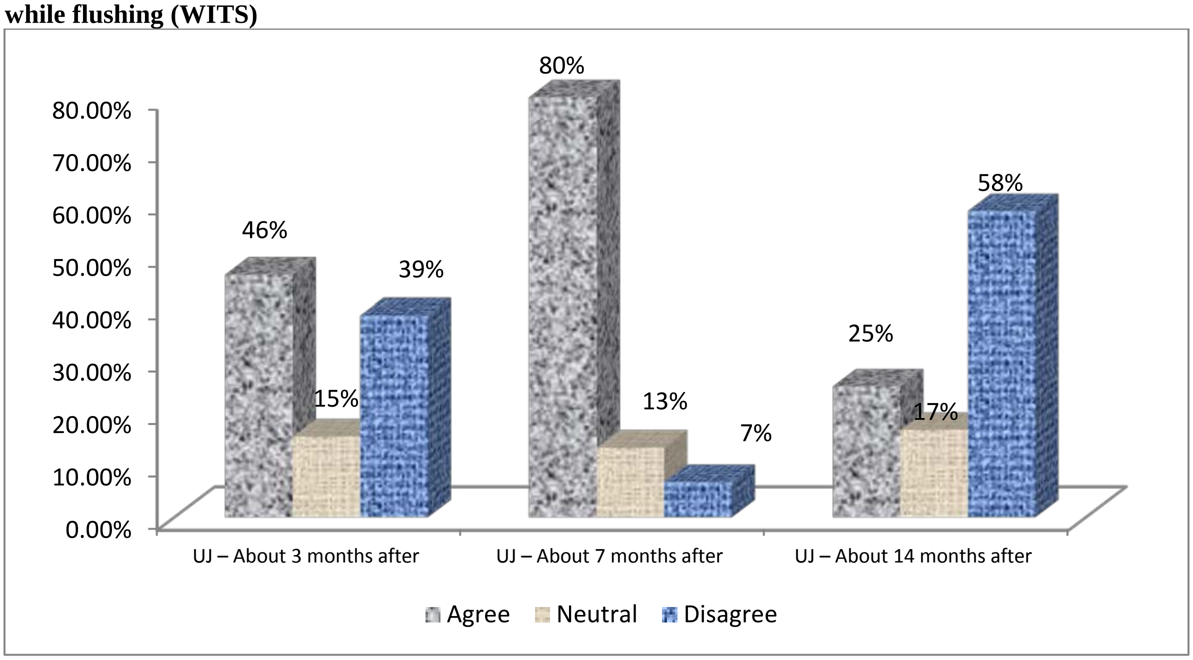


Figure 4.10b: I am satisfied with the reduction in unpleasant smells emanating from the greywater toilet while flushing (UJ)

- **Frequency of greywater toilet use**

Respondents were asked the following question: "*How often do you use the greywater toilet?*". At WITS, about 72% of respondent (3 and 7 month after implementation) indicate that they use the GWR toilets more than or equal to 50% of the time (2 out of 4 time) while at UJ these values were 55%,80%and 67%.3,7 and 14 month after implementation. At both sites, the above values show most respondents pro-action in using the toilets even though there is a visible decline in use at UJ. This was likely due to the ineffective maintenance mention in the previous 2 sections.

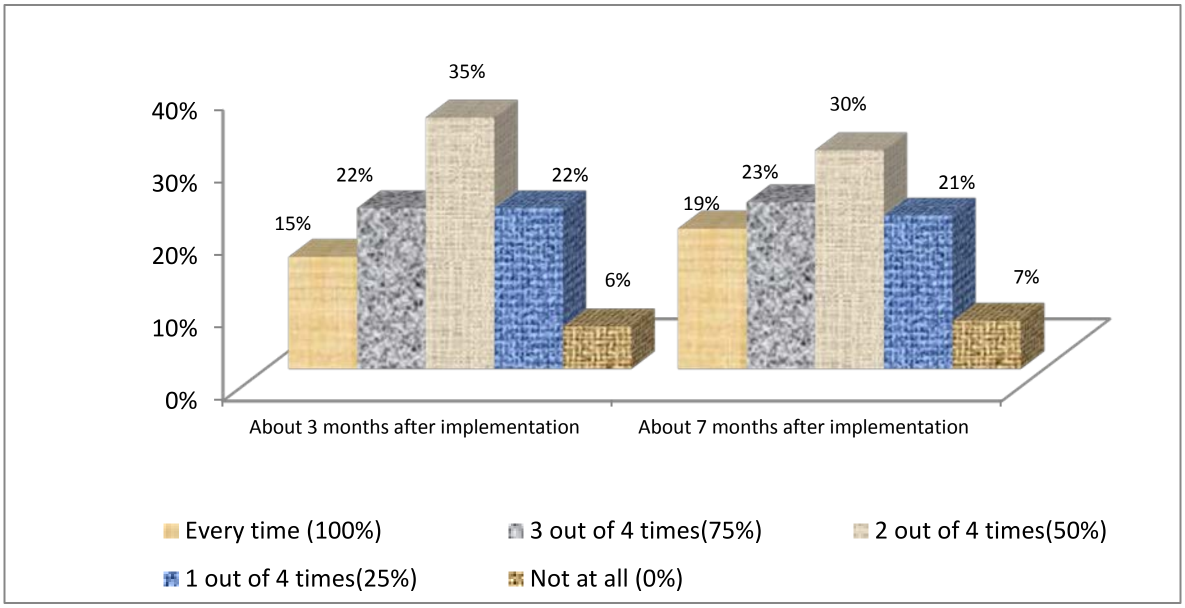


Figure 4.11a: Frequency of greywater toilet use at WITS

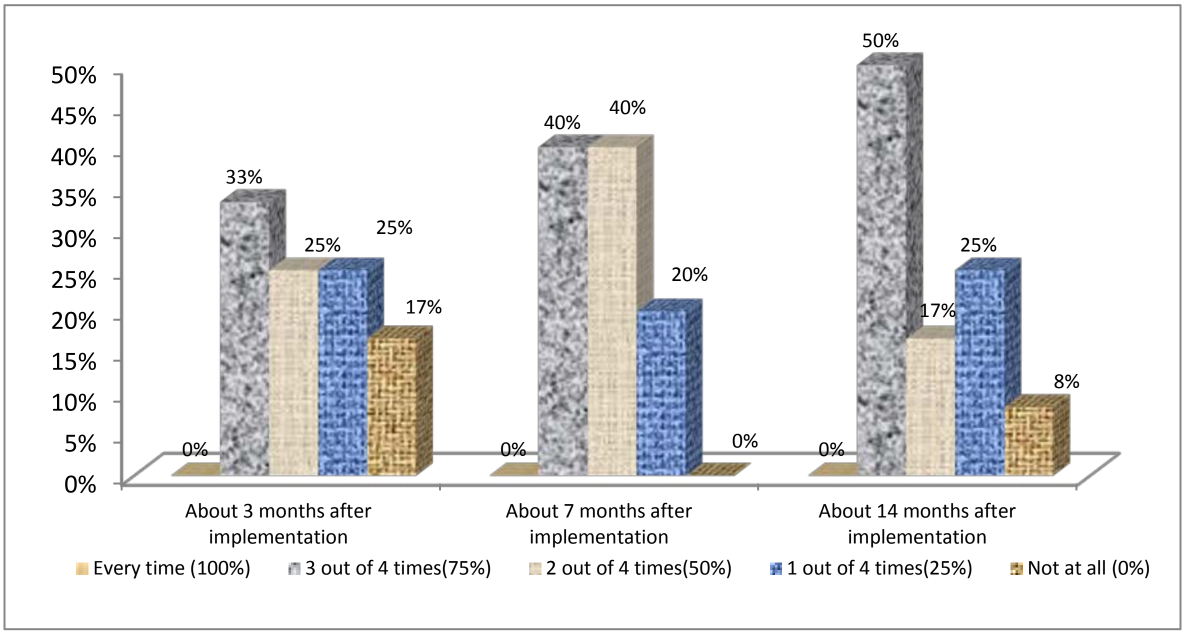


Figure 4.11b: Frequency of greywater toilet use at UJ

4.2.5 Summary of the evolution of perceptions

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 due to irregular maintenance) 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 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) 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. It is the responsibility of the implementing authorities to guarantee this until such a time that beneficiaries are confident to operate the systems themselves. The following are some of the highlight on the similarity and difference between the University of Witwatersrand (WITS) and University of Johannesburg (UJ):

- The level of trust in implementing authorities at both universities was high (above 64%).
- There was a reduction in concern levels at both universities which may have resulted from an increased in level of confidence in the project team who regularly held awareness sessions with the respondents, routine maintenance and water quality tests to ensure that the greywater system was safe and hygienic for their use.
- There was an increase in the level of satisfaction with regards to colour at WITS with an increase from 56% to 71% from 3 months after implementation to 7 months after implementation. At UJ, the results also show an increase from 62% to 67% in the level of satisfaction from 3 months after implementation to 7 months after implementation and a decline in satisfaction after the 14^{th} month.

- At WITS there was an increase from 55% to 78% in the level of satisfaction with regards to smell from 3 months after implementation to 7 months after implementation. At UJ the responses show an increase from 46% (3 month after implementation) to 80% (7 month after implementation) and a decline to 25% about 14 month after implementation.
- Two issues likely resulted in the decline in satisfaction as regards smell from 7 months after implementation to 14 months after implementation. Firstly, the ineffective maintenance and secondly, the smell of chlorine which was used as the disinfectant and which many of the respondents deemed to be a persistent and unpleasant smell.
- At both sites, most respondents were pro-active about the use of the greywater toilets even though there was a visible decline in use at UJ. This was likely due to the ineffective maintenance mentioned in the previous section.
- Smell and Colour were highlighted as two attributes of greywater of importance to respondents at both sites. Beneficiaries' receptivity of reuse schemes will therefore depend heavily on these attributes being sustainably satisfactory. Greywater systems, such as the one employed in this study, will therefore need to look into the elimination of unpleasant smells and include a final, polishing filter to reduce turbidity and remove scum prior to use;
- With regards to demographics, respondents younger than 21 years were generally more comfortable about greywater reuse than older respondents at WITS and therefore should be targeted when considering greywater reuse for toilet flushing (or similar interventions).

4.3 Public awareness and involvement

4.3.1 Background

Public awareness and involvement is the process by which all stakeholders within a community are provided the opportunity to make their views known and to contribute to designing initiatives which will improve the targeted project/programme. Effective public involvement ensures that stakeholders recognize and understand the activities of a project and its guiding polices. Public involvement also enhances the legitimacy of decisions made and ensures the programmes' goals reflect public concerns, values and priorities (SERM 1995).

Public participation has many components, all of which should ideally be considered within any project. These components may include the direct involvement of stakeholders in planning committees, public involvement in informational meetings through written and/or oral submissions, participation in community training events (such as training on a demonstration unit) and public involvement in the development and distribution of educational maternal, such as fact sheets, posters, radio adverts, brochures, and artwork (FPTCDW/CCME, 2004). This section highlights the public awareness and involvement programmes/events implemented within this study to manage/mitigate risks of failure at the GWR pilot sites.

To this end the following educational and awareness activities were carried out:

i. Several meetings were held prior to the installation of the GWR system at WITS and UJ. This included meetings with relevant management and maintenance personnel at WITS and UJ to obtain permission and inform on progress on the project.
ii. There were several meetings held at the UJ pilot site after the implementation of the GWR system. These meetings were targeted at administering the perception surveys and providing residents' ample opportunities to air their concerns, questions and receive feedback from the project team about various issues (see Figure 4.12a and b).
iii. Awareness sessions were held with the technical staff and different student cohorts (1^{st} - 4^{th} year B.Sc. civil engineering students) at the WITS GWR pilot sites shortly after the system was implemented. These sessions were aimed at describing the system and 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;

iv. A school seminar on the GWR system was presented in 2010 by two 4th year B.Sc. civil engineering students at Wits who were conducting their investigational project on the GWR system. 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 school building;

v. The GWR system formed part of the exhibition showcased by the school to visitors and potential students during its annual information days at WITS;

vi. Size A3, A4 and A5 posters were put up within the building and bathrooms (Figures 4.13 (a), (b) and (c). These posters help to create awareness about the GWR system and to inform users about how to use the system.

vii. The GWR project was presented at the WITS 2010 university-wide postgraduate symposium.

Figure 4.12 (a) Some of the residents of UJ Unit 51 during a meeting (b) Project team answering questions

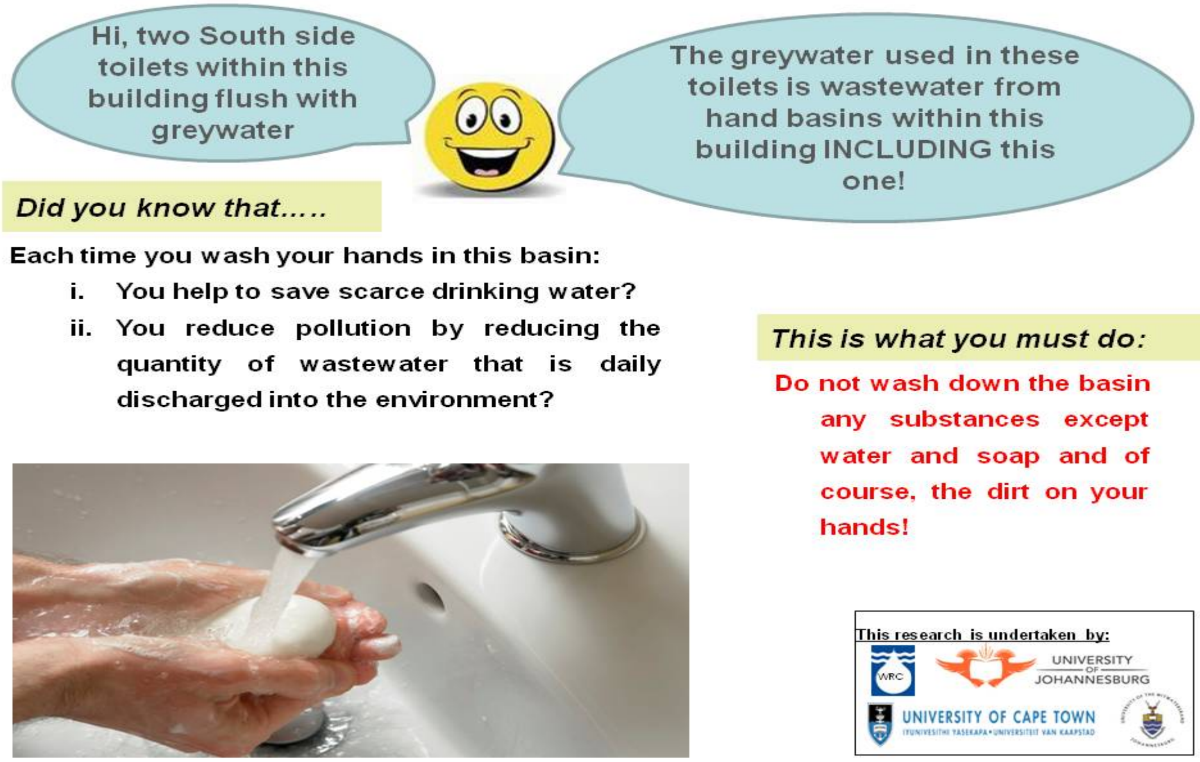


Figure 4.13 (a): A5 posters placed in front of each hand basin

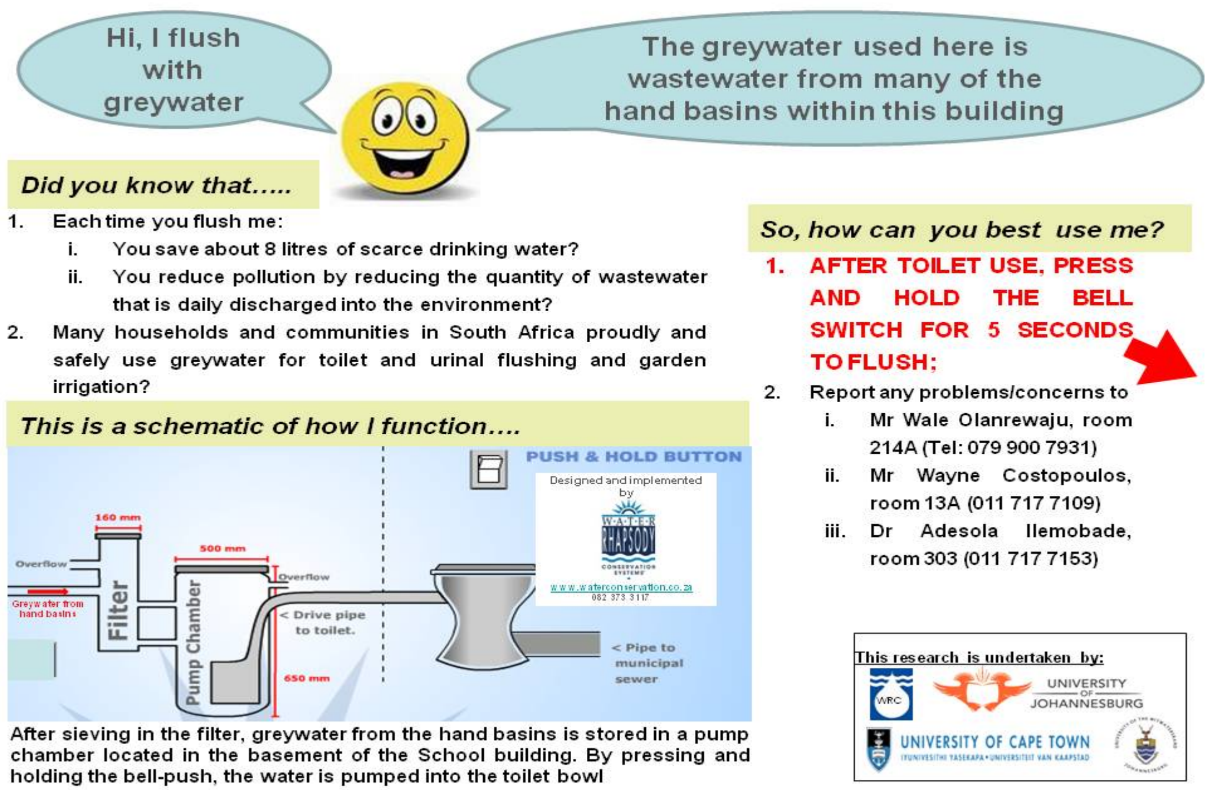


Figure 4.13 (b): A3 posters placed above toilet cisterns guiding users about how to use the system

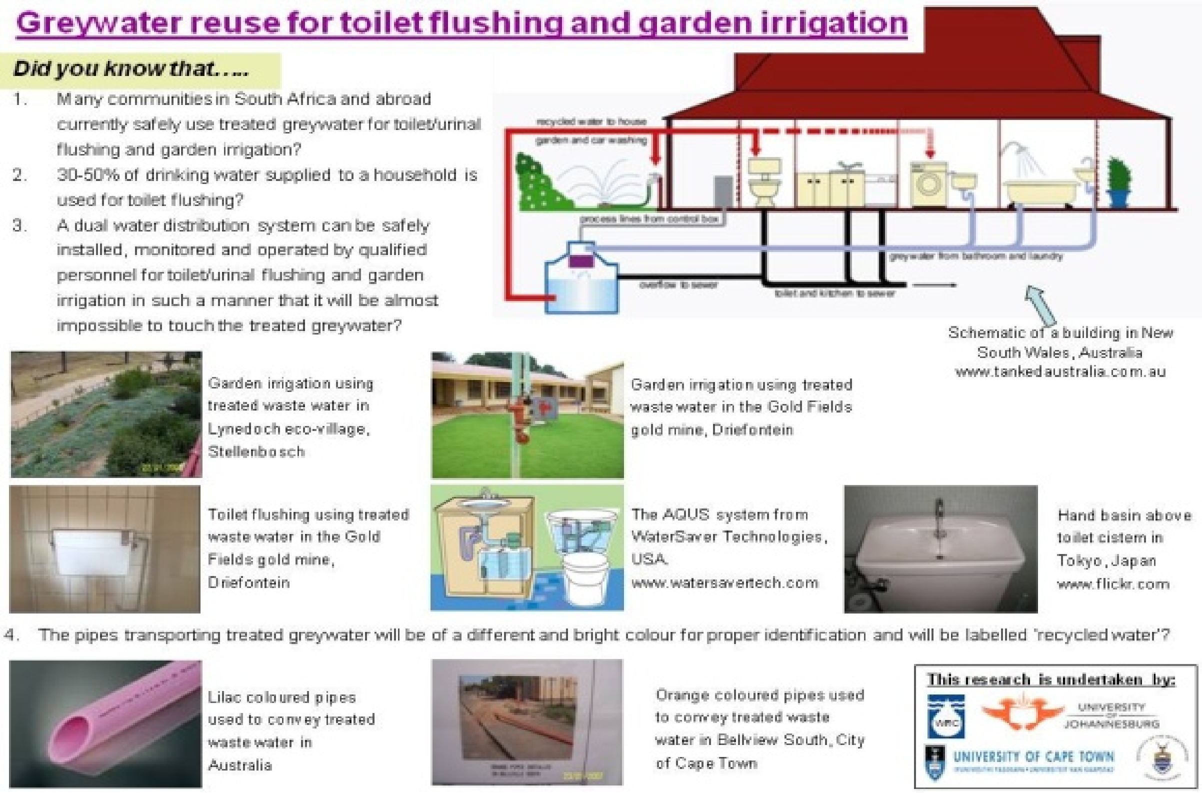


Figure 4.13 (c): A3 posters placed above toilet cisterns guiding users about how to use the system

4.3.2. Highlights from the public awareness and involvement

The implementation of the above public awareness and involvement programmes/events provided education and information to potential and actual beneficiaries of the GWR project. It also assisted in identifying the needs and priorities of beneficiaries of the project with respect to water quantity and quality. The programme/events also provided opportunities for building of relationships between stakeholders and beneficiaries. A significant highlight is that awareness and involvement assisted in identifying issues of concern and in setting up preventive measures. 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 was 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.

4.4 Analysis of the attributes that are of importance to beneficiaries regarding GWR and understanding the willingness of beneficiaries to pay for some of these attributes.

4.4.1 Background

The attributes that are of importance to recycled water vary from that of drinking water and the extent to which they vary depends largely on the source of the water (Hurlimann and McKay, 2007). For recycled water, these attributes can also vary from the source to the process of treatment and aesthetics. In order to implement successful GWR, it is therefore important to identify the attributes that are of importance to beneficiaries and their willingness to pay (WTP) for these attributes. The section below investigated beneficiaries' attitudes to price, colour and odour of greywater. It also estimates WTP for some of these attribute of greywater.

Conjoint Analysis (CA) was used to evaluate respondents' preferences for the above attributes of greywater and to also estimate WTP for these attributes.

4.4.2 Methodology

In determining the attributes to investigate in this study, the most prominent concerns expressed by the pilot study beneficiaries (see section 4.2.4.3) were selected alongside attributes in literature (Hurlimann and McKay, 2007) deemed to be critical in recycled water use. This process led to the selection of the attributes of colour, odour and price. The matrix shown in Table 4.4 was developed based on these 3 attributes. As can be seen, price of greywater is expressed as a percentage of the price of drinking water. Based on the matrix (Table 4.3) and the possible attribute combinations (2x2x3=12), Table 4.5 was administered to respondents. Respondents were asked to rate their preference for each scenario on a scale of 1–12, where 1 represented the least desirable preference and 12, the most desirable preference. This questionnaire was only administered to the UJ respondents 14 months after the greywater reuse system had been implemented and was not administered at WITS because of its inappropriateness – WITS is an academic institution where students do not pay for municipal services. This is in contrast to the UJ site, which is a residential unit where students are required to pay for services.

Table 4.4: Attributes of recycled water and the different levels tested

Attribute	**Colour (value)**	**Odour (value)**	**Tariff per m^3 (as a% of the price of drinking water) (value)**
Level	Grey colour (1)	Pleasant smell (1)	50 (1)
	Blue colour (2)	Unpleasant smell (2)	75 (1.5)
			100 (2)

Note:
Grey colour (original colour of greywater)
Blue colour (using cistern blocks that change the grey colour to blue)
Pleasant smell (this is as a result of using the cistern blocks)

Table 4.5: Possible combinations of attributes tested.

S/N	Colour (value)	Odour (value)	Price per m^3 (as a% of the price of drinking water)	Preference on a scale of 1-12
1	Grey colour (1)	Pleasant smell (1)	50 (1)	
2	Grey colour (1)	Pleasant smell (1)	75 (1.5)	
3	Grey colour (1)	Pleasant smell (1)	100 (2)	
4	Grey colour (1)	Unpleasant smell (2)	50 (1)	
5	Grey colour (1)	Unpleasant smell (2)	75 (1.5)	
6	Grey colour (1)	Unpleasant smell (2)	100 (2)	
7	Blue colour (2)	Unpleasant smell (2)	50 (1)	
8	Blue colour (2)	Unpleasant smell (2)	75 (1.5)	
9	Blue colour (2)	Unpleasant smell (2)	100 (2)	
10	Blue colour (2)	Pleasant smell (1)	50 (1)	
11	Blue colour (2)	Pleasant smell (1)	75 (1.5)	
12	Blue colour (2)	Pleasant smell (1)	100 (2)	

4.4.3 Data Analysis

Conjoint Analysis (CA) was used to evaluate respondents' preferences for the different attributes of greywater and to estimate willingness to pay for these attributes. CA has been extensively used by marketers to assess/understand consumer attitudes to new commodities or new attributes/features of an existing product. CA is based on the assumption that complex decisions by consumers are not based on a single factor or criteria but on several factors 'considered jointly' (Hurlimann and McKay, 2007). SPSS version 16.0.1 was used in the analysis. An Ordinary Least Squares (OLS) method was used to estimate the coefficients and the statistical significance of the independent variables. The objective of an OLS CA is to produce a set of additive regression equations that identify each respondent's preferences amongst different attribute combinations. Hence, the OLS method solves for preferences using a set of dummy independent variables which may take a value between 0 (unimportant attribute) and 1 (important). The model used in this study (after Hurlimann and McKay, 2007) considers the 3 attributes of greywater –*colour*, *smell* and *tariff* and is expressed as:

$U = \beta_1$ (colour) $+\beta_2$ (smell) $+\beta_3$ (tariff) + ej,…………………………(4.1)

Where U is the utility (respondent's preference score) for a particular combination of the 3 attributes. As shown in Table 3 (see page 109) the assigned values for β_1 (*colour)* were 1 (grey) or 2 (blue); for β_2 (smell), the values assigned were 1 (pleasant) or 2 (unpleasant); for β_3 (greywater tariff per m^3), the values assigned were 1 (50% of the tariff for drinking water), 1.5 (75%) or 2 (100%) and ej is the constant of the equation.

To determine the least and most desirable combinations, an initial regression analysis was conducted on all the variables. The result from the initial regression analysis indicates the influence of the each attribute on the overall preference (utility) score (Table 4.6). The more positive or negative the coefficient, the more influence that attribute has on the overall preference score. Table 4.6 shows an initial coefficient of +5.27 for pleasant smell to coefficient 0 for an unpleasant smell. This makes pleasant smell more desirable, while 2.52 for blue coloration and 0 coefficient for grayish colour. While greywater tariff per m^3 – 1 for (50% of the tariff for drinking water) has the value of 0, (75% of the tariff for drinking water) has the value -0.54 and or -1.29 (100% of the tariff for drinking water). After the initial regression analysis conducted, a dummy variable regression analysis was conducted on the most desirable combination and the least desirable combination. The result of the two separate dummy variable regression analysis gives two separate intercept which makes the values of the two constants.

Table 4.6: Results of initial regression analysis.

	Coefficients
Intercept	3.18
Greyish colour	0.00
Blue colour	2.53
Pleasant smell	5.28
Unpleasant smell	0.00
0.5	0.00
0.75	-0.54
1	-1.29

Willingness to pay (WTP) was calculated using equation 2 (Hurlimann and McKay, 2007):

$WTP = \beta c/\beta y$……………………………………………………………. (4.2)

Where βc represents the coefficient of an attribute (either *colour* or *smell*) and βy represents the coefficient for *greywater tariff*. For example, if coefficient of the *colour* attribute is 5.2 and the coefficient of the *greywater tariff* is 2.0, then WTP would equal 2.6.

4.4.4 Results

4.4.4.1 Analysis of the attributes of importance to beneficiaries regarding GWR

The results from the regression analysis carried out are reported in Table 4.7. The coefficients indicate the influence of the specific attribute on the overall preference (utility) score. The more positive or negative the coefficient, the more influence that attribute has on the overall preference score. The coefficient of determination, R^2 shows how good the fit is between the data and the least square model. The closer R^2 is to 100% the better the fit. In the analysis of the most desirable and least desirable preferences, an R^2 value of 69% was obtained. The largest coefficient (in this case = 5.28 and related to smell) had the largest influence on respondents' preference followed by the blue colour (2.53) and then the price of greywater which was 50% of the price of drinking water (1.29). A change in smell of greywater from pleasant to unpleasant (-5.28) will have a significantly larger influence on respondents' preference than changes in colour (-2.53) or price (-0.54 for 75% the price of drinking water or -1.29 for 100% the price of drinking water). Hence, of the 3 attributes-odour, colour and price, odour had the largest influence while price influenced respondents' preference the least. As expected, respondents preferred the cheapest price for GWR (i.e 50% water).

These results conform to the report by Hurliman and Mckay (2007) which determined a relatively small coefficient on the price of the resource in comparison to the other greywater attributes, for different uses of greywater including garden watering, toilet flushing and cloth washing.

Table 4.7: Results of dummy variable regression analysis.

Variable	Coefficient for the most desirable preference	Coefficient for the least desirable preference
Multiple R	0.83	0.83
R^2	0.69	0.69
Adjusted R^2	0.66	0.68
Standard error	2.03	2.03
Observation (12 attribute x 12 respondents)	144	144
Constant, ej	**1.89**	**10.99**
Blue Colour	**2.53**	**0**
Grey Colour	**0**	**-2.53**
Pleasant smell	**5.28**	**0**
Unpleasant smell	**0**	**-5.28**
Price (50% of drinking water)	**1.29**	**0**
Price (75%of drinking water)	**0.75**	**-0.54**
Price (100% of drinking water)	**0**	**-1.29**

4.4.5 A practical example of the application of the model.

A practical example based on what one of the respondents selected as her preferences is shown in Table 4.8.

Table 4.8: A sample of a respondent's preferences

S/N	Colour (value)	Odour (value)	Price per m^3 (as a % of the price of drinking water)	Respondent's preference on a scale of 1-12
1	Grey colour (1)	Pleasant smell (1)	50 (1)	**9**
2	Grey colour (1)	Pleasant smell (1)	75 (1.5)	**8**
3	Grey colour (1)	Pleasant smell (1)	100 (2)	**7**
4	Grey colour (1)	Unpleasant smell (2)	50 (1)	**3**
5	Grey colour (1)	Unpleasant smell (2)	75 (1.5)	**2**
6	Grey colour (1)	Unpleasant smell (2)	100 (2)	**1**
7	Blue colour (2)	Unpleasant smell (2)	50 (1)	**6**
8	Blue colour (2)	Unpleasant smell (2)	75 (1.5)	**5**
9	Blue colour (2)	Unpleasant smell (2)	100 (2)	**4**
10	Blue colour (2)	Pleasant smell (1)	50 (1)	**12**
11	Blue colour (2)	Pleasant smell (1)	75 (1.5)	**11**
12	Blue colour (2)	Pleasant smell (1)	100 (2)	**10**

From Table 4.7, the most desirable preference was given a value of 12 (the combination of Blue colour, Pleasant smell and 50% of the price of drinking water). By inserting the coefficient of the variables in Table 4.6, we can compare if the model predicts the respondent's most desirable attribute properly.

In testing for the most desirable attribute combination, the value of the coefficients that are presented in Table 4.7 under the most desirable column are given the value of 1 while the attributes not selected are allocated a 0 value.

Therefore the combination preference = Constant + {(1) * coefficient of blue colour} + {(0) * coefficient of grey colour} + {(1) * coefficient of pleasant smell} + {(0) * coefficient of unpleasant smell} + {(1) * (coefficient of 50% of the price of drinking water)} + {(1) * (coefficient of 75% of the price of drinking water)} + {(0)*(coefficient of 100% of the price of drinking water)}

= 1.89 + {(2.53) * 1} + {(0) * 1} + {(5.28) * 1} + {(0) * (1)} + {(1.29) * (1)} + {(0.75) * (1)} + {(0)*(1)} = 11.73

The result shows a value of 11.73. When compared to 12, the most desirable preference shown in Table 4.7, there is an error of 0.27 (12 - 11.73). This error is negligible when considering the total range of preferences between 1 and 12 and thus, this model is a good predictor of the selected respondent's attribute of importance.

In testing for the least desirable attribute combination, the value of the coefficients that are presented in Table 4.67 under the least desirable column, are given the value of 1 while the attributes not selected are allocated a 0 value.

Therefore the combination preference = Constant+ {(0) * coefficient of blue colour} + {(1) * coefficient of grey colour} + {(0) * coefficient of pleasant smell} + {(1) * coefficient of unpleasant smell} + {(0) * (coefficient of 50% of the price of drinking water)} + {(1) * (coefficient of 75% of the price of drinking water)} + {(1)*(coefficient of 100% of the price of drinking water)}

= 10.99 + {(0) * 0} + {(-2.53) * 1} + {(0) * 1} + {(-5.28) * 1} + {(0) * (1)} + {(-0.54) * (1)} + {(-1.29)*(1)} = 1.35

The result shows a value of 1.35. When compared to 1, the least desirable preference shown in Table 4.7, there is an error of 0.35 (1 - 1.35). This error is negligible when considering the total range of preferences between 1 and 12 and thus, this model is a good predictor of the selected respondent's attribute of importance.

4.4.6 Analysis of Willingness to Pay

Even though the greywater being supplied to the student's residence is not provided at a cost, WTP is an important consideration that attempts to establish if consumers will be willing to pay the cost required for GWR. Therefore, the willingness to pay (WTP) was estimated by dividing the coefficients of either colour or odour by the coefficient of price. The values displayed in Table 4.9 were converted to South African Rand from the coefficient values based on the 2010/11 commercial/domestic price of drinking water (R10.59/KL) by Johannesburg Water.

Table 4.9: WTP for various water attributes.

Attribute	**Coefficient value βc/βy (Coefficient of odour/colour divided by coefficient of price for the most desirable preference)**	**Rand /m^3 (Coefficient x 2010/11 price of drinking water)**
Odour	4.1	R0.43
Colour	2.0	R0.21

From the result above, it shows that respondents were rather willing to spend about double the amount of money to improve the colour on the smell of the greywater. This is evident in the WTP values determined for smell (4.1) in comparison to colour (2.0).

4.7.4. Summary

This section reports on the social measures that were implemented to manage and therefore mitigate the risks associated with the implementation of GWR for toilet flushing at the pilot sites. These measures were: (i) the evaluation of perception surveys carried out on potential and actual beneficiaries of GWR for toilet flushing; (ii) public awareness and involvement and; (iii) an analysis of the attributes that are important to beneficiaries regarding GWR and understanding the willingness of beneficiaries to pay for some of this attributes. The following are the key findings from the measures carried out in this section of the study:

(i) The evaluation of perceptions:

- The level of trust in authorities at both universities was high (above 64%). There was a reduction in concern levels at both universities which may have resulted from an increase in the level of confidence in the project team who regularly held awareness sessions with respondents, routine maintenance and water quality tests to ensure that the greywater system was safe and hygienic for their use.
- There was an increase in the levels of satisfaction with regards to colour at WITS with an increase from 56% to 71% from 3 months after implementation to 7 months after implementation. At UJ, the results also show an increase from 62% to 67% in the levels of satisfaction from 3 months after implementation to 7 months after implementation and a decline in satisfaction after 14 months.
- At WITS, there was an increase from 55% to 78% in the levels of satisfaction with regards to smell from 3 months after implementation to 7 months after implementation. At UJ the responses show an increase from 46% (3 month after implementation) to 80% (7 month after implementation) and a decline to 25% about 14 month after implementation. Two issues likely resulted in this decline of the levels of satisfaction from 7 months after implementation to 14 months after implementation. Firstly, the ineffective maintenance at the time and secondly, the smell of chlorine which was used as the disinfectant and which many of the respondents deemed to be a persistent and unpleasant smell.
- At both sites, most respondents were generally pro-active in the implementation and use of the greywater toilets even though there is a visible decline in use at UJ. This was likely due to the ineffective maintenance at the time of the survey.

Overall, the results highlight the positive impact regular community engagement and awareness by the project team and regular maintenance had on respondents.

(ii) Public awareness and involvement: During these process, the majors concerns raised by respondents were recorded and addressed promptly. Some of these concerns helped to identify some attributes of importance regarding the smooth running of the GWR system. Some of the concerns raised included the following:

- the back-up of bath and shower greywater into the ground floor bath and shower when released from the 1st floor just after the system was implemented;
- unpleasant smells from the greywater during flushing after a long holiday with no maintenance carried out on the system prior to respondents' resumption at the residence;
- the effect of the disinfected greywater on feminine hygiene while using the greywater toilet especially if there is a splash during toilet use;
- the ring of scum/soap often seen in the greywater toilet bowl; and
- low flushing pressure in the ground floor greywater toilet.

(iii) The major highlights of the attributes of importance and estimation of respondents' willingness to pay for greywater included:

- The positive and largest coefficient (5.28) determined for the smell attribute of greywater indicated that respondents viewed a pleasant smell as the most important attribute of the greywater. Second to smell was the colour of greywater with a coefficient of 2.52. This indicated that the elimination of unpleasant smells and the addition of cistern blocks to colour the greywater blue will increase the preference for GWR.
- Respondents were rather willing to spend about double the amount of money to improve the colour on the smell of the greywater. This is evident in the WTP values determined for smell (4.1) in comparison to colour (2.0).

CHAPTER 5

TECHNICAL AND ECONOMIC MEASURES TO RISK MANAGEMENT

Reclaimed greywater is expected to fulfil four main criteria (hygienic safety, aesthetics, environmental tolerance and economic feasibility) (Nolde, 1999; Li et al., 2009). To achieve these criteria, technical and economic measures in addition to others must be put in place to manage and therefore mitigate the risks associated with the implementation of GWR for toilet flushing. According to Adewumi (2011) and WHO (2006), technical and economic factors are important in determining the viability of a new reuse scheme. Technical measures include the selection and implementation of the most suitable technology, determining downstream demand and preventive measures put in place to ensure that the use of recycled water in dual pipe schemes is environmentally sustainable (USEPA, 2005). While economic measures involve employing various instruments to determine the economic feasibility of a proposed project, economic measures also consider the optimal use of limited resources, opportunities foregone by their uses and comparisons between competing options (WHO, 2006).

This section reports on the technical and economic measures put in place to manage and therefore mitigate the risks of failure associated with the implementation of GWR for toilet flushing. These measures include:

- The development of a framework for evaluating locally available greywater package plants. No tool such as this currently exists. With increased greywater reuse within South Africa and beyond, and the plethora of treatment units purporting to produce suitable toilet flushing effluent from greywater/wastewater, the framework developed offers decision-makers with an efficient tool for evaluating a diversity of plants and selecting the most suited for specific requirements;
- The estimation of toilet flushing water consumption in high density urban buildings and consequently, develop a model for this purpose; and
- The evaluation of the costs and benefits of GWR at the two pilot sites – WITs and UJ. This evaluation is timely as no South African study exists that investigates the economics associated with greywater reuse for toilet flushing within a residential nor non-residential building.

5.1 Development of a framework for evaluating locally available greywater package plants

5.1.1. Background

The selection of the most appropriate or the best available technology in the execution of any GWR project will most likely play a key role in its operational reliability, the suitability of recycled water quality and a reduction in the health risks associated with GWR.

To optimally facilitate this selection of technology for the pilot projects employed in this study, a framework to evaluate available greywater treatment package plants was developed. The development of the framework involved the following tasks:

1. A literature review to understand greywater treatment technologies typically employed in small package plants. Small package plants are used to treat wastewater in small communities or in individual households with about 4 to 1000 PE. They commonly treat flows between 37.85 m^3/day and 946.25 m^3/day;
2. The population of a database of locally available small package plants;
3. The development of a framework for evaluating these plants with the treated greywater effluent specifically for toilet flushing.

5.1.2. Review of greywater treatment technologies

Various authors have worked extensively on the review of greywater treatment options and application among them are Pidou et al, (2007) and Li et al (2009). In Li et al. (2009), greywater treatment for unrestricted, non-drinking urban reuses (including toilet flushing) typically requires four processes – pre-treatment, chemical/biological treatment, filtration and disinfection (if restricted reuse, disinfection may be excluded). Individually, these processes cannot guarantee adequate treatment. Figure 5.1 shows Li et al.'s (2009) proposed treatment flow for different qualities of greywater for urban non-drinking purposes.

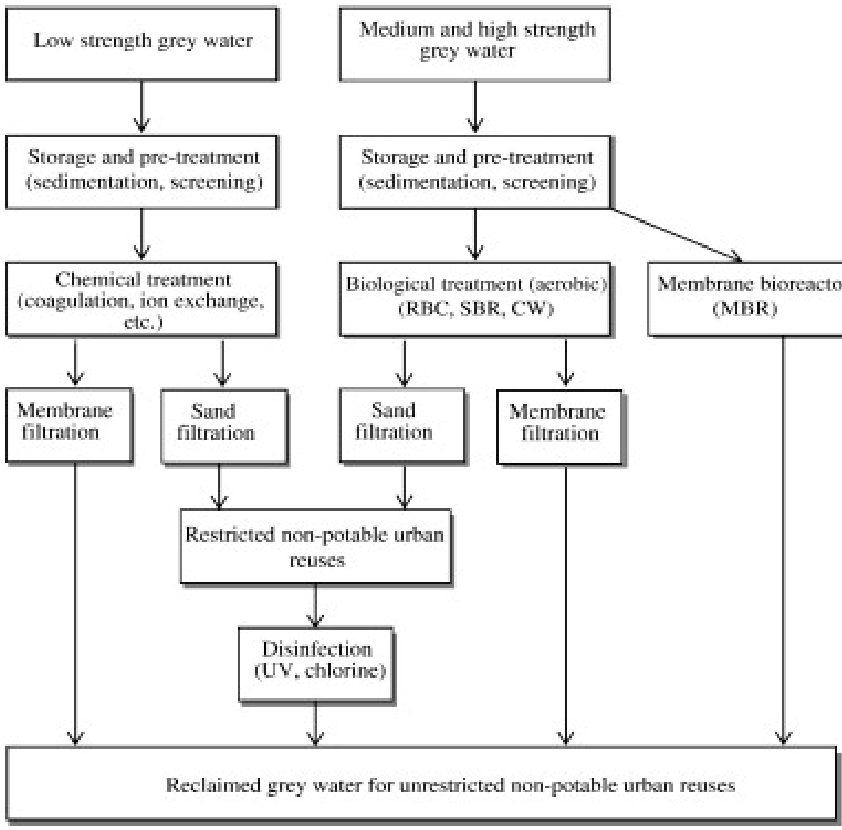


Figure 5.1: Greywater treatment for non-drinking urban reuses (Li et al., 2009).

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 (details of these processes are presented below) (Hulsman & Swartz, 1993, Laas & Botha, 2004 and Gaydon et al., 2006). There are however other package plants that make use of reverse osmosis, chemical treatment or other processes. The sections below briefly describe the suspended growth and fixed film/growth systems.

5.1.2.1 Suspended Growth Systems

(Elisabeth V. 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. Activated 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 floc. 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:

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

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 an 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 system and membrane filtration into a single unit process. MBRs replace the need for a separate filtration process attached to a suspended growth system with a treatment process that has a small footprint and produces high quality effluent with low TSS, BOD, and turbidity. There are two basic configurations for a MBR: a submerged membrane bioreactor that immerses the membrane within the suspended growth system (Figure 5.2) 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 GWR 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.

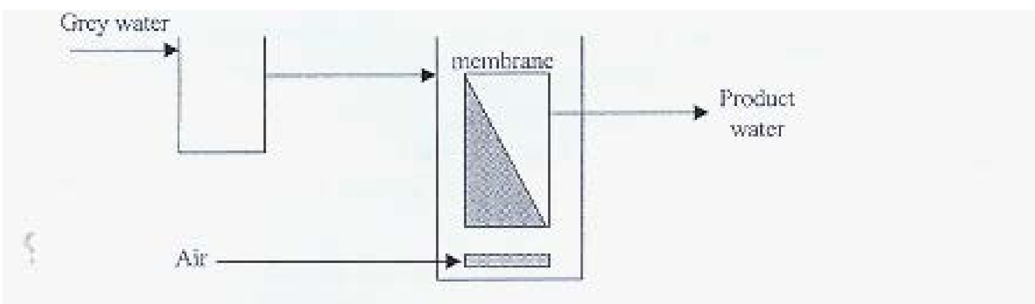


Figure 5.2: An immersed membrane bioreactor (Jefferson et al., 2001)

5.1.2.2 Fixed Film/Growth Systems

(Elisabeth V. 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. Two variations of this system are briefly described below:

a) Rotating Biological Contractor (RBC)

The Rotating Biological Contactor (RBC) (Figure 5.3) supports a biologically active film, or biomass, of aerobic micro-organisms. An RBC treatment system typically comprises of three units:

- Primary Zone: A settlement/sedimentation tank where wastewater enters and solids settle and are stored for subsequent removal. Anaerobic digestion may take place in this 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/clearing tank: Here settlement of the mixed liquor and excess biomass takes place.

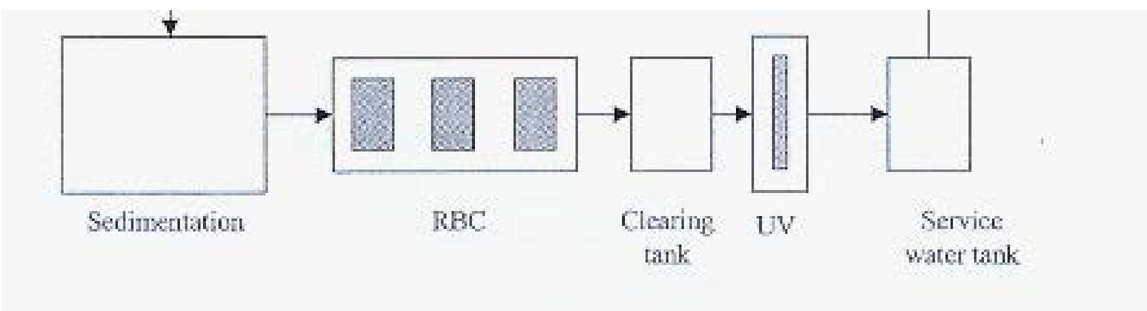


Figure 5.3: A rotating biological contactor (Jefferson et al., 2001)

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.

5.1.3. The range of locally available greywater package plants for toilet flushing

The range of locally available on-site greywater and wastewater treatment units that exist locally and whose effluent has been advertised as suitable for toilet flushing is presented in Appendix B1. Information on these plants was obtained from the following sources:

- Guidebook for the selection of small water treatment system for potable water supply to small communities. WRC report no TT 319/07. (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 requesting specific information from manufacturers/suppliers using performance criteria obtained from the documents above. 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. This letter and questionnaire was faxed or emailed to the relevant contact personnel and telephone calls were made to confirm receipt and request responses. 30 manufacturers were originally collated, 25 were sent questionnaires and 10 responded. Table 5.1 presents the summary of the 10 locally available greywater/wastewater treatment package plants and the key element in the selection process.

Table 5.1: Summaries of the 10 locally available greywater/wastewater package plants and the key elements in the selection process

Plant Number	Treatment Processes	Features of the package plant (e.g. treatment technology)	Operating range in L/Hour or	Cost of purchasing the plant	Approximate cost of operating the	Energy consumption	Footprint	Level of skill required for operation	Ease to Upgrade	Water quality is suitable for
1	Physical + Tertiary treatment (Chlorine)	Greywater is collected and channelled through a two 2 mm sieves in series (which are housed within a cylindrical pipe) and disinfected using 200 g Sanni Tabs4a (chlorine + bromine tablets) which were inserted into the sieves once a week. The greywater was then stored within a 200 litre greywater tank which houses 2 submersible pumps (each pump was connected to a toilet). When the bell-push is pushed and held, filtered and disinfected greywater is pumped directly into the toilet pan for flushing without the need for a toilet cistern. As soon as bell-push is released, the flushing stops.	No restriction to flow rate	R8000 to R12000 per unit this exclude the installation cost	R1200 per year	360 watts	$1m^2$	Moderate	Yes	Irrigation Tiolet flushing Car wash
2	Biological treatment (Aerobic -combination of Suspended growth and Fixed film method) + Tertiary treatment (Chlorine, ozone, UF or activated carbon)	The system is based on a Submerged Fixed-film Aeration technology where bacteria are supplied with air (oxygen) and food (sewage) and thus perform biochemical breakdown of the effluent. It consist of two bioreactors, clarifier and chlorine disinfection.	1500 to 3000 l/day	Above R100,000	Not specified	Not specified	Not specified	Low	Yes	Irrigation Tiolet flushing
3	Pre-treatment + Biological treatment (Aerobic - two stages of Suspended growth method) + Tertiary treatment (Chlorine,Ozone or UV	The system is fully automated. The treatment unit consist of (1) a filter which removes the coarse particles from the incoming grey water from the shower or bath tub. (2) Then the water undergoes the first stage of biological treatment with the supply of atmospheric oxygen, microorganisms degrade the contaminants in the water. (3) In the second stage of biological treatment, the process of the first stage is repeated. (4) In the final stage, the water is disinfected by using an UV lamp and stored in	500 – 3000 kL/d.	AUS \$6,680 Above R100,000	High	approx. 2.5 kWh / day	$2m^2$ -$100m^2$	High	No	Irrigation Tiolet flushing
4	Biological treatment (Anaerobic) + Biological treatment (Aerobic - Suspended growth method) + Tertiary	The treatment process involves an activated sludge process, which involve four major processes: 1. Collection and anaerobic storage 2. Aeration of the sludge 3. Settling of the sludge removing all solids 4. Chlorination to bring the final effluent up to the required standand	Not specificed	R27,000 for the unit only	R500 per month including electricity	Not specified	Not specified	High	Moderate	Irrigation
5	Physical + Tertiary treatment (Ozone)	Ozone disinfection. For a greywater system, it can be a combination of a 50 liter Jojo tank for storing bathing water and can be connected to an ozone generator while the effluents are later stored in another jojo tak before it is pumped out.	75 l/day	R20,000 carbon filter +ozone genrator onlu	Not specified	60amps	$3m^2$	low	Yes	Irrigation Tiolet flushing

Table 5.1 (continued): Summaries of the 10 locally available greywater/wastewater package plants and the key elements in the selection process

Plant Number	Treatment Processes	Features of the package plant (e.g. treatment technology)	Operating range in L/Hour or	Cost of purchasing the plant	Approximate cost of operating the	Energy consumption	Footprint	Level of skill required for operation	Ease to Upgrade	Water quality is suitable for
6	Biological treatment (Aerobic -combination of Suspended growth and Fixed film method) + Tertiary treatment (Chlorine, ozone, UF or activated carbon)	The operation process of the treatment plant is mainly extended Aeration. Activated sludge or submermerged aerated fixed film both utilizing ozone..,Ultral UF and activated carboon dosing sytem for disinfection and for pH correction and phosphorus removal	15000 l/day to 2Ml/day	R 350,000	R15,000p/a	20kw/hrs	40-60m^2	Low	Yes	rrigation iolet flushing ;ar wash
7	Physical + Biological treatment (Anaerobic) + Biological treatment (Aerobic - Suspended growth method) + Tertiary treatment (Chlorine,Ozone or UV light)	Submerged Aeration Media" (SAM) . The method of treatment comprises seven sequential treatment steps and involves: (i) solids removal by either a solids collection basket or a screening grid,ii) an anaerobic settler, followed by (iii) an anoxic settler and (iv) an aeration chamber into which air is blown to supply the required volume of oxygen. (v) the settler, in which micro-organisms and any remaining inorganic material is settled out and returned to the primary anaerobic settler by a unique efficient venturi method (vi) an extended anoxic chamber after the settler that assists in the removal of nitrates (vii) a disinfection chamber that uses either chlorine,	10 -100 l/day	Above R100,000	Not specified	2.2-5.5kw	16m^2-160m^2	low	Yes	Irrigation Tiolet flushing Car wash
8	Physical + Tertiary treatment (Ozone)	Ozone disinfection. For a greywater system, it can be a combination of a 50 liter Jojo tank for storing bathing water and conneted to an ozone generator. The effluents are later stored in another jojo tank before it is pumped out.	Not specified	R 87,000	Not specified	Not specified	Not specified	Not specified	Not specified	rrigation Tiolet flushing
9	Physical + Biological treatment (anaerobic) + Biological (aerobic - Fixed film method) + Tertiary treatment (Chlorine)	The operational process of the plants is simple and comprises of a primary combined settlement tank and anaerobic digester,a secondary aerobic process comprising of the Bio-Filter RBC fixed film reactor units, followed by a humus settlement tank and a disinfection tank.	10kl/day (50 persons) - 500kl/day (2500)	Above R100,000	Not specified	0.5-6kw	150m^2-1200m	Low	Yes	Irrigation Tiolet flushing Car wash
10	Physical + Biological treatment (Anaerobic) + Biological treatment (Aerobic - Suspended growth method) + Tertiary treatment (Chlorine)	The treatment process consists of a septic tank which acts as a primary digestion. From the septic tank effluent flows to the aeration chamber of the bioreactor, in this tank compartment an aerator blows a huge volume of air into the water at an adjustable depth, in the form of micronized bubbles. It mixes with the turbulence optimizing the dissolution of air and oxygen in the water, neutralizing polluting elements. Immediately after the aeration chamber is a settling chamber which acts as a clarifier. This is where the sludge is separated and pumped back to the septic tank. The effluent from the settling tank is pumped via a submersible pump through a flow meter with a pulse emitter, which activates the desired units of chlorine into the liquid, and then on to a contact tank. In order to maintain the correct balance the plant needs supplementary dosing of enzymes and bacteria monthly.	500 l/day	Above R100,000	Not specified	Not specified	Not specified	Low	Yes	Irrigation

5.1.4. Framework for the evaluation of greywater reuse package plants

5.1.4.1. Performance criteria for evaluating package plants and standards/guidelines

The performance criteria used in the framework for the evaluation of the 10 package plants were obtained from the following standard/guideline documents:

1. The Water Act No 36 of 1998 (DWAF, 1998)
2. The Official Journal of the European Union (2005).
3. Landcom's WSUD strategy (2003) (Appendix B3).
4. The USEPA Code of Practice for Wastewater Treatment Systems for single Houses (PE < 10) (Appendix B4) (USEPA, 2007).
5. National and international wastewater quality guidelines in Surendran & Wheatley (1998)

5.1.4.2 The framework, weights and scoring range

The framework for evaluating package plants for greywater/wastewater recycling for toilet flushing is shown in Table 5.3. Specific references for the evaluation of each criterion are included on the framework.

The weights employed in the framework are based on the average weights obtained by Ilemobade et al. (2009a). Ilemobade et al. (2009a) developed these weights 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 5.2). For the purpose of this report, the three key issues, confirmed by the literature in sections 5.2.2 and 5.2.3 are technical/engineering, public health and safety, and economics.

Table 5.2. Decision-makers ranking of key issues to be considered when assessing the feasibility of implementing a dual water reticulation system (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 package plants is as follows:

- Criteria within each of the key issues are scored using a scale of 0 (low), 1(moderate) and 2(high)
- The score for each criterion is multiplied by the weight of the key issue to obtain a weighted real score
- For each key issue, the weighted mean of the real scores is calculated
- For the framework, the aggregate of the weighted mean of the real scores is calculated. This aggregate ranges between 0.00 (most preferred package plant) and 6.78 (the least preferred package plant)

Table 5.3. Framework for evaluating greywater treatment plants for toilet flushing

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 (m^2)	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	EPA Code of Practice for single houses (2007) and WRC report No 1539/1/06
Level of operator skill	Low	Moderate	High / no info	1.00	EPA Code of Practice for single houses (2007) and WRC report No 1539/1/06
Ease to upgrade	Yes	No / no info		1.00	EPA Code of Practice for single houses (2007) and WRC report No 1539/1/06
WEIGHTED MEAN OF REAL SCORES					
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					
PUBLIC SAFETY AND SAFETY (I.E. WATER QUALITY) KEY ISSUE					
BOD (mg/l)	<= 10	> 10 / no info		1.13	USA, EPA Standard
COD (mg/l)	< 75	> 75 / no info		1.13	DWAF (1998); Prathapar et al (2005)
Total Suspended Solids (mg/l)	< 30	> 30 / no info		1.13	German Standard
Turbidity (NTU)	<= 2	> 2 / no info		1.13	USA, EPA Standard
Free chlorine (mg/l)	>= 1	<1 / no info		1.13	USA, EPA Standard
PH	6 to 9	no info		1.13	DWAF (1998); USA, EPA Standard
Total Coliform	Non detected	Detected / no info		1.13	USA, EPA Standard
E.Coli	Non detected	Detected / no info		1.13	DWAF (1998); USA, EPA Standard
WEIGHTED MEAN OF REAL SCORES					
AGGREGATE OF THE WEIGHTED MEAN OF REAL SCORES					

5.1.5. Results and discussion

Table 5.4 represents the results of our evaluation of the 10 locally available greywater / wastewater treatment package plants.

Table 5.4: Results of the evaluation of ten greywater/wastewater treatment package plants with effluent for toilet flushing

Criteria	Weight	Plant 1	Plant 2	Plant 3	Plant 4	Plant 5	Plant 6	Plant 7	Plant 8	Plant 9	Plant 10
		Real Score x Weight									
Technical											
Technology	1.00	0	1	0	0	1	0	0	1	0	2
Pre-treatment and 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 (m²)	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**
	Aggregate of weighted mean of real scores for Technical and Economics	**0.38**	**0.63**	**1.39**	**0.88**	**1.51**	**2.52**	**2.90**	**3.27**	**3.77**	**4.52**
	Score range	0.00				2.26					4.52
Public health and safety (i.e. water											
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
Total Suspended 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 weighted mean of real scores for Technical, Economics and Public health and safety	**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

Most manufacturers/suppliers of package plants contacted for information concerning their products responded by sending leaflets with little information on treated effluent quality. Hence, where no responses were given to specific criteria, the highest score was assigned. The final score is the aggregate of the weighted mean real score of the three key issues.

a) Technical

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

- Package plants 1, 2 and 3 scored the lowest in this key issue. Most of their treatment is biological followed by disinfection;
- Manufacturers of package plants 6 and 7 did not specifically mention whether the treated effluents of their plants could be used for toilet flushing. However, the effluents may be used for toilet flushing as their quality parameters are within DWAF (1998) and international guidelines;
- Package plant 7 can only treat effluent produced by not more than 35 people; and
- An advantage of package plants 1 and 3 is that they cover a wide operating range i.e. from household level to clustered developments.

b) Economic

Cost determines if a package plant will be affordable. Cost is directly related to the treatment technology employed. Hence, the more complex the treatment process, the more expensive the package plant will likely be. Actual costs were obtained for Package plants 1, 2, 3, 4, 6 and 8.

- Package plants 1, 2, and 4 score the lowest in this key issue;
- Package plant 2, which includes a pump chamber, pump, sieve, plumbing retrofitting and installation, costs the least with a range of between R8,000 and R12,000 per toilet.;
- Costs of operating the above units depend on local circumstances (e.g. disinfection and electricity).

c) **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 being cautious in releasing such information.

- Package plants 3,5 and 1 scored the lowest in this key issue;
- Package plant 6 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 (1998) and international guidelines
- Treated effluent from a Package plant 3 was analysed. The presence of the above water quality parameters were negligible;

5.1.6. Preferred greywater treatment package plant based on the aggregate of the weighted mean of the real scores

There is no simple formula for selecting a package plant because of the trade-offs that need to be made between the three key issues i.e. technical, economics and public health and safety.

- Package plants 1, 2 and 3 achieved the lowest scores in the framework and are hence, the most favoured for the pilot project:
- Package plant 3:
  - Sensitive to influent quality. Hence, a drastic change in influent quality would negatively affect effluent quality;
  - Aesthetic, compact, automated and its effluent can also be used for irrigation;
  - Three times the cost of package plants 1 and 2;

a. Package plant 2:
  - Uses a filter/sieve with disinfection cubes and can easily be programmed to ensure that treated greywater is not stored in the pump chambers for more than 24 hours –

thereby reducing the possibility of pathogen growth. Failure to ensure this will likely result in the growth of bacteria;

- Package plant 2 costs the lowest among the three;
- Indigenous technology;

b. Package plant 1:

- The plant with the most favourable score on the framework;
- Indigenous technology;
- Water quality parameters were evaluated based on information provided by the manufacturer/supplier;

5.1.7 The Water Rhapsody Conservation System

After the extensive investigation into the locally available greywater technologies, Water Rhapsody Conservation Systems emerged from Section 5.1.6 as the preferred system appropriate for the two pilot sites (UJ and WITS). The selection was based on the fact that it was cheap, rugged, functional and easy to change/upgrade if and when necessary. A schematic diagram of the original greywater system is shown in Figure 5.3. Greywater is collected from 12 bathroom hand basins and 2 laboratory basins within the building[1]. After collection, the greywater passes through two 2mm sieves[2] in series which are housed in a cylindrical pipe[3] (Figure 5.4(b)) and is disinfected using 200g Sanni Tabs[4a] (chlorine/bromine tablets) (Figure 5.4(c)) which are inserted into the sieves once a week. The filtered greywater is then stored within a 200 litre greywater tank[5] which houses 2 submersible pumps (each pump is connected to a toilet – a male toilet on the ground floor and a female toilet (Figure 5.4 (d)) on the first floor). When pressed, the bell switch[6] (Figure 5.4 (d)), which is attached to the wall close to the toilet cistern, activates the pump it is connected to and conveys the sieved greywater into the toilet bowls[7]for flushing. A second tank[8], situated close to the greywater storage tank, 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].

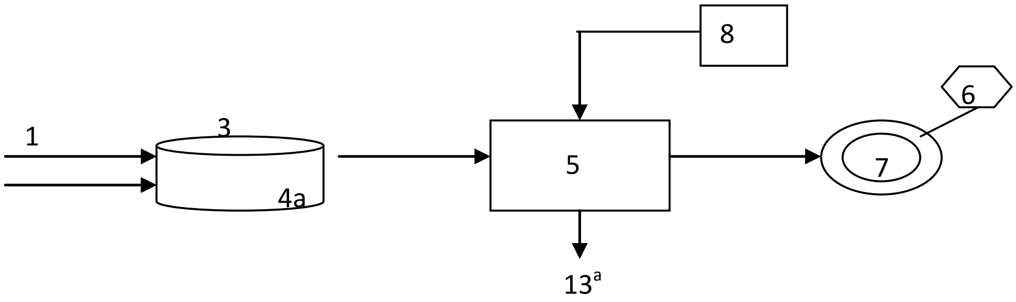


Figure 5.3. The original Water Rhapsody greywater reuse system

Figure 5.4 (a) The installed greywater (collection, sieving, pumping and storage backup) system (b) The 2 No. 2mm sieves used to sieve the greywater (c) Samples of the 200g Sanni Tabs (d) The female toilet connected to the greywater system

5.1.8. The modified greywater reuse system at WITS.

Some issues/highlights that crept up just before and after installation of the system and in some instances, required the original greywater reuse system (shown in Figure 5.3) to be modified include (Ilemobade et al.,2012):

i. Weekly, blue or green toilet cistern blocks[4b] (Figure 5.5) were inserted into the sieves. This was done in order to provide an aesthetic greywater colour;

Figure 5.5. Cistern blocks used to colour the greywater

ii. An additional back-up measure was provided (Figure 5.6) - The toilet cistern[9] which previously used municipal 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;

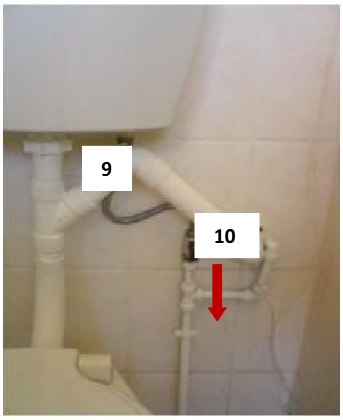


Figure 5.6. Additional backup measure in the event of greywater supply failure

iii. Unknowingly, the lab basins were used for washing dishes and disposing cleaning fluids. Unfortunately, this introduced foods, cleaning chemicals and dirt, fats and oils into the sieves (Figure 5.7) and greywater tank and resulted in unpleasant greywater odours and colour. When this problem was identified, posters were placed near the sink and an awareness session was held within the school. In addition, sink strainers were installed as a first barrier to trap food and other materials from finding their way into the greywater system. Initially, this made a significant difference to the physical quality (colour and smell) of the greywater;

Figure 5.7. The sieves a few days before and after the awareness session

iv. Despite the steps above, 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 5.8);

Figure 5.8. The sieves after disconnection of the laboratory hand basins

v. To improve the disinfection of the greywater, inline chlorine capsules were installed (Figure 5.9);

Figure 5.9. Inline chlorinators installed to improve disinfection of the greywater

vi. A diversion[12] was introduced 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 for long periods of time.

vii. An additional overflow pipe[13b] to the sewer was added to the system in the event that a blockage occurred in the filter during operation.

Based on the above, the original Water Rhapsody greywater reuse system (Figure 5.3) was modified to become Figure 5.10.

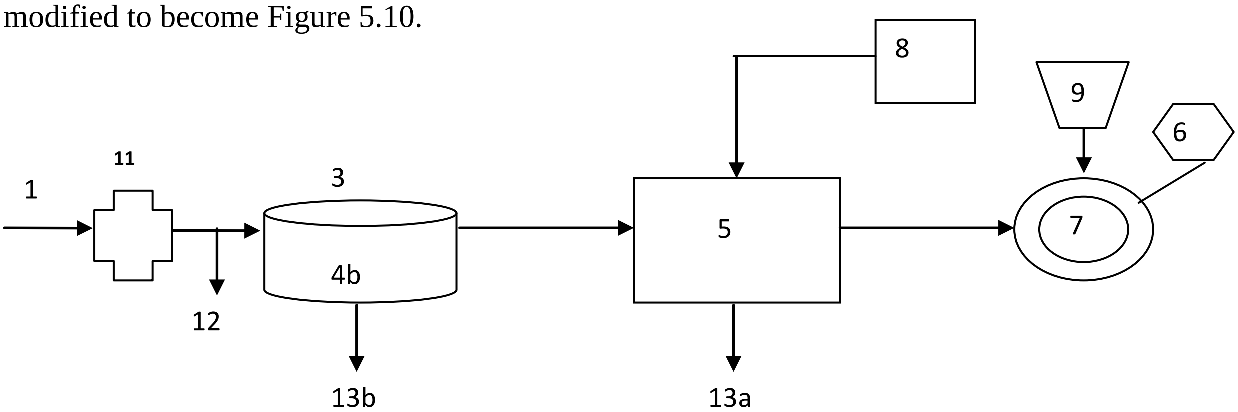


Figure 5.10. The modified and current greywater reuse system for toilet flushing at the School of Civil and Environmental Engineering, WITS

5.1.9. The modified greywater reuse system at UJ

The greywater system, which was similar in construction to the greywater system installed at WITS, had the following modifications (Figure 5.11):

- Initially, greywater was sourced from the 2 showers, 2 baths and 6 hand basins within the unit. Subsequently, due to water quality problems, the hand basins were disconnected;
- A rainwater harvesting system was installed as the primary water supply backup to the greywater tank. Prior to greywater implementation, the rainwater gutters were already implemented at UJ. It therefore seemed a waste not to use rainwater since it could function as a primary back-up to the greywater tank. Municipal potable water therefore became the secondary water backup into the greywater system;
- The greywater tanks and filters were buried in the soil in the enclosure behind the unit as the unit did not have a basement below the bathrooms as was the case at WITS;

The schematic of the current greywater system at Unit 51A is shown below.

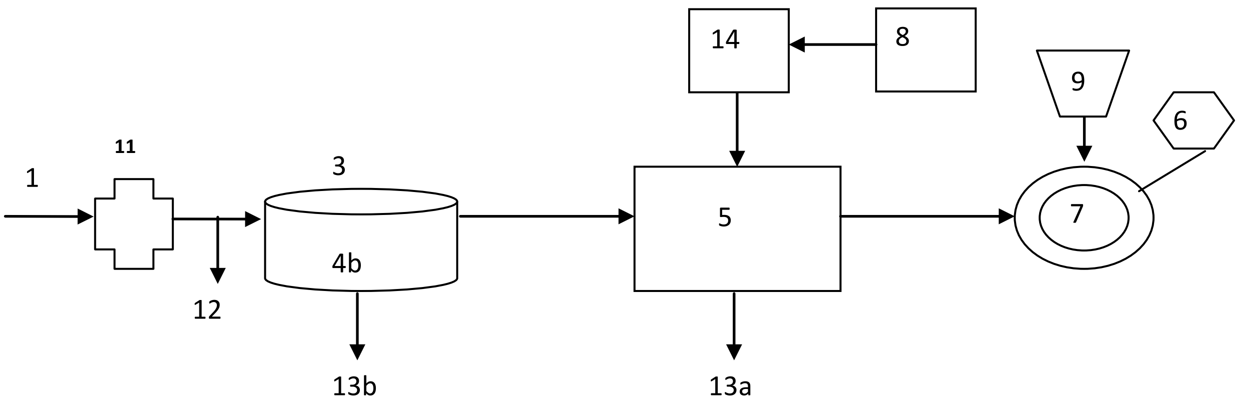


Figure 5.11. Schematic of the greywater system for toilet flushing at Unit 51, Student Town, UJ

[1]*Greywater collection from 2 bath tubs and 2 showers within the unit*
[3]*The cylindrical pipe housing the two 2mm sieves in series*
[4]*bCistern blocks inserted weekly into the sieves to provide colour to 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*
[13]*An overflow pipe from the greywater tank to the sewer*
[14]*A rainwater harvesting system providing supplemental water to the greywater tank*

5.1.10. Conclusion

This section presents a valuable and holistic tool for evaluating locally available GWR technologies for toilet flushing in South Africa as it became evident that there were no simple formulas for selecting a technology due to the trade-offs that had to be made between the three key evaluation criteria i.e. technical, economics and public health. Three package plants rated lowest in the framework and are hence, the most favoured for the pilot project treatment. The Water Rhapsody Conservation Systems emerged as the most appropriate system out of the three package plants for the two pilot sites (UJ and WITS). The selection was based on the fact that it was cheap, rugged, functional and easy to change/upgrade if and when necessary. Some modifications were made to the original greywater system, due to some issues/highlights that crept up before and after installation of the original greywater system. After the several modifications, a significant difference was observed in the aesthetics and quality of the greywater at the two pilot sites.

5.2 Development of a model to estimate historical toilet flushing demands within non-residential buildings

5.2.1 Background

Water systems must be appropriately sized in order to cater for expected demands. The same holds true for GWR systems which can fail technically if the implemented system is incapable, due to under-design, to meet expected demand. On the other hand, over-design of the GWR system would imply failure, not in the system's ability to meet demands but in the waste of resources used to provide excess capacity that will not be optimally used (Summerfelt, 1996).

To mitigate this potential area of failure in respect of GWR systems, this section generates and analyses toilet flushing data at WITS and presents a regression model for estimating toilet flushing demand based on various influencing parameters. In planning for greywater reuse for toilet flushing therefore, this model will be valuable in scientifically determining historical toilet flushing demand within a facility as long as data on the independent variables (i.e. bulk water demand, rainfall, max temperature and min temperature) are available.

5.2.2 Methodology

5.2.2.1 Logging toilet flushing water demand

Toilet flushing water demand data was collected at the WITS School of Civil and Environmental Engineering over a period of 6 months (from the 21st of May 2009 to the 20th of November 2009) prior to the installation of the greywater treatment unit. A displacement counter (Figure 5.12) was installed in each toilet cistern next to the float. Each time a toilet was flushed, the counter recorded an additional digit. The frequency of toilet flushes was recorded at three hour intervals between 06h00 and 18h00 and six hour intervals between 18h00 and 06h00. Each toilet was labelled for proper identification. Climatic data and data relating to the university's academic calendar were also collected/recorded for the same period as the water data.

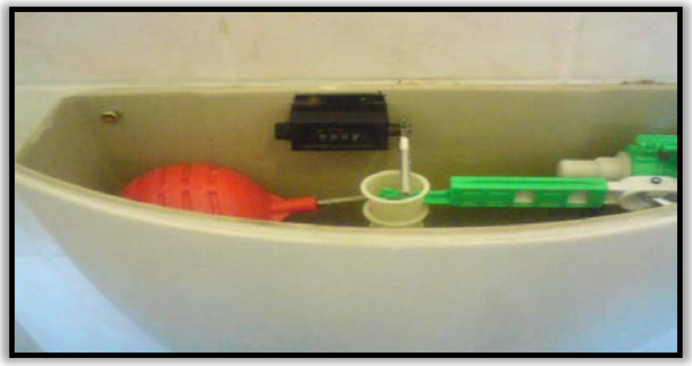


Figure 5.12: A displacement counter installed within a toilet cistern

Due to the tediousness of manually logging toilet flushes and the repeated failures of some of the counters due to interaction with moisture within the toilet cisterns, an electronic data logger was subsequently purchased and installed to log toilet flushes (Figure 5.13). The electronic data loggers measure voltage across 2 probes - positive and negative. These probes are placed within the cistern (Figure 5.14). When the probes are submerged in water, a voltage reading is read across the probes. When the toilet is flushed and the water level within the cistern drops, the probes, which are no longer immersed in the water, are exposed and an approximate zero reading is read. These loggers can be programmed to measure voltage drops of durations between 1 second and 12 hours and can store up to 32,510 readings. A zero voltage reading is regarded as a single flush even though this may not be the case at all times e.g. when the cistern takes longer to fill than the programmed logging duration of data, a logger may record more than 1 flush. Detailed specifications for the logger are shown in Table 5.4.

In order to ensure unrestricted access, the data loggers were placed in a box within the service area behind the toilet cubicles (Figure 5.15). To download data, a logger is connected to a computer and data is imported into Microsoft Excel® (Figure 5.16).

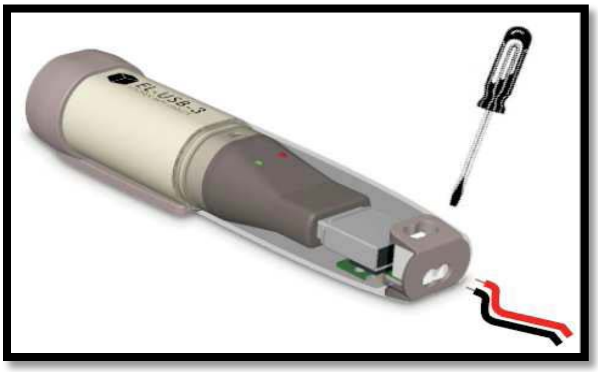


Figure 5.13: A data logger

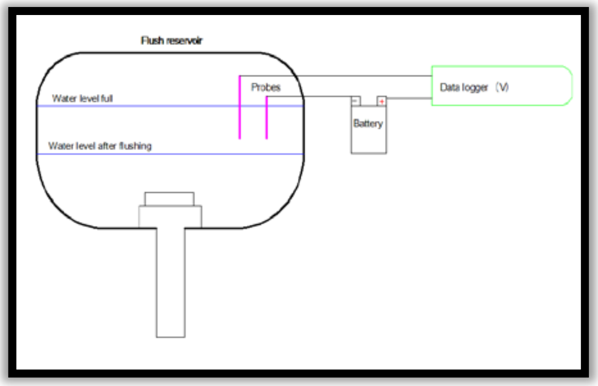


Figure 5.14: Setup of the loggers within the cisterns

Table 5.4: Detailed specifications of the Lascar Electronics Voltage USB Data Logger (EL-USB-3)

SPECIFICATIONS

Specification	Min.	Typ.	Max.	Unit
0-30V d.c. measurement range	0		30	V d.c.
Internal resolution		50		mV d.c.
Accuracy (overall error)		±1		%
Logging rate	every 1s		every 12hr	-
Operating temperature range	-25 (-13)		+80 (176)	°C (°F)
1/2AA 3.6V Lithium Battery Life*	1			Year

* depending on ambient temperature, logging rate and use of alarm LED.

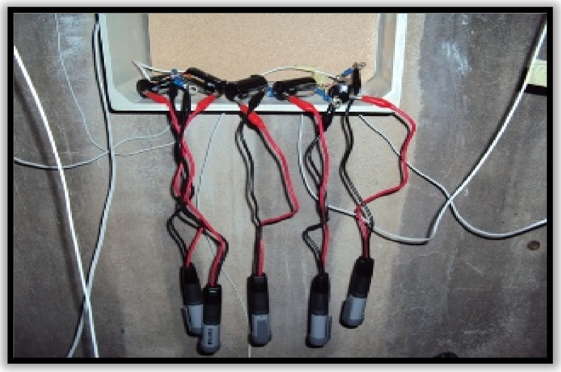
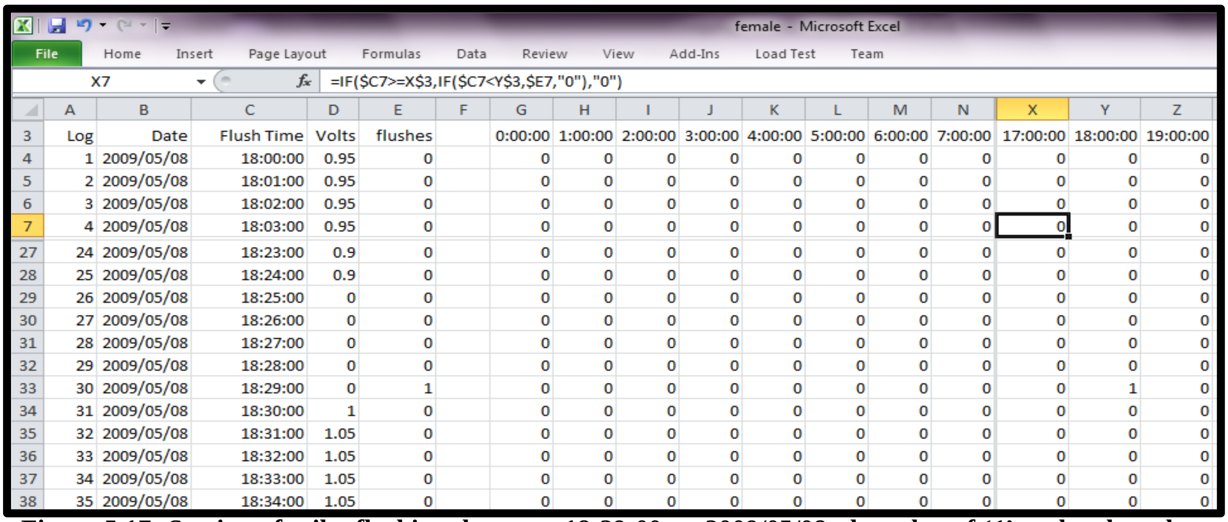


Figure 5.15: The data loggers within a box

Figure 5.16: Downloading data from a logger

For consistency with the measurement of greywater toilet flushing, data was sorted hourly (Figure 5.17).



female - Microsoft Excel

X7 =IF($C7>=X$3,IF($C7<Y$3,$E7,"0"),"0")

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	X	Y	Z
3	Log	Date	Flush Time	Volts	flushes		0:00:00	1:00:00	2:00:00	3:00:00	4:00:00	5:00:00	6:00:00	7:00:00	17:00:00	18:00:00	19:00:00
4	1	2009/05/08	18:00:00	0.95	0		0	0	0	0	0	0	0	0	0	0	0
5	2	2009/05/08	18:01:00	0.95	0		0	0	0	0	0	0	0	0	0	0	0
6	3	2009/05/08	18:02:00	0.95	0		0	0	0	0	0	0	0	0	0	0	0
7	4	2009/05/08	18:03:00	0.95	0		0	0	0	0	0	0	0	0	0	0	0
27	24	2009/05/08	18:23:00	0.9	0		0	0	0	0	0	0	0	0	0	0	0
28	25	2009/05/08	18:24:00	0.9	0		0	0	0	0	0	0	0	0	0	0	0
29	26	2009/05/08	18:25:00	0	0		0	0	0	0	0	0	0	0	0	0	0
30	27	2009/05/08	18:26:00	0	0		0	0	0	0	0	0	0	0	0	0	0
31	28	2009/05/08	18:27:00	0	0		0	0	0	0	0	0	0	0	0	0	0
32	29	2009/05/08	18:28:00	0	0		0	0	0	0	0	0	0	0	0	0	0
33	30	2009/05/08	18:29:00	0	1		0	0	0	0	0	0	0	0	0	1	0
34	31	2009/05/08	18:30:00	1	0		0	0	0	0	0	0	0	0	0	0	0
35	32	2009/05/08	18:31:00	1.05	0		0	0	0	0	0	0	0	0	0	0	0
36	33	2009/05/08	18:32:00	1.05	0		0	0	0	0	0	0	0	0	0	0	0
37	34	2009/05/08	18:33:00	1.05	0		0	0	0	0	0	0	0	0	0	0	0
38	35	2009/05/08	18:34:00	1.05	0		0	0	0	0	0	0	0	0	0	0	0

Figure 5.17: Sorting of toilet flushing data – at 18:29:00 on 2009/05/08, the value of '*1*' under the column '*flushes*' represents 1 toilet flush.

5.2.2.2. Logging bulk water demand

Bulk water demand at WITS was measured using a data logger connected to the bulk water meter (Figure 5.18a and Figure 5.18b). The logger was programmed to read 0.5 litres for every pulse sent out by the bulk water meter. Each time the logger receives a pulse, it automatically produces a data set that can be exported into Microsoft Excel® (Figure 5.19).

Figure 5.18a: One of the WITS water meters **Figure 5.18b: Downloading data from the water meter**

	C	D	E	F	G	H	I	J	K	L
29	Pulse Number	Date	Hour	Minute	Second	Litres	Seconds to Pulse	L/s (ave)	m3/s (ave)	
30	0	2010/07/20	12	:00	:32	0.5	53	0.009434	0.033962	
31	1	2010/07/20	12	:01	:36	0.5	64	0.007813	0.028125	
32	2	2010/07/20	12	:02	:46	0.5	70	0.007143	0.025714	
33	3	2010/07/20	12	:04	:01	0.5	75	0.006667	0.024	
34	4	2010/07/20	12	:05	:22	0.5	81	0.006173	0.022222	
35	5	2010/07/20	12	:06	:46	0.5	84	0.005952	0.021429	
36	6	2010/07/20	12	:08	:11	0.5	85	0.005882	0.021176	
37	7	2010/07/20	12	:09	:40	0.5	89	0.005618	0.020225	
38	8	2010/07/20	12	:11	:08	0.5	88	0.005682	0.020455	
39	9	2010/07/20	12	:12	:34	0.5	86	0.005814	0.02093	

Figure 5.19: Bulk water demand data generated by the logger

5.2.2.3. Collation and analysis of data

Toilet flushing demand (in litres per day) was calculated by multiplying total flushes by an average cistern volume of 9 litres. Two different analyses were conducted on the data. The first analysis was conducted on the data logged prior to the installation of the electronic data loggers and bulk water meters i.e. 6 months between May and November, 2009 using the manual displacement counters. The analysis was conducted to determine the effect of some socio-economic factors (such as gender, status, time of day, and academic calendar) on toilet flushing demand. The university academic calendar was separated into 3 - teaching periods (1), study break (2) and examination period (3) (Table 5.5). A model was developed using this data but was deficient in estimating toilet flushing demand because it relied on some parameters which could not be quantified.

Table 5.5: Extract of data showing the different socio-economic parameters influencing toilet flushing

		Flushing demand	Temperature			Academic Calendar	Demand based on gender		Demand based on status		Time					
Month	**DAY**	**DEMAND**	**Max**	**Min**	**Average**	**PERIOD**	**TDM**	**TDF**	**UG**	**PG/ST**	**T1**	**T2**	**T3**	**T4**	**T5**	**T6**
May	21	1647	15	6	10.5	1	1044	603	900	747	2	34	73	41	27	6
May	22	1566	17	7	12	1	792	774	891	675	1	34	71	46	20	2
May	23	459	20	7	13.5	2	351	108	135	324	0	16	18	11	6	0
May	24	342	18	10	14	2	234	108	162	180	0	8	11	11	6	2
May	25	1062	20	8	14	2	432	630	486	576	0	21	42	33	16	6
May	26	1143	20	10	15	2	738	405	702	441	0	29	55	24	17	2
May	27	1350	20	6	13	2	720	630	810	540	0	34	42	38	20	16
May	28	1368	20	10	15	3	711	657	765	603	1	34	49	46	20	2
May	29	729	20	11	15.5	3	468	261	207	522	0	23	28	14	10	6
May	30	261	18	5	11.5	3	108	153	153	108	0	3	14	2	5	5
May	31	171	16	5	10.5	3	136	36	99	72	0	6	3	3	4	3
June	1	1125	16	5	10.5	3	531	594	450	675	0	24	43	36	16	6
June	2	819	20	5	12.5	3	405	414	378	441	2	22	45	20	1	1
June	3	1377	18	11	14.5	3	693	684	747	630	1	34	50	46	20	2
June	4	1134	20	10	15	3	621	513	459	675	1	31	53	30	10	1
June	5	945	20	7	13.5	3	585	360	423	522	1	28	42	16	12	6
June	6	252	20	11	15.5	3	135	117	144	108	0	3	13	2	5	5
June	7	162	20	5	12.5	3	126	36	99	63	0	4	3	4	4	3
June	8	1026	12	7	9.5	3	432	594	450	576	0	21	38	33	16	6

- TDM = Total Demand for toilet flushing in the Male toilets
- TDF= Total Demand for toilet flushing in the Female toilets
- UG = Total Demand for toilet flushing by Undergraduate students
- PG/ST= Total Demand for toilet flushing by Postgraduate students and staff
- T1 (06h00), T2 (09h00), T3 (12h00), T4 (15h00), T5 (18h00) and T6 (00h00) = Total Demand for toilet flushing at the respective times
- Period = 1 (Teaching Period), 2 (Study Break) and 3 (Examination Period).

Due to the deficiency in the data and therefore previous model, a second analysis and modelling exercise was conducted in 2011 based on data collected between March – December 2010 with the aim of estimating toilet flushing demand using other variables i.e. bulk water demand, rainfall and temperature. These parameters are selected based on literature which showed the direct relationship between climatic data, such as rainfall and temperature and residential water demand (Babel et al., 2007). Typically, with increased temperature, there is an increase in water demand. Table 5.6 shows an extract of data used in this exercise.

Table 5.6: Extract of data showing the different climatic parameters generated and toilet flushing and bulk demand

Months	Toilet flushing demand (liters)	Daily bulk water demand (liters)	Rainfall (mm)	Max temperature (^{0}C)	Min temperature (^{0}C)	Average temperature (^{0}C)
March-10	461.32	2794.25	118.50	26.40	14.80	20.60
April-10	546.30	5302.17	113.90	22.10	12.20	17.15
May-10	351.00	5856.94	16.50	21.30	8.30	14.80
June-10	220.50	4208.83	0.00	18.60	2.90	10.75
July-10	395.71	3951.33	0.00	18.00	4.10	11.05
August-10	367.84	4696.29	0.00	22.10	5.20	13.65
September-10	409.20	5404.83	0.00	26.60	9.60	18.10
October-10	405.00	4060.32	41.50	28.10	12.50	20.30
November-10	398.70	3749.00	69.50	26.80	14.00	20.40
December-10	100.16	1720.61	173.90	27.10	14.90	21.00

5.2.2.4. Modelling toilet flushing water demand

The methodology employed in this section consisted of 3 steps. Firstly, the data was plotted in order to preliminarily visualize trends in the data. The second step involved finding a statistical relationship between two random variables or two sets of data. This process is referred to as correlation of dependence. The relationship between the two data sets was determined using correlation coefficients, often denoted by ρ or r. The more common of the two coefficients is the Pearson correlation coefficient (ρ) with a range of between -1 and +1. The value of the correlation coefficient represents the level of relationship and the statistical significance of each independent variable in relation with the dependent variable (e.g. 0.7 represents a strong positive correlation while -0.7 represent a strong negative correlation). Lastly, a stepwise regression analysis was carried out on the data using the Statistical Package for the Social Sciences (SPSS® 10.1) for Windows®. The stepwise regression involves the combination of two approaches: (1) Forward selection, which involves starting with no variables in the model, trying out the variables one by one and including them if they are 'statistically significant' and; (2) Backward elimination, which involves starting with all candidate variables and testing them one by one for statistical significance, deleting any that are not significant.

5.2.3 Results and discussion

5.2.3.1 Results of preliminary analysis

For toilet flushing demand which was logged from March 2010 to December 2010, the bulk water demand ranged from 1729 l/d to 5856 l/d while toilet flushing water demand from 10 of the 12 toilets ranged from 150 l/d to 500 l/d. This resulted in toilet flushing demand comprising 2.6 – 8.5% of bulk water demand. The reason for the small percentage in toilet flushing demand can be attributed to fact that the modeling exercise was conducted in the academic building which consists of laboratories and offices. Other demands such as the water consumed by the laboratory most especially the concrete laboratory and the water flume in the hydraulic lab may consume larger percentage of the water in the building. Another reason for such a small percentage is that the two month data that were compared to determine the water savings were done during an off peak period within the building.

5.2.3.2. Correlation between toilet flushing demand, climatic and demographic data

Table 5.6 shows the results of the correlation analysis between toilet flushing demand, temperature, rainfall and bulk water demand. The results show a strong correlation between bulk water demand and toilet flushing demand i.e. bulk water demand is a very good preditor of toilet flushing demand. For other variables, the correlation is not significant. The effects of muilti-collinearity were also studied in order to produce a stable regression equation. The muilti –collinearity test showed that there is high corelation between average temperture and minmum and max temperture thus, the average temperature was removed from the regression model varibles (Table 5.7).

Table 5.7: Correlation between toilet flushing demand, climatic and demographic data

	Toilet flushing demand	**Daily demand**	**Rainfall**	**Max temperature**	**Min temperature**	**Average temperature**
Toilet Flushing demand	1.00					
Daily Bulkwater demand	0.52	1.00				
Rainfall	-0.15	-0.66	1.00			
Max temperature	0.02	-0.38	0.51	1.00		
Min temperature	0.13	-0.45	0.82	0.85	1.00	
Average temperature	0.08	-0.43	0.71	0.95	0.97	1.00

5.2.3.3. The model for estimating toilet flushing demand

The analysis carried out immediately above is summarised in Table 5.8. The regression model which estimates toilet flushing demand is shown in equation 5.1. The first predictor in equation 5.1 is bulk water demand (BWD) and is the first predictor as a result of the high correlation value of 0.512 with the flushing demand (Table 5.7). This is followed by rainfall (R), maximum temperature (MaxT), and minimum temperature (MinT). From the column of 'R^2 change' in Table 5.8, the R^2 change value for BWD is 0.512 and indicates that 51.2% of the variance for toilet flushing demand is explained by the daily bulk water demand (BWD). This is followed by rainfall (R) which explains 5% of the variance in toilet flushing demand while maximum temperature and minimum temperature explain 1% in flushing demand respectively.

Toilet flushing Demand = 642.13 + 0.03BWD -2.19R - 36.25MaxT - 57.66MinT … (5.1)

Table 5.8: Table showing coefficients of the independent variables for the regression model

No of Observations	**R^2**	**Adj R^2**	**Std error**	**F-value**	**Sig.F**
10	0.58	0.04	108.58	1.70	0.31
	Coefficients	**R^2 change**	**F change**	**t Stat**	**P-value**
Intercept	642.13			1.134	0.308
Daily bulkwater demand (BWD)	0.03	0.512	104.53	0.669	0.533
Rainfall (R)	-2.19	0.05	68.73	-1.170	0.295
Max temperature (MaxT)	-36.25	0.01	6.62	-1.285	0.255
Min temperature (MinT)	57.66	0.01	3.53	1.617	0.167

5.2.3.4. Plot of actual and fitted values

Figure 5.20 shows the graphs of the actual/measured and the fitted/estimated values. The actual data points are represented by the blue line with the "x" data points while the fitted data points are represented by the yellow line with the solid "o" data points. The accuracy of the estimated values generated by the regression model is shown by the similarity in the trend exhibited by the two lines.

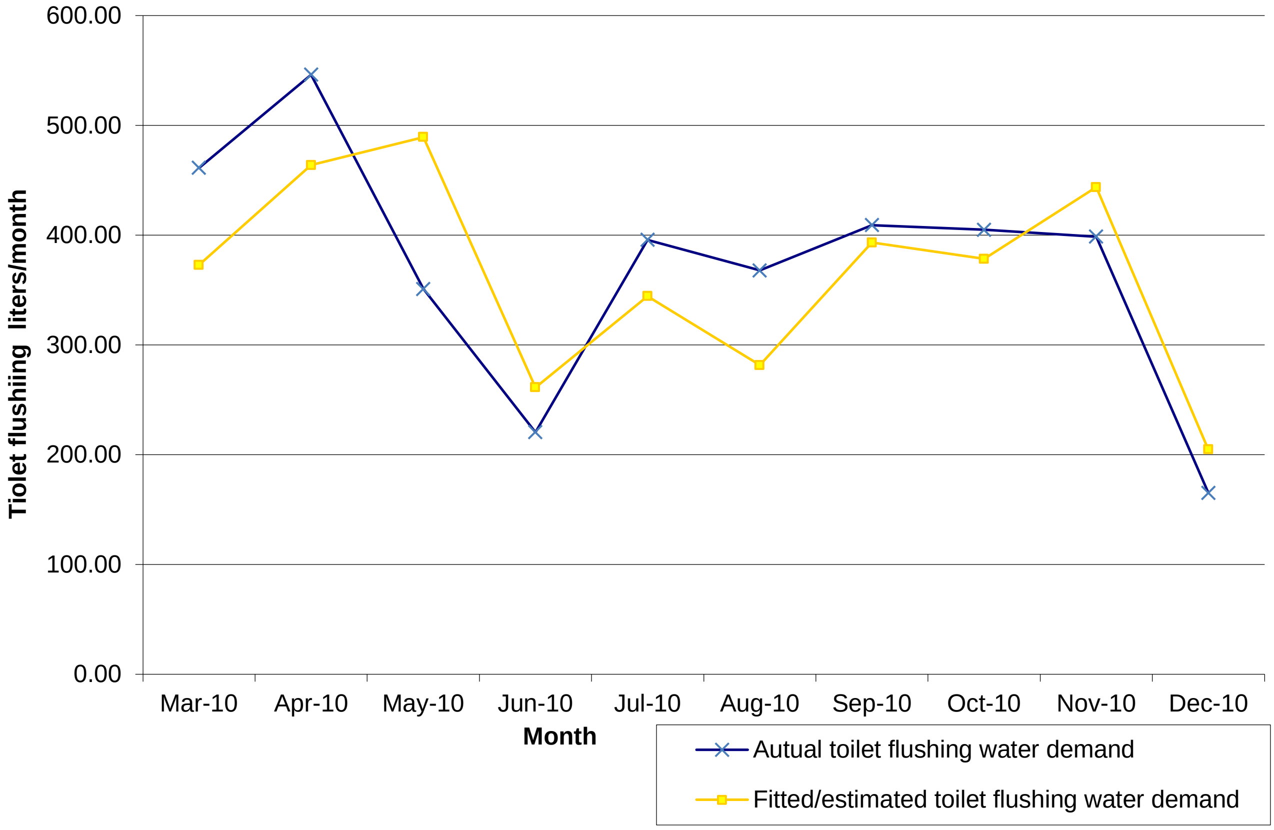


Figure 5.20: Plot of actual and fitted values for toilet flushing water demand.

5.2.4. Summary

This section presents a regression model (equation 5.1) that estimates toilet flushing demand based on bulk water demand (BWD), rainfall (R), maximum temperature (MaxT) and minimum temperature (MinT) measured between March and December 2010 at WITS. This exercise was aimed at developing a model that will assist in the determination of historical toilet flushing demand based on the availability of historical data on the independent variables within the model. Therefore, in planning for greywater reuse for toilet flushing, equation 5.1 will assist decision-makers determine historical toilet flushing volumes within academic buildings and thus be better informed as to the potential savings in potable water used for toilet flushing and thus costs, if reuse is be implemented. In summary therefore, if toilet flushing volumes can be calculated, potential drinking water savings can be estimated and the decision can be made whether to implement or not to implement greywater reuse.

5.3. The costs and benefits of GWR at the WITS (academic) and UJ (residential) buildings.

5.3.1 Background

It is important to undertake an economic analysis of a reuse project as it forms a major part of the feasibility study and thus, equips decision makers to make correct judgements on the implementation of reuse projects. The economic analysis evaluates the benefits of a project from its investments over a determined planning horizon (WHO, 2006). This analysis therefore assists to mitigate the failure of a GWR project from an investment and returns perspective.

This section presents the investigation that was carried out to determine the spectrum of costs (economical and environmental) and benefits (economical and environmental) that could be achieved through GWR for toilet flushing at WITS and UJ. A Cost-Benefit analysis was performed over a 20 year design life by calculating the Net Present Value (NPV), Cost-Benefit ratio and Payback period. Economical costs were calculated based on the capital and recurrent expenditure on the GWR system while environmental costs were calculated using the Disability Adjusted Life Year index (Liang and van Dijk, 2008) which quantifies in currency terms, the impact of the system on human health. The economical benefit was calculated based on the potable water saved from GWR while the environmental benefit was quantified based on the savings achieved through GWR from reducing the quantity of sewage requiring treatment.

5.3.2 Methodology

5.3.2.1 Determination of the potable water saved due to greywater reuse

Potable water saved due to GWR was calculated by logging demand for toilet flushing over 2 similar months before and after GWR implementation. The ‘after’ value was then subtracted from the ‘before’ value to obtain the potable water saved.

The average potable water saved due to GWR in 2 of the 12 toilets at WITS amounted to 137 litres per day (Table 5.9). This was due to the potable water demand and therefore savings calculated for the months of November and December 2009 and 2010, which fall within the off-peak months on the WITS academic calendar. The average potable water saved was then multiplied by an estimated peak factor of 3 to achieve the potable water savings estimated for peak academic periods (=412 litres per day). The logic behind the estimation is that in November /December the occupation of the building is predominantly by postgraduate students and staff which is about 30 percent of the total population. Hence, during the peak period, the total population is expected to include undergraduate students with an average demand increase to a factor of 3 therefore; a peak factor of 3 is used.

The potable water saved at UJ due to GWR in 2 of the 4 toilets amounted to 72.69 litres per day (Table 5.10). Using a peak factor of 2, the estimated savings amounted to 145 litres per day for August and September 2010 which typically fall within the peak period of the UJ academic calendar. The potable water saved was then calculated using the 2010 Johannesburg Water (the water service provider) potable water price of R10.58 per kiloliter. This price was projected to increase by 10% per annum over 20 years.

Table 5.9: Potable water saved due to GWR for flushing in 2 toilets at the School of Civil and Environmental Engineering, WITS

Method of Logging	Month and Year	Monthly toilet flushing consumption (litres)	No of days logged	Average potable water consumption for toilet flushing per day (litres)	No of toilets logged	Average potable water consumption per day from Nov to Dec 2009 for 12 toilets (litres)	Average potable water consumption per day from Nov to Dec 2010 for 10 toilets (litres)	Difference in potable water savings per day where method of logging was similar (litres)	Peak (x3) potable water saved per day where method of logging was similar (litres)
Electronic	Nov-09	18 162	30	605	12				
	Dec-09	6 804	31	219	12	412			
	Mar-10	14 301	22	650	10				
	Apr-10	16 389	30	546	10				
	May-10	10 881	31	351	10				
	Jun-10	6 615	30	221	10				
	Jul-10	12 267	31	396	10				
	Aug-10	11 403	31	368	10				
	Sep-10	12 276	30	409	10				
	Oct-10	12 555	31	405	10				
	Nov-10	7 695	20	385	10				
	Dec-10	5 130	31	165	10		275	137	412

Note: GWR system was implemented in March 2010.

Table 5.10: Potable water saved due to GWR for flushing in 2 toilets at Unit 51A, Student Town, UJ.

Logging methodology	Month	Monthly toilet flushing consumption (litres)	No of days logged	Average potable water consumption for toilet flushing per day (litres)	No of toilets logged	Average potable water consumption per day from Aug to Sept 2009 for 4 toilets (litres)	Average potable water consumption per day from Aug to Sept 2010 for 2 toilets (litres)	Difference in potable water consumption per day over Aug and Sept 2009 (before GWR) and Aug and Sept 2010 (after GWR) and where method of logging was similar (litres)	Peak (x2) potable water saved per day where method of logging was similar (litres)
Electronic	Aug-09	6678	22	607.09	4	599.26		72.69	145
	Sep-09	6210	21	591.43	4				
	Mar-10	3780	15	252.00	4				
	Apr-10	4725	30	157.5	4				
	May-10	7704	28	275.14	4				
	Jun-10	1809	13	139.15	2				
	Jul-10	9810	22	445.91	2				
	Aug-10	16821	28	600.75	2		526.58		
	Sep-10	6786	15	452.4	2				

Note: GWR was implemented in May2010.

5.3.2.2 Determination of the costs and benefits of greywater reuse

a) Economical costs

In general, the economic costs for a GWR system include: (1) the design cost and local government permit fee, if applicable, (2) purchase and installation costs; and (3) operation and maintenance costs. The installation costs which would include materials and labour which would be site and system specific; the operation and maintenance costs would include costs of energy needed for treatment and conveyance, maintenance personnel, spare parts, and disinfectants. The energy consumed in pumping treated greywater to the toilet bowl amounted to approximately R3 per month. This value was calculated using meters which logged energy consumption at the pumps. Tables 5.11 and 5.12 summarize the capital and recurrent costs over a 20 year GWR system design life at the WITS and UJ buildings assuming a 5% annual increase.

Table 5.11: Capital and recurrent costs for the WITS greywater reuse system over a 20-year design life

Table	*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)	-38,045																			
Electricity consumption (R)	-36	-47	-61	-79	-87	-96	-105	-116	-127	-140	-154	-170	-186	-205	-226	-248	-273	-300	-330	-363
Chlorine (R)	-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)	-360	-378	-397	-417	-438	-459	-482	-507	-532	-558	-586	-616	-647	-679	-713	-748	-786	-825	-866	-910
Service agreement (R)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pump replacement (R)	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 5.12: Capital and recurrent costs for the UJ greywater reuse system over a 20-year design life

Cost items	*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)	-38,200																			
Electricity consumption (R)	-36	-47	-61	-79	-87	-96	-105	-116	-127	-140	-154	-170	-186	-205	-226	-248	-273	-300	-330	-363
Chlorine (R)	-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)	-360	-378	-397	-417	-438	-459	-482	-507	-532	-558	-586	-616	-647	-679	-713	-748	-786	-825	-866	-910
Service agreement (R)	-7,200																			
Pump replacement (R)											-7,787									
Cost of the rain water harvesting system (R)	-9,300																			
Total (R)	-55,896	-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

b) Environmental Cost

The Disability Adjusted Life Year (DALY) index was employed in this study as a suitable measurement unit for the impact of GWR on beneficiaries' health. DALY is an index of health risk, developed by the World Health Organization (WHO) and the World Bank (Zhang, 2002). DALY considers the impact of life loss caused by death, deformity after disease, and healthy life years (WHO, 2005). It is the sum of discounted and age-weighted years of life lost. One DALY corresponds to one lost year of healthy life, and the burden of diseases (WHO, 2007).

The calculation of the DALY in this study focuses on the health risk related to diarrhoea disease due to GWR. Diarrhoea disease is estimated to be the largest contributor to the burden of water-related disease (OECD, 2007). Prüss and Fewtrell (2002) considered infectious diarrhoea as the most frequent, non-vector, water-related health outcome, both in the developed and under developed countries. Apart from that, Hutton et al., (2007) argued that most diseases relating to water and sanitation comprise mainly of infectious diarrhoea which include *cholera, salmonellosis, shigellosis, amoebiasis,* and other protozoals and viral intestinal infections. Worldwide, unsafe water and lack of sanitation and hygiene are key risk factors for diarrhoea and other diseases. Diarrhoea disease is an important cause of morbidity and mortality in low- and middle-income countries, resulting in the death of 4.9 out of every 1 000 children aged less than 5 years annually (Prüss et al., 2002; Kosek et al., 2003). In South Africa, diarrhoea disease accounts for 3.1% of total deaths – the eighth largest cause of death nationally. Among children under 5, diarrhoea disease is the third largest cause of death (11.0% of all deaths), and the third largest contributor to the burden of disease, constituting 84% of all deaths attributable to unsafe water, sanitation and hygiene, or about 13 368 deaths and 8.8% of all disability-adjusted life years (DALYs) in this age group (Table 5.13) (Norman et al., 2000 and Bradshaw et al., 2003).

Table 5.13: Burden of several diseases including diarrhoea attributed to unsafe water, sanitation and hygiene in South Africa in 2000. (Lewin et al., 2007)

Disease	**Deaths**	**YLLs***	**YLDs****	**DALYs**
Diarrhoea	13368	375476	10685	386160
Schistosomiasis	20	445	21617	22062
Internal parasites including ascariasis, hookworm	46	1612	8956	10568
Total attributed burden	13434	377533	41258	418790

**YLLs = years of life lost, ***YLDs =years lived with disability.*

In Zhang (2002), the valuation of health risk was calculated at the national or regional level. Valuing the health impact of GWR at the level of a small project has not been investigated. Usually, the main route of exposure to hazards from using greywater for toilet flushing is by ingestion. Aerosols and droplets may be deposited on the surface of the toilet bowl or seat and can in turn, be touched by users, and subsequently ingested through hand-to-mouth contact. In this section, we adopt a direct valuation method to assess the health impact on the population affected by the GWR project. Health risk was determined by multiplying the DALY number related to diarrhoea risk caused by the GWR project and the DALY cost rate.

The DALY number related to diarrhoea risk was calculated based on pathogenic organisms which cause diarrhoea. According to Ottoson (2003), pathogenic organisms that cause diarrhoea include faecal bacteria, *campylobacter*, Enteric viruses (especially *rotavirus*), and protozoa (especially *cryptosporidium*). Table 5.14 presents the risk calculation from the three major diarrhoea causing pathogens.

Table 5.14: Potential disease burdens for aerosols from toilet flushing

	Cryptosporiduim	*Rotavirus*	*Campylobacter*	***Comments***
Organisms per liter in source water[a,b]	35	31	150	Oesterholt et al 2007. From the range of values reported, the highest value was selected
Log reduction provided by treatment[c]	1	0.1	0.01	0 log reduction Cryptosporidum , 1 log reduction for virus and 2 log reduction for bacterial using Chlorine Appendix D
Exposure per event(L)	1.00E-05	1.00E-05	1.00E-05	Health Canada 2010
Dose per event (L)	3.50E-04	3.10E-05	1.50E-05	Box B3
Number of events per year	1100	1100	1100	Table 3.3 page 62
Dose-response constants[d] (α)	**r= 0.059**	**0.253**	**0.145**	Constants for alpha and beta in Table 3.4 page 64
		0.426	**7.58**	
Risk of infection(P_{inf}) (Probability of infection per event)	2.06E-05	0.000	0.000	Dose-response relationships for different microorganisms Table 3.4
Ratio of illness /infection[e]	0.70	0.88	0.3	
Risk of illness (P_{ill}) per event	1.45E-05	1.62E-05	2.67E-06	
Risk of illness (per year, i.e, 1100 events)	1.59E-02	1.78E-02	2.94E-03	
Disease burden[f] (DALY per case)	1.50E-03	1.30E-02	5.50E-02	
Susceptibility fraction (%)[g]	100	6	100	
DALY per year (DALY per person per year)	2.39E-03	1.39E-03	1.62E-02	

[a] Concentrations of Cryptosporidium and rotavirus in raw sewage are taken from NRMMC-EPHC (2006); numbers of adenovirus are used as an indication of rotaviruses because of lack of enumeration methods for rotavirus

[b] Concentration of E.coli O157:H7 is calculated assuming the 2% of the maximum number of generic E.coli enumerated in raw wastewater samples from Canadian cities are pathogenic (6.2 x 10^6; Payment et al., 2001). More information is needed to refine this estimate.

[c] Based on log reductions shown in tables D1 and D2 (see Appendix D); hazard concentrations reduced by secondary treatment, coagulation, filtration and disinfection.

[d] Models used to calculate risk of infection are shown in Table 3.4

[e] Havelaar and Melse (2003)

[f] DALY per case based on Havelaar and Melse (2003)

[g] The proportion of the population susceptible to developing disease following infection. The figure of 6% for rotavirus is based on the fact that infection is common in very young children. The 6% equates to the percentage of population aged less than five years.

The selection of the preferred pathogenic organism for the risk calculation was based on the following assumptions:

- *Susceptibility fraction:* This is determined by the age group of the exposed population. e.g The proportion of the population susceptible to developing diseases caused by *rotavirus* is 6%. The figure of 6% for *rotavirus* is based on the fact that infection is common in very young children. The 6% equates to the percentage of population aged less than five years. Therefore the probability of students at the pilot sites getting rotavirus is negligible (Health Canada, 2010).
- *Persistence and growth in water:* After leaving the body of their host, most pathogens gradually lose viability and the ability to infect. The most common waterborne pathogens and parasites are those that have high infectivity and either can proliferate in water or possess high resistance to decay outside the body. Bacteria's are known to grow and persist in water (WHO, 2008).
- *Severity of illness:* Apart from illness caused by Hepatitis E virus and Hepatitis A virus and diseases caused by *Shigella* spp. and *E. coli* O157. The severity of illness by *campylobacter* is sometimes life-threatening (WHO, 2008).

Based on the above assumptions, *campylobacter* was selected as the reference organism to calculate the health risk related to diarrhoea. Health risk was calculated by multiplying the calculated DALY number related to *Campylobacter* (bacteria causing diarrhoea) and the exposed population. The DALY burden of diarrhoea at WITS with approximately 500 students and staff conducting their business within the building housing the School of Civil and Environmental Engineering is equal to the: Calculated DALY burden from *Campylobacter* × The exposed population at WITS (approximately 500 students and staff).

$$(1.62 \times 10^{-2}) \times 500 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5.2)$$

$$= 8.08 \text{ DALY/year}$$

At the UJ residential unit housing 16 students, the DALY burden of diarrhoea disease is equal to the: Calculated DALY burden from *Campylobacter* × The exposed population at UJ (approximately 16 students)

$$(1.62 \times 10^{-2}) \times 16 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5.3)$$

= 0.26 DALY/year

According to Pegram et al. (1998), the cost of treating diarrhoea in South Africa was estimated to be R3.375 billion/year in 1995. With a 5% annual inflationary increase, the cost of treating diarrhoea was estimated to be R6.68 billion/year in 2009. Therefore:

The South African DALY unit cost due to diarrhoea = Total cost of treatment/DALY burden of diarrhoea =

$$\left(R6.68 * 10^{9} / 386{,}160 DALY \right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5.4)$$

= R17,299/DALY

Therefore, the health risk cost (due to diarrhoea) of greywater reuse for toilet flushing at WITS = DALY unit cost rate × DALY burden of diarrhoea x Impact factor (area impacted by the greywater reuse within the City of Johannesburg (Liang and van Dijk, 2010)).
= R17, 299 x 8.08 x 0.002 = R 279.55/year

At UJ, the health risk cost = R 8.95/year

c) Economical benefit

The economic benefit of GWR is the savings in municipal potable water as a result of GWR for toilet flushing. It is calculated based on the Johannesburg Water tariff, and the annual average potable water saved due to GWR. The 2010 tariff for potable water was ZAR10.58/kilolitre. Historically, municipal potable water increases between 7 to 14% per year. Therefore, forecasting into the future, a 10% increase per year was adopted. Table 5.13 presents the economic benefit of the GWR system at WITS and UJ over a 20 year design life. The peak potable water savings of 412 litres per day due to the 2 greywater reuse toilets was employed in this analysis for WITS (Table 5.9) while the savings of 145 litres per day was employed for UJ (Table 5.10).

d) Environmental benefit

The environmental benefit of GWR for toilet flushing considered in this study was the savings to be achieved through a reduction in sewage to be treated. Conservatively, it was assumed that the reduction in sewage to be treated was 55% of the savings in potable water due to GWR. Therefore the environmental benefit = savings due to a reduction in sewage × the sewage unit cost (Table 5.15).

Table 5.15: Benefits of the UJ and WITS GWR system over a 20-year design life

	Case Study	**UJ**	**WITS**
Economic benefit - savings in municipal potable water as a result of GWR	Savings in potable water on a peak day due to GWR in 2 toilets (litres)	278 L	440 L
	Annual savings in potable water due to GWR in 2 toilets (litres) (x 330 days at WITS and 200 days at UJ)	55.60 kL	145.20 kL
	Annual potable water savings at ZAR10.58 per kl	R 588.25	R 1,538.22
Environmental benefit – reduced sewage treatment costs due to reduced return flows	Savings in sewage per day due to GWR in 2 toilets (litres) (approximately 55% of potable water savings)	152.90 L	242.00 L
	Annual savings in sewage due to GWR in 2 toilets (litres) (x 330 days at WITS and 200 days at UJ)	30.58 kL	79.86kL
	Annual sewage savings at ZAR7.00 per kl	R 214.06	R 559.02

5.3.2.3 Economic analysis

a) Cost-benefit ratio calculation

After evaluating the benefit and cost items, the present values of costs and benefits were evaluated. The following equations represent the valuation process. C_O represents economic cost and C_E represents environmental cost. B_O denotes the economic benefits and B_E denotes the environmental benefits. The annual discount rate employed was 10%. As indicated earlier, the analysis was undertaken over a period of 20 years. The system's operational requirements were assumed to be consistent over the period considered.

$$C = C_O + C_E \quad \text{..(5.5)}$$

$$B = B_O + B_E \quad \text{......................(5.6)}$$

The comparison between costs and benefits were based on the following:

If B/C > 1, then the project is economically feasible; Else

If B/C < 1, the project is not economically feasible.

b) Net present value calculation

Net present value calculations first discounts each future cost and benefit to a present value, using an assumed discount rate, and then aggregates the set of present values into a single value. A positive NPV indicates a net benefit and a negative NPV indicates a net loss (Schuen et al., 2009). Different Scenarios can be compared – those with higher NPV values are typically the more favourable. NPV can be calculated based on the equation below:

$$NPV = \sum_{t-1}^{T} \frac{C_t}{(1+r)^t} - C_0 \qquad \text{………… ……………………................} \; (5.7)$$

Where

r is the discount rate (i.e. the rate of return that can be earned on an investment in the financial markets with similar risk). C_t is the net cash flow at time t_x and T is the design life of the system.

c) Payback period calculation

The equation for calculating payback period is:

Payback period = Investment required / Net annual cash inflow……………………….. (5.8)

5.3.3. Results

The results of the analysis conducted for the WITS GWR system are shown in Table 5.16 and generated a benefit-cost ratio of -0.65, an NPV of –ZAR19, 269.94 and payback of 18 years. The results show that implementing GWR for toilet flushing at WITS is not economical within a 20-year period.

The result in Table 5.17 for UJ shows a benefit-cost ratio of -0.21, an NPV of –ZAR53, 667.31 and a payback of more than 20 years. Similar comment made for WITS also applies to UJ. The GWR system would have been viable if the price of potable water was significantly higher, larger volumes of potable water were saved, or there were subsidies on capital and/or operational costs.

Table 5.16: Economic analysis of the WITS greywater reuse system over a 20 year design life

	Present value	***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)	-52,401.15	-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 treatment savings) cost (R)	36,517.14	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
Health risk cost (R)	-3,385.93	-279.55	-293.53	-308.20	-323.61	-339.79	-356.78	-374.62	-393.35	-413.02	-433.67	-455.36	-478.13	-502.03	-527.13	-553.49	-581.16	-610.22	-640.73	-672.77	-706.41
Net cash flow (R)		-37,425.31	735.25	862.92	1,003.36	1,172.93	1,362.50	1,574.19	1,810.32	2,073.47	2,366.47	-5,094.57	3,054.78	3,457.29	3,904.13	4,399.86	4,949.52	5,558.64	6,233.32	6,980.25	7,806.82
Cumulative cash flow (R)		-37,425.31	-36,690.06	-35,827.14	-34,823.79	-33,650.86	-32,288.35	-30,714.16	-28,903.84	-26,830.37	-24,463.90	-29,558.47	-26,503.70	-23,046.40	-19,142.28	-14,742.42	-9,792.90	-4,234.26	1,999.05	8,979.30	16,786.13
Interest rate	**10%**																				
Benefit/Cost ratio	**-0.65**																				
Net Present Value (R)	**-19,269.94**																				
Payback period (years)	**18**																				

Table 5.17: Economic analysis of the UJ greywater reuse system over a 20 year design life

	Present value	***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)	-67,542.06	-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 treatment savings) cost (R)	13,983.15	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
Health risk cost (R)	-108.40	-8.95	-9.40	-9.87	-10.36	-10.88	-11.42	-11.99	-12.59	-13.22	-13.88	-14.58	-15.31	-16.07	-16.88	-17.72	-18.61	-19.54	-20.51	-21.54	-22.62
Net cash flow (R)		-55,102.64	-395.94	-388.15	-379.69	-355.39	-325.71	-289.97	-247.44	-197.28	-138.58	-7,857.32	8.61	99.45	203.58	322.51	457.90	611.62	785.70	982.39	1,204.19
Cumulative cash flow (R)		-55,102.64	-55,498.58	-55,886.73	-56,266.42	-56,621.80	-56,947.51	-57,237.48	-57,484.92	-57,682.20	-57,820.78	-65,678.10	-65,669.49	-65,570.03	-65,366.45	-65,043.95	-64,586.04	-63,974.42	-63,188.72	-62,206.32	-61,002.14
Interest rate	**10%**																				
Benefit/Cost ratio	**-0.21**																				
Net Present Value (R)	**-53,667.31**																				
Payback period (years)	**Not within 20 years**																				

5.4 Summary of findings.

This section reports on the technical and economic measures that were implemented to mitigate the risks of failure associated with the implementation of GWR for toilet flushing. The following are the key findings from this section:

- There are no simple formulas for selecting a package plant because of the trade-offs that need to be made between the three key issues involved i.e. technical, economic and public health. In this project, the GWR package plant 2 achieved the lowest score in the framework and was hence, the favoured GWR system for the pilot project.
- The factors influencing toilet flushing water demand at WITS (and likely typical of academic buildings) were bulk water demand, rainfall, maximum and minimum temperature. The developed model can be reliably used to estimate toilet flushing demand within the School of Civil and Environmental Engineering, WITS based on the 4 independent variables and hence, would be valuable in estimating toilet flushing demand in the event that a GWR system for toilet flushing is being planned for all toilets within the building. The concept adopted in developing the model can in addition to the above, be used to estimate toilet flushing demand in similar high density buildings.
- The results of the cost-benefit analysis for WITS and UJ greywater reuse systems shows payback periods of 18 years and longer than 20 years respectively. For both systems, Benefit-Cost ratios were less than 1 and NPVs were less than R0.00. These results therefore generate a net economic loss and are economically infeasible if beneficiaries are to pay the full costs of the systems.
- To achieve better results, subsidies may have to applied, potable water tariffs may have to increase, larger savings in potable water quantities and sewage treatment costs may have to be achieved, or greywater reuse system costs may have to be lower. Unfortunately, lower cost systems often imply lower treatment technologies which typically produce low quality greywater, and demand high maintenance. Trade-offs therefore have to be made by beneficiaries and decision-makers between lower and higher cost greywater reuse systems.

CHAPTER 6

ENVIRONMENTAL MEASURES TO RISK MANAGEMENT

6.1. Introduction

Despite the benefits of reuse, the risks to public health due to the possible transmission of infectious diseases from greywater ingress (accidental or deliberate) into potable networks, continues to be of great concern. Greywater may contain chemical and microbiological agents which pose a health risk to users and the environment, and the accidental ingestion of contaminated greywater can cause gastrointestinal illness. In a risk assessment conducted by Ottoson and Stenstroem (2003a), rotaviruses pose the most significant risk to human health. Micro-organisms such as adenoviruses and enteroviruses have been found to cause respiratory illnesses as a result of the inhalation of recycled water (NRMMC-EPHC, 2006).

Although most studies on this subject have focused on microbiological hazards, chemical hazards also pose significant risks to the environment and human health (Health Canada, 2010). Some emerging concerns are of the long term exposure to these chemical hazards. These chemicals (inorganic and organic) include pesticides, potential endocrine disruptors, pharmaceuticals and disinfection by-products. An Australian draft of the National Guidelines for Water Recycling (NRMMC-EPHC, 2006) identified 9 environmental hazards that should be prioritised when assessing environmental risks associated with specific uses (including agricultural and residential) of recycled water. Nitrogen and phosphorus are listed as 2 of the 9 hazards. Having high levels of phosphorus and nitrates within a portable water network may result in algae growth within the pipe network leading to unpleasant smells and methaemoglobinaemia (in infants who ingest the contaminated water) respectively (Cantor et al., 2000).

The main route of exposure to microbial and chemical hazards from recycled water is ingestion (including the ingestion of droplets produced by sprays of the recycled water). In the case of greywater used for toilet flushing, aerosols and droplets may be deposited on the surface of the toilet bowl or seat and can in turn, be touched by users, and subsequently, ingested through hand-to-mouth contact. Although it is reasonable to assume that children will take less care to avoid hand-to-mouth contact after touching contaminated surfaces, there is little information available to quantify this potential route of exposure (Trevett, 2005).

There is also the possibility of dermal exposure, even though there is also a lack of evidence about the health hazards that could occur through this route. It is therefore reasonable to assume that in properly designed and managed recycled water systems where recycled water is limited to toilet and urinal flushing, the above hazards are not expected to be high because of the relatively low exposure (Health Canada, 2010). When they do occur however, the consequences can be severe. On the other hand, cross-connections between a greywater pipe and potable water pipe can easily occur within a building housing both networks and can lead to greywater ingress. This route of ingress has the potential to affect a lot more people at a given period of time, than the other routes described above, as it impacts on the quality of the potable water which is typically consumed in one way or another throughout a typical day (Oesterholt et al., 2007).

In order therefore to reduce hazards that may result from the reuse of greywater for toilet flushing, multiple strategies are typically used and may include combinations of the following:

- Promoting general hygiene (e.g. hand washing with soap after toilet use);
- On-site/off-site effluent treatment to reduce pathogens and chemicals to a level that presents a tolerable risk;
- Exposure control methods that limit public access to recycled water such as wearing certain protective clothing while carrying out maintenance tasks;
- Understanding the impact cross-connections may have within buildings housing GWR systems by modelling and simulating the transport of chemical and microbiological substances in potable water reticulation systems.

Modelling and simulation are important tools in predicting the fate of disinfectants and contaminants within a potable water pipe network. As these contaminants are carried within a potable network, they display different characteristics under different conditions thus, making the modelling process complex. It is therefore imperative that such movements and the associated risks be studied.

Several models that have been developed to analyze and as a consequence, improve water quality are discussed below. Based on the survey of models presented below, this chapter presents the methodology employed (and results generated) to model the movement of nitrates and phosphorus within a dual (potable and grey) water network due to greywater ingress.

6.2 Water quality models

Water quality models can be divided into two categories. The first and earlier category of models describe water quality parameters, such as for the decay of disinfectants, using independent, single species mass balances typically paired with first-order kinetics for the reaction terms. These models are called "single species models". The second and more recently developed category of models is called "multi-species models", because they describe water-quality reactions using sets of co–dependent mass balance equations capable of tracking multiple contaminants (Woolschlager et al., 2005).

6.2.1. Single species models

Single species models typically use first-order kinetic terms (e.g. as presented in Meader and Hart, 1988 and Zhang et al., 1992). The most prominent model of this type is the Dynamic Water Quality Model (DWQM) (Grayman et al., 1988). DWQM is the basis of the initial water quality module housed within EPANET. Later versions of EPANET have included a pipe wall demand to simulate constituents reacting at pipe surfaces, such as chlorine loss at iron pipe surfaces (Rossman et al., 1994). Single species models typically assume plug-flow advection and do not allow a deeper understanding of the trends that influence water quality in distribution systems due to continuous pollution. Also, because the kinetic parameters are site-specific fitting parameters, the single species models cannot predict results for other systems or for the same system when significant changes are made to operation or input quality. For example, the chlorine demand in bulk water actually depends on reactions with organic and inorganic compounds. These reactions depend on the concentration of chlorine and the reactive species (e.g. organic matter or nitrite), which change within the distribution system. Therefore, to overcome these limitations, multi-species models, described in the next section, were developed.

6.2.2. Multi-species models

Multi-species models more accurately describe microbial metabolism and disinfectant decay by using sets of interdependent, multi-species, mass-balance equations based on fundamental processes. The first multi-species model designed for drinking water systems is the SANCHO model described by Servais et al. (1995). The SANCHO model comprises mass-balance equations describing microbial synthesis, biodegradable organic matter (BOM) utilization, chlorine reactivity with organic matter, and disinfection processes. Also, SANCHO calculates biomass concentrations in the bulk water and attached to pipe surfaces. Although the SANCHO model was limited to the analysis of straight pipes of decreasing diameter, it has been applied to full-scale distribution systems (Laurent et al., 1997). Although the SANCHO model has proven to be a useful research and analysis tool, as at 2001, it had not been developed into a commercially available model with a user-friendly graphical interface (Servais, 2001). Another model, which is similar to the SANCHO model, and which simulates the growth and decay of heterotrophic bacteria in bulk water in the absence of disinfectants was developed by Jegatheesan et al. (2004). Jagatheesan et al.'s, (2004) model predicts disinfectant decay due to organic matter in the bulk water, as well as that due to biofilm. It simultaneously predicts the growth of biofilm in terms of carbohydrate and protein densities. Jagatheesan et al.'s, (2004) was followed by PICCOBIO model as described by Dukan et al., (1996). The PICCOBIO model contains similar processes to those contained in the SANCHO model. However, these models differ in how some of these processes are represented. For example, the PICCOBIO model contains a complex, multilevel bio-film growth and disinfection sub-model. Furthermore, it accounts for important chlorine loss by reactions with pipe surfaces. The PICCOBIO model was originally calibrated to a pilot pipe system. Later, it was revised by Piriou et al., (1998) to be solvable for, and was field-tested with, a full-scale pipe distribution network (Piriou et al., 1998a, b).

Another multi-species model called the Comprehensive Disinfection and Water Quality Model (CDWQ) was developed to address special issues in systems where chloramines are used for disinfection. CDWQ contains a detailed chloramine and free chlorine chemistry subroutine to accurately model chloramine and chlorine decay, and heterotrophic and nitrifying bacterial processes (Woolschlager, 2000). CDWQ was field tested using data generated from a full-scale distribution system (Woolschlager et al., 1999).

Table 6.1 provides a summary and some comparison of a variety of other single and multi-species water quality models that have been developed to achieve similar water quality function.

Table 6.1. Summary and comparison of water quality models (Woolschlager et al, 2005)

Model	Disinfectant decay	Microbial growth	Software source	Note
Single species				
EPANET	nth-order in bulk water and zero or first order at pipe	None	US Environmental Protection Agency, Cincinnati, Ohio (USA) (www.epa.gov)	Graphical user interface.
WaterCAD	First-order in bulk water and zero-order at pipe surface	None	Haestad methods, Inc Waterbury, Connection (USA) (www.haestad.com)	Graphical user interface.
H_20NET	First-order in bulk water and zero-order at pipe surface	None	MW soft, inc Pasadena California (USA)[www.mwsoft.mw.com]	Graphical user interface with AutoCAD.
Synergee	First-order in bulk water and zero-order at pipe surface	None	Stoner, Inc. Carlisle, Pennsylvania (USA)[www.stoner.com]	Graphical user interface. Two species allowed.
PICCOLO_ chlorine	First-order in bulk water and zero-order at pipe surface	None	Infeo Boulogne Billancourt, Billancourt,infeo.ornis.net/ (France) [http://	Graphical user interface.
Multi_species				
SANCHO (Servais et al.,1995)	Second-order reaction with organic matter	Fixed and suspended heterotrophs	Not commercially available.	No pipe wall reactivity for disinfectants
Jagatheeesan et al. (2004)	No disinfection	Suspended	Not commercially available.	Includes nutrient balance.
PICCOBIO (Dukan et al., 1996)	First-order in bulk water and zero-order at pipe surface	Fixed and suspended heterotrophs	Not commercially available.	Multi-layer biofilm growth and disinfection routine
PICCOBIO (Piriou et al., 1998b)	First-order in bulk water and zero-order at pipe surface	Fixed and suspended heterotrophs	Infeo Boulogne Billancourt, Billancourt,infeo.ornis.net/ (France) [http://	Graphical user interface. Based on Dukan et al. model.
CDWQ (Woolschalager, 2000)	Complex chloramine and free chlorine chemistry subroutine	Fixed and suspended heterotrophs and nitrifiers	Not commercially available.	Field tested for chloraminated system.
PICCOBIO - chloramine	Complex chloramine and free chlorine chemistry subroutine	Fixed and suspended heterotrophs and nitrifiers	Infeo Boulogne Billancourt, Billancourt,infeo.ornis.net/ (France) [http://	Graphical user interface. Based on CDWQ model.

6.3. Tools for the modelling and simulation of nitrates and phosphorus within drinking water pipe networks

This section presents some prominent tools/software packages used to model and simulate nitrate and phosphorus ingress into drinking water distribution networks.

6.3.1 EPANET

EPANET is a computer program that performs extended period simulation of hydraulic and water quality behaviour within pressurized pipe networks (Rossman, 2000). EPANET models systems of diverse sizes; computes friction losses using the Hazen-Williams, Darcy-Weisbach or Chezy-Manning equations; computes minor losses and pumping energy. EPANET models constant or variable speed pumps, various types of valves (including shutoff valves, check valves, pressure regulating valves and flow control valves), storage tanks of any shape, and allows variable demand at nodes. In addition to hydraulic modelling, EPANET models water quality i.e. the movement and fate of a non-reactive material within a pipe network over time (Melo et al., 2009). EPANET uses several order kinetics to model reactions in the bulk flow and zero or first order kinetics for reaction at the pipe wall. The overall reaction rate coefficients can be specific for each pipe and the wall reaction rate coefficients can be correlated with pipe roughness. It is also possible to determine the effects of concentration or mass input at any location in the network (Rossman, 2000). The governing equations for EPANET's water quality solver are based on the principles of conservation of mass conjugated with reaction kinetics. The equations involve (Melo et al., 2009) :

- Advective transport in pipes;
- Mixing in storage facilities;
- Bulk flow reactions;
- Pipe wall reactions;
- System of equations;
- Lagrangian transport algorithm;

EPANET also provides an integrated set of conditions for editing network input data, running hydraulic and water quality simulations, and viewing the results in a variety of formats, such as colour-coded network maps, data tables, time series graphs and contour plots. EPANET was initially developed to model single chemical species transportation through the water distribution network and storage tanks. But due to quest for modelling more than one contaminant, a new extension software package to EPANET which is called EPANET-MSX was released by National Homeland Security Research Center (NSHRC) of EPA (Rossman, 2000).

6.3.2. EPANET MSX

EPANET-MSX (Multi Species Extension) was developed to model more than one chemical or biological species and their interactions with each other in bulk water and at pipe walls. The toolkit library of functions of EPANET-MSX is used to build custom hydraulic and water quality applications. The chemical equilibrium and reaction rate equations are defined for the species and the differential algebraic equations are solved by numerical methods of Euler, Runge-Kutta and Rosenbrock. The algebraic equations are solved by the Newton-Raphson method (Rossman, 2000; Shang et.al, 2007; Shang and Uber, 2007).

EPANET-MSX allows modelling chemical reactions such as auto-decomposition of chloramines to ammonia, the formation of disinfection by-products, biological re-growth, combined reaction rate constants in multi- source systems and mass transfer limited oxidation-pipe wall adsorption reactions (Shang et al., 2008).

The EPANET-MSX system is supplied as two different formats: a stand-alone console application (epanetmsx.exe) that can run standard water quality analysis without any additional programming effort, and a function library (epanetmsx.ddl) that is used with the original EPANET function library (epanet2.ddl) to produce customised programming applications. In both formats, the user must prepare two input files to run a multi-species analysis. One of them is the standard EPANET input file for giving the data required for the network hydraulic components: junctions, reservoirs, tanks, pipes, pumps and valves. The data file includes elevation, demand and demand patterns for junctions, head and pattern for reservoirs, elevations, initial, minimum and maximum levels and diameter values for tanks, pipe lengths, diameters, roughness, pump curves, position of valves for specified conditions, X-Y coordinates of the nodes, initial quality values at nodes, source types, duration of simulation, time steps, reporting time and other various simulation options such as units, viscosity, diffusivity, specific gravity, accuracy and tolerance. The second file is a special EPANET-MSX file that describes the species being simulated and the chemical reaction/equilibrium models that govern their dynamics (Shang et al., 2008). Some of the parameters defined in the EPANET-MSX file are chemical species, reaction coefficients and terms, rate equations for pipes and tanks, sources and initial conditions for selected species, patterns for sources, parameters for pipes and reporting options (Rossman, 2000; Shang et.al., 2007; Shang and Uber, 2008).

6.4. Description of a the UJ pipe network

The network consists of 19 nodes including 2source reservoir (which is the greywater tank) and campus supply. The network also consists of 18 pipes linking the nodes and two pumps. The greywater system collects raw greywater from 2 showers and 2 bath-tubs only. The greywater then passes through a chlorinator which disinfects using chlorine tablets before it passes through two 2mm sieves in series which are housed within a cylindrical pipe. A cistern block, which provides colour to the greywater, is inserted into one of the 2mm sieves weekly. The sieved greywater is then stored within a 200 litre greywater tank which houses 2 submersible pumps (each pump is connected to a toilet). When pressed, the bell switch, which is mounted on the wall close to the toilet cistern, activates its pump and conveys the sieved greywater into the toilet bowl for flushing. Figure 6.1a depicts the UJ dual system with the location of the cross-connection (Figure 6.1b) just before the first and ground floor greywater toilets. Pipe and node properties are listed in Tables 6.2 and 6.3 respectively.

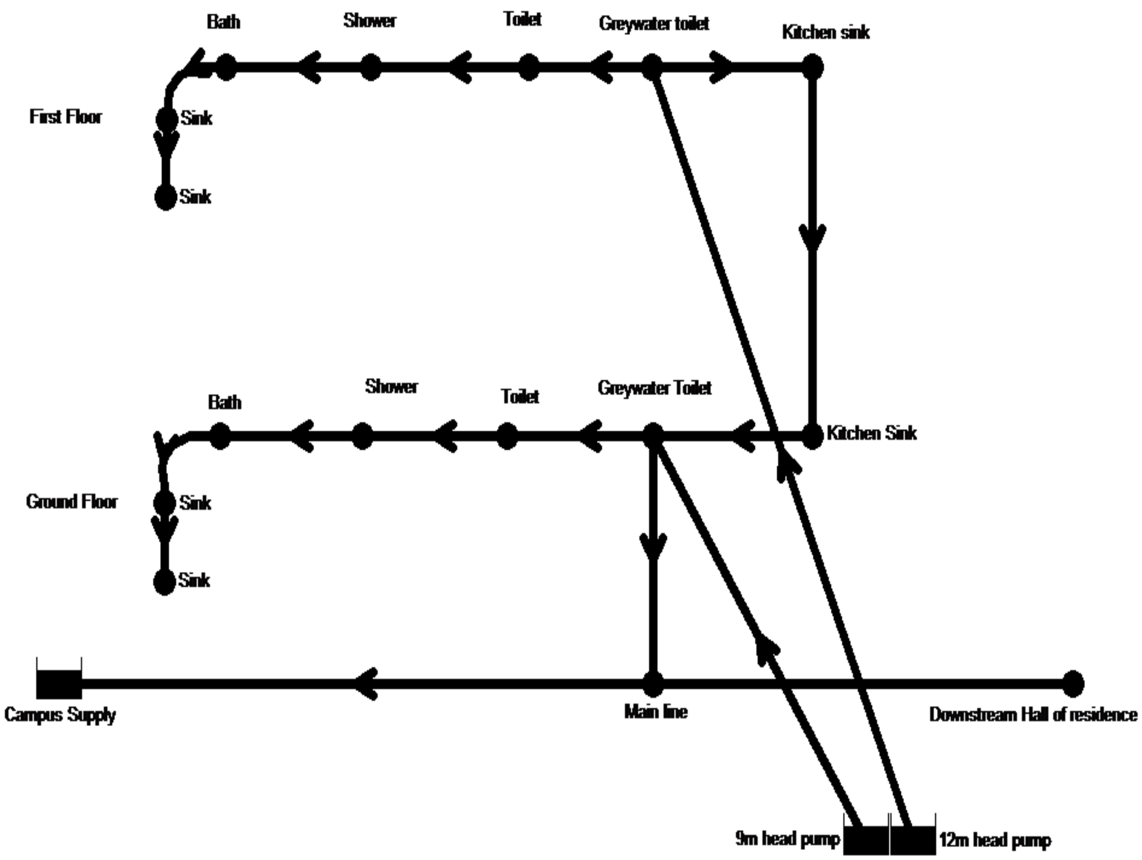


Figure 6.1a: The UJ dual potable and greywater pipe network.

Figure 6.1b: The UJ dual potable and greywater pipe network showing the point of cross-connection located just before the greywater toilets (nodes 3 and 11 in Figure 6.1a)

Table 6.2: UJ network pipe properties

	Length	Diameter	Roughness
Link ID	**m**	**mm**	
Pipe 3	1.5	15	100
Pipe 4	1.5	15	100
Pipe 5	1.5	15	100
Pipe 6	1.5	15	100
Pipe 7	1.5	15	100
Pipe 8	1.5	15	100
Pipe 15	3.5	15	100
Pipe 9	1.5	15	100
Pipe 10	1.5	15	100
Pipe 11	1.5	15	100
Pipe 12	1.5	15	100
Pipe 13	1.5	15	100
Pipe 14	1.5	15	100
Pipe 16	20	50	100
Pipe 17	10	50	100
Pipe 20	1.5	15	100
Pipe 21	6.0	50	100
Pipe 19	2.5	50	100

Table 6.3: UJ network node properties

		Elevation	Base demand
Node ID	**Node name**	**m**	**LPM**
Junc 9	Kitchen Sink ground floor	2	0.05
Junc 3	Greywater toilet ground floor	2	0.5
Junc 4	Normal toilet ground floor	2	0.5
Junc 5	Shower ground floor	2	0.4
Junc 6	Bath ground floor	2	0.4
Junc 7	Sink 1 ground floor	2	0.05
Junc 8	Sink 2 ground floor	2	0.05
Junc 10	Kitchen Sink 1st floor	5.5	0.05
Junc 11	Greywater toilet 1st floor	5.5	0.5
Junc 12	Normal toilet 1st floor	5.5	0.5
Junc 13	Shower 1st floor	5.5	0.4
Junc 14	Bath 1st floor	5.5	0.4
Junc 15	Sink 1 1st floor	5.5	0.05
Junc 16	Sink 2 1st floor	5.5	0.05
Junc 2	Mains	2	0
Junc 18	Downstream node	2	0
Resvr Supply	Campus supply	8	#N/A
Resvr greywater	Greywater tank	12	#N/A
Resvr greywater	Greywater tank	9	#N/A

6.5. Setting of properties

After representing the network on EPANET, the next step involved the setting of object properties. The setting of properties is mainly for the network hydraulic components: junctions, reservoirs, tanks, pipes, pumps and valves. The following were put into consideration before the setting of properties:

1. The greywater tank was set as the reference point, (i.e. the datum).
2. The ground floor was considered to be about 2m above the greywater tank
3. The pump is inside the greywater tank and it is considered to be 1m below the ground level.
4. The second floor was considered to be 3.5m from the first floor, thus making it 5.5m from the datum.
5. Distance from one end use to the other was about 1.5 meters apart.
6. 15mm pipes supply potable water within the residence and 50mm pipes supply greywater.
7. The base demand was calculated using the average per capita daily water consumption within the residential unit. This was later multiplied by the number of students living in the residence. This demand was later related to the water demand for each end use.
8. In order to model the pump to supply intermittently, pumps were removed and replaced with two reservoirs with each having different pump heads. These pump heads (pressure) are added to the total head of the reservoir thereby representing the pressure coming out from the pump.
9. A different water demand pattern which is the toilet flushing demand pattern is assigned to the greywater toilet. This represents the demand which is initiated with the bell push that comes from the greywater tank causing the pump to supply greywater intermittently.

Based on the above assumptions, the properties that were edited include elevation, demand and demand patterns for junctions, pipe lengths, diameters, roughness, pump curves, X-Y coordinates of the nodes, initial quality values at nodes, source types, duration of simulation, time steps, reporting time, and other various simulation options such as units, viscosity, diffusivity, specific gravity, accuracy and tolerance.

For the extended water quality simulation, the water demand pattern was calculated from the daily bulk water demand recorded at Unit 51 between the period of August and September, 2010 prior to the toilet flushing modelling exercise. Multipliers (Table 6.4a and b) were used to modify the daily diurnal demand from its base level for each time period, and a new pattern was created using a Pattern Editor dialog shown in Figure 6.5. Due to the extended period simulation over 72 hours, the daily diurnal demand pattern was repeated after every 24 hours.

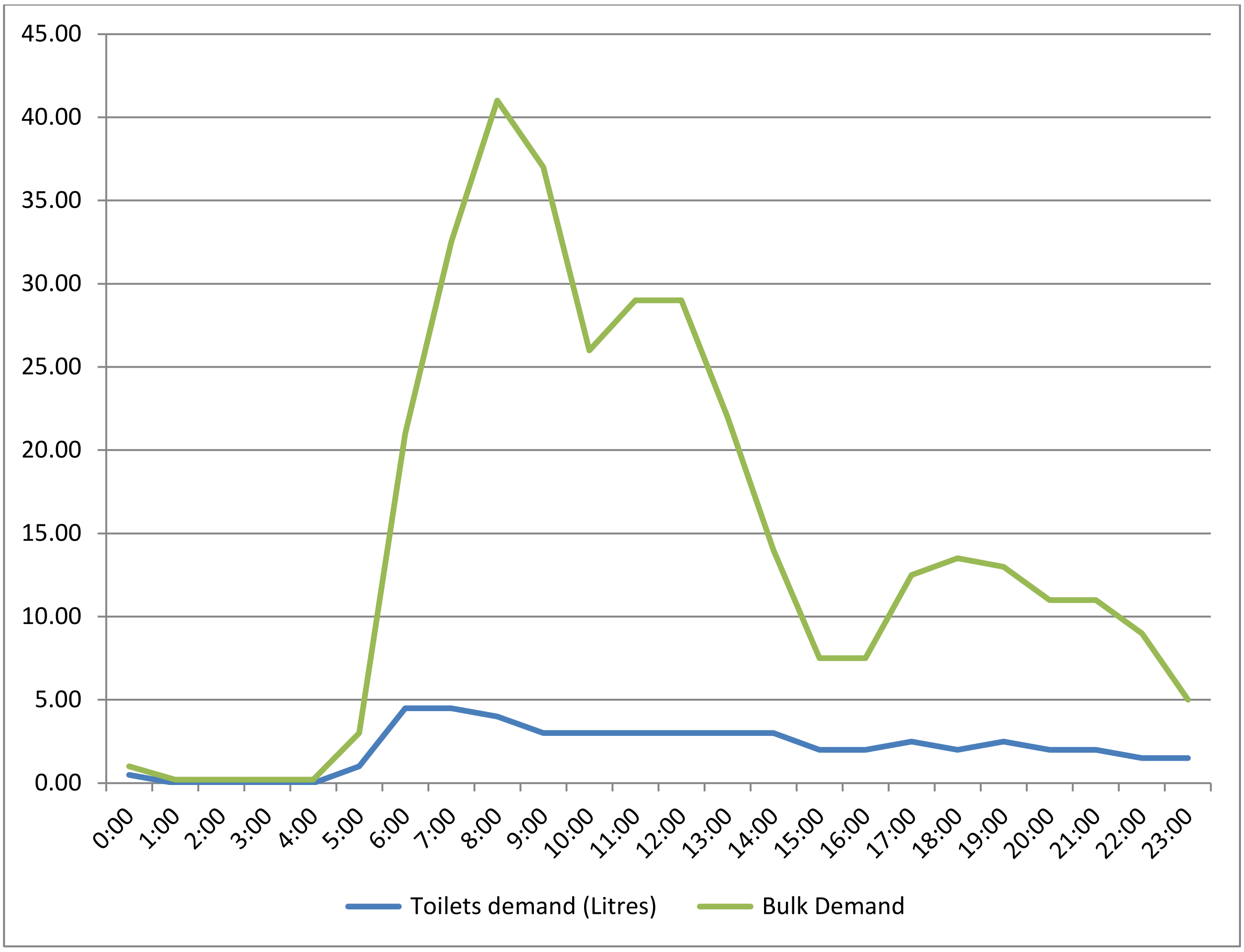


Figure 6.5: Diurnal Bulk and Toilet flushing demand pattern for Units 51, UJ.

Table 6.4a: Conversion of the bulk demand into the daily diurnal demand pattern 1 using multipliers

Time	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00	11.00	12.00
Bulk water demand (liters)	0.20	0.20	0.20	0.20	3.00	21.00	32.50	41.00	37.00	26.00	29.00	29.00
Multiplier	0.01	0.01	0.01	0.01	0.21	1.46	2.25	2.84	2.56	1.80	2.01	2.01
Time	13.00	14.00	15.00	16.00	17.00	18.00	19.00	20.00	21.00	22.00	23.00	24.00
Bulk water demand (liters)	22.00	14.00	7.50	7.50	12.50	13.50	13.00	11.00	11.00	9.00	5.00	1.00
Multiplier	1.52	0.97	0.52	0.52	0.87	0.94	0.90	0.76	0.76	0.62	0.35	0.07

Table 6.4b: Conversion of the toilet demand into the daily diurnal demand pattern 2 using multipliers

Time	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00	11.00	12.00
Bulk water demand (liters)	0.00	0.00	0.00	0.00	1.00	4.50	4.50	4.00	3.00	3.00	3.00	3.00
Multiplier	0.00	0.00	0.00	0.00	0.48	2.14	2.14	1.90	1.43	1.43	1.43	1.43
Time	13.00	14.00	15.00	16.00	17.00	18.00	19.00	20.00	21.00	22.00	23.00	24.00
Bulk water demand (liters)	3.00	3.00	2.00	2.00	2.50	2.00	2.50	2.00	2.00	1.50	1.50	0.50
Multiplier	1.43	1.43	0.95	0.95	1.19	0.95	1.19	0.95	0.95	0.71	0.71	0.24

6.6 Estimation of bulk and wall coefficients for chlorine, nitrate, and phosphorus.

The bulk (0.50 1/day) and wall (0.15 l/day) coefficients for chlorine were based on Clark et al. (1993) and Powell et al. (2000) respectively. The bulk coefficient chosen for nitrate (a first-order decay rate of 0.05 1/day) was based on its decay rate within a water column (Ohio EPA, 2008) while the bulk coefficient chosen for phosphorus (a first-order decay rate of 0.013 1/day) was based on decay within an intensive fish pond system (Lefebvre et al., 2001).

6.7 Modelling the chemical reaction of nitrates and phosphorus in potable water

The chemical reactions of nitrates and phosphorus (from greywater ingress) into a potable water network were modelled using a pathogen inactivation model (i.e. assuming nitrates and phosphorus were pathogens in water) (equations 6.1 and 6.2) and the kinetics of chlorine in greywater (equation 6.3) (March et al., 2005). These equations were input into the EPANET-MSX file (Shang et al., 2008). Brief descriptions of these models are presented below:

6.7.1 Pathogen inactivation model

Chick (1908) and Watson (1908) studied the rate of inactivation of microorganisms and proposed equation 6.1.

$$r_1 = -k_p C^n I \qquad \text{……………………………………………}(6.1)$$

Where I is the number of pathogens per litre, C is the disinfectant concentration in mg/l, k_p is the pathogen decay rate constant in l/mg.min and n is the reaction order. Assuming a first order reaction of n=1, equation 6.1 becomes equation 6.2.

$$\frac{dI}{dt} = -k_p CI \qquad \text{……………………………………………}(6.2)$$

6.7.2 Kinetics of chlorine in greywater

In relation to the kinetics of chlorine (equation 6.3), the disinfectant (i.e. hypochlorite, C_{added}) was divided into three fractions of different reactivity. The first, C_w includes the reactions with reducing reagents (e.g. inorganic reductants and commercial organic antioxidants) that reduce hypochlorite to a chloride ion. The second and third fractions are chlorinated products which maintain oxidative and disinfectant properties. The second fraction involves a higher reactive fraction, whose concentration is denoted by $C_0.x$ and the third fraction involves the formation of and a slower reactive fraction, whose concentration is $C_0.(l - x)$.

$$C_{added} = C_w + C_0.x.\exp(-k_1.t) + C_0.(1-x).\exp(-k_2.t) \ldots\ldots\ldots\ldots\ldots..(6.3)$$

6.8 Simulation of contaminants within the potable water network

The potential pathways for ingress and nodes where possible human exposure to the contaminants could take place were identified. A list of nodes where humans exposure to contaminants could occur are shown in Table 6.5.

Table 6.5: A list of nodes where human exposure to contaminants could occur showing activities that could lead to ingress and potential pathways

Node ID	Node name	Description of activity that could lead to a hazard during an ingress event.	Pathway for human exposure
Junc 9	Kitchen Sink ground floor	Cooking and washing of dishes	Dermal
Junc 3	Greywater toilet ground floor	Toilet flushing	Dermal and inhalation
Junc 4	Normal toilet ground floor	Toilet flushing	Dermal and inhalation
Junc 5	Shower ground floor	Bathing	Dermal, inhalation and ingestion
Junc 6	Bath ground floor	Bathing and washing	Dermal, inhalation and ingestion
Junc 7	Sink 1 ground floor	Brushing of teeth	Dermal and ingestion
Junc 8	Sink 2 ground floor	Brushing of teeth	Dermal and ingestion
Junc 10	Kitchen Sink 1st floor	Cooking and washing of dishes	Dermal
Junc 11	Greywater toilet 1st floor	Toilet flushing	Dermal and inhalation
Junc 12	Normal toilet 1st floor	Toilet flushing	Dermal and inhalation
Junc 13	Shower 1st floor	Bathing	Dermal, inhalation and ingestion
Junc 14	Bath 1st floor	Bathing and washing	Dermal, inhalation and ingestion
Junc 15	Sink 1 1st floor	Brushing of teeth	Dermal and ingestion
Junc 16	Sink 2 1st floor	Brushing of teeth	Dermal and ingestion

Hydraulic analysis of the potable water network over 72 hours using EPANET was undertaken prior to water quality simulation. The water quality simulation included trace flow and multi-species analyses using a developed EPANET-MSX input file. The EPANET-MSX file was run using the EPANET-MSX Programmers' Toolkit. When contamination is simulated and considering the potable demand events taking place within the building, the contaminant quantities at each node are determined. When compared with drinking water standards, the quantities of these contaminants at the different end users will determine the degree of hazard users may be exposed to. Various contamination events (e.g. different injection locations, different contaminant quantities, and different times of injection) were investigated. Some of the assumptions that were considered for the simulation include the following:

1. The pump is supplying water intermittently;
2. Point of ingress for each of the scenarios is at the node just before the greywater toilets. This is because the potable water supply pipes, previously serving the toilets now retrofitted to flush with greywater, were not removed during the implementation of the greywater toilets, but simply disconnected. Hence, the only possible locations for a cross-connection with a potable water pipe were just before the greywater toilets.

6.9 Results

SCENERIO 1: Time of injection = 08h00 on Day 1; point of injection = node just before the 2 greywater toilets; and quantity injected=0.35 mg/l for nitrate and 10 mg/l for phosphorus

The contaminants from a greywater supply pipe were injected into a potable pipe at the ground and first floors at 08h00 on Day 1. Based on research conducted in South Africa on the typical ranges of nitrates and phosphorus in greywater (Englbrecht and Murphy, 2006), a concentration of 0.35 mg/l for nitrate was injected through the cross-connection from the greywater toilet over 72 hours. Similarly, a concentration of 10 mg/l for phosphorus was injected through the cross-connection. During simulation, nitrate and phosphorus showed similarities in the movement of their respective residual quantities. Figure 6.6 depicts the UJ dual system with the nitrate quantities at 08h00. Figure 6.7 depicts the nitrate reaching the greywater toilets at 08h01 - about 1 minute after injection. Figure 6.8 depicts the time it took the whole network to be completely contaminated with nitrate which is 7 minutes after greywater injection into the potable supply network, while Figure 6.9 depicts the time it took the whole network to reach it highest nitrate concentration at the furthest fixtures which is 8 minutes after greywater injection into the potable supply network. Tables 6.6, 6.7, 6.8 and 6.9 show the concentration of nitrate and phosphorus for each node at 08h00, 08h01, 08h07 and 08h08 respectively. Listed below are some observations:

- There was similarity in the pattern of movement of nitrate and phosphorus within the network (see Figures 6.15 (a and b) and 6.16 (a and b)).

- It took less than 1 minute for nitrate to reach the greywater toilets. This result was compared to the real situation, It was observed that after a bell push for toilet flushes it takes less than 1 minute (btw 10-40 seconds) for the greywater to get to the greywater toilets (Figure 6.7);
- It took 7 minute for the contaminant to reach the entire network and at the 8th minute the entire network was fully contaminated. The highest nitrate pollution load within the network was reached at 8 minutes after initial injection. Thereafter, it remained steady for 24 hours before the cycle is repeated for another day.;
- After 8 minute of greywater injection, at least 80% of contaminant (nitrate and phosphorus) were observed at the entire fixture including the furthest fixtures.
- Results show that the sinks which are the furthest fixture from the point of injection were the least affected. Hence, the further the end use from the point of injection, the less affected a person using that end use will be during a contamination event;
- The highest concentrations of contaminants were observed at the two greywater toilets with over 90% of the total nitrate and phosphorus at various times during the simulation period. This can be attributed to the fact that the greywater toilet receives the greywater before it is injected to the other fixtures within the residences.
- The second fixture that has the highest concentration is the 2 toilets which flush with potable water. This was likely as a result of the proportionally larger demand for toilet flushing in comparison with the other potable water uses occurring after the greywater ingress. This showed that contaminant movement was directly dependent on the demand occurring adjacent to the time of ingress. Also, in relation to the previous point, the toilets are the closest end use to the point of ingress.
- Potable water downstream of the potable supply pipe was not affected by the contaminants ingress. This was as a result of the zero demand at this section of the network. Thus, the movement of contaminants is a function of demand;
- The health risk associated with the contaminant ingress in this network is dependent on the concentration of nitrate and phosphorus injected. With the injection of 0.35 mg/l of nitrate and 10 mg/l of phosphorus from the sieved and disinfected bath and shower greywater, the above results show that the largest concentration of nitrate within the potable network, posed an insignificant health risk according to SANS 0241 (SABS 241-2001) which specifies nitrate concentrates of higher than 10mg/l as

harmful to human health. In the SANS 0241 standard (SABS 241-2001), the concentration of phosphorus is not specified.

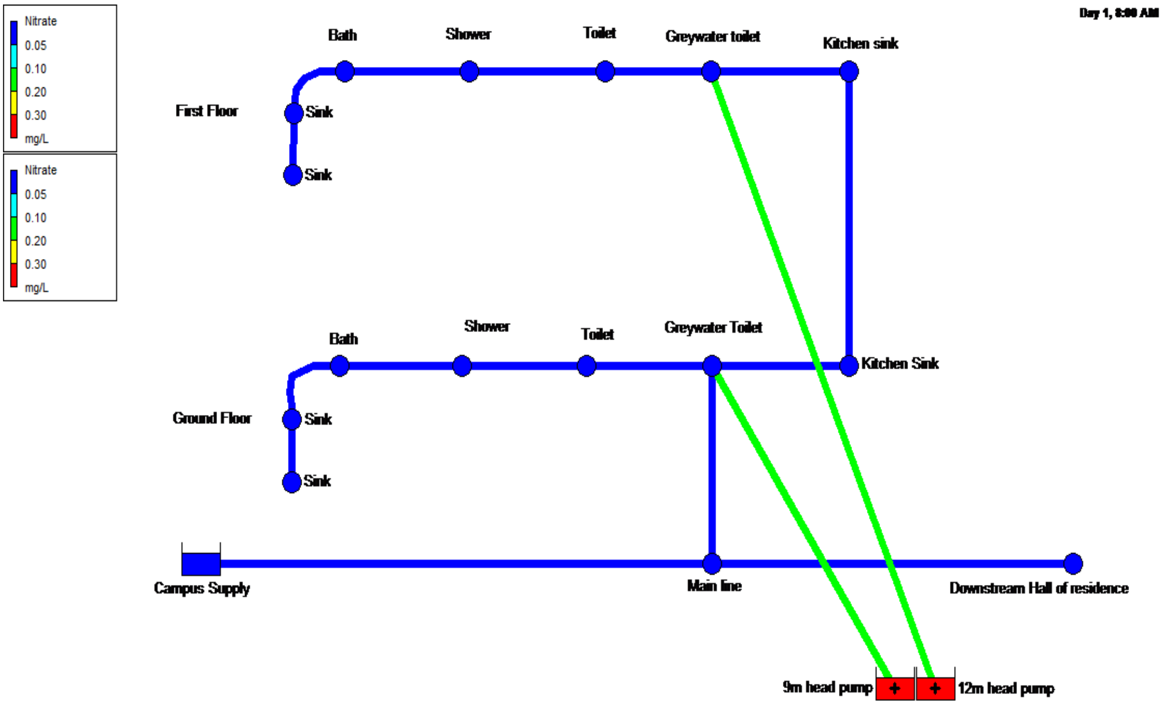


Figure 6.6: Nitrate concentrations at 08h00 of Day 1

Table 6.6: Concentration of phosphorus and nitrate at all network nodes at 08h00 of Day 1

	Elevation	**Base demand**	**Phosphorus**	**Nitrate**
Node Name	**m**	**LPM**	**mg/l**	**mg/l**
Kitchen Sink ground floor	2	0.05	0.00	0.00
Greywater toilet ground floor	2	0.50	0.00	0.00
Normal toilet ground floor	2	0.50	0.00	0.00
Shower ground floor	2	0.40	0.00	0.00
Bath ground floor	2	0.40	0.00	0.00
Sink 1 ground floor	2	0.05	0.00	0.00
Sink 2 ground floor	2	0.05	0.00	0.00
Kitchen Sink 1st floor	5.5	0.05	0.00	0.00
Greywater toilet 1st floor	5.5	0.50	0.00	0.00
Normal toilet 1st floor	5.5	0.50	0.00	0.00
Shower 1st floor	5.5	0.40	0.00	0.00
Bath 1st floor	5.5	0.40	0.00	0.00
Sink 1 1st floor	5.5	0.05	0.00	0.00
Sink 2 1st floor	5.5	0.05	0.00	0.00
Mains	2	0.00	0.00	0.00
Downstream node	2	0.00	0.00	0.00
Resvr Supply	8	#N/A	0.00	0.00
GreyRes9m	9	#N/A	10.00	0.35
GreyRes12m	12	#N/A	10.00	0.35

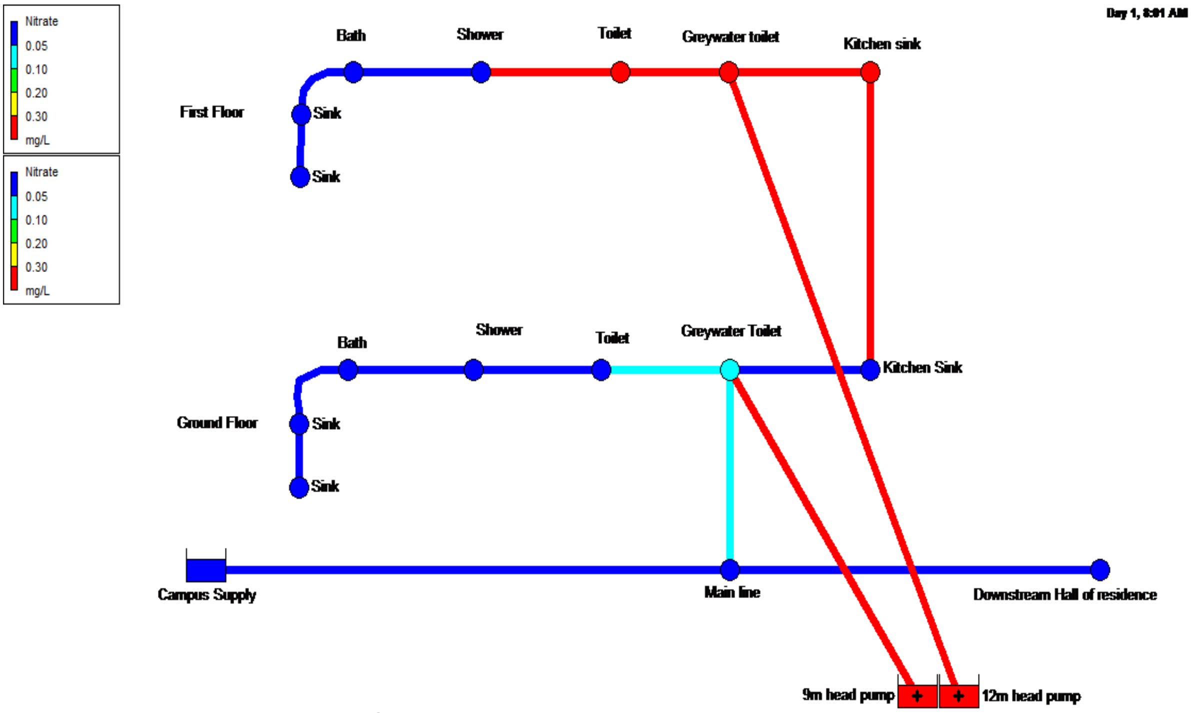


Figure 6.7: Nitrate concentrations at 08h01 of Day 1

Table 6.7: Concentration of phosphorus and nitrate at all network nodes at 08h01 of Day 1

	Elevation	**Base demand**	**Phosphorus**	**Nitrate**
Node Name	**m**	**LPM**	**mg/l**	**mg/l**
Kitchen Sink ground floor	2	0.05	0.00	0.00
Greywater toilet ground floor	2	0.50	2.21	0.08
Normal toilet ground floor	2	0.50	0.05	0.00
Shower ground floor	2	0.40	0.00	0.00
Bath ground floor	2	0.40	0.00	0.00
Sink 1 ground floor	2	0.05	0.00	0.00
Sink 2 ground floor	2	0.05	0.00	0.00
Kitchen Sink 1st floor	5.5	0.05	9.38	0.33
Greywater toilet 1st floor	5.5	0.50	9.89	0.35
Normal toilet 1st floor	5.5	0.50	9.46	0.33
Shower 1st floor	5.5	0.40	0.00	0.00
Bath 1st floor	5.5	0.40	0.00	0.00
Sink 1 1st floor	5.5	0.05	0.00	0.00
Sink 2 1st floor	5.5	0.05	0.00	0.00
Mains	2	0.00	0.05	0.00
Downstream node	2	0.00	0.00	0.00
Resvr Supply	8	#N/A	0.00	0.00
GreyRes9m	9	#N/A	10.00	0.35
GreyRes12m	12	#N/A	10.00	0.35

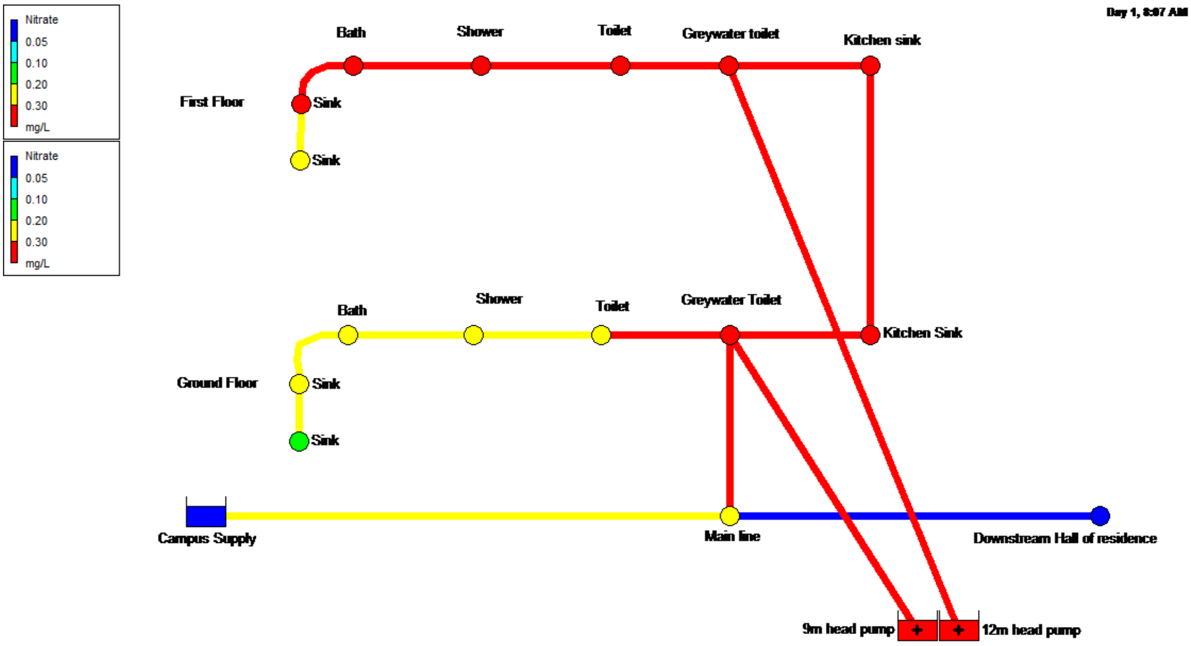


Figure 6.8: Nitrate concentrations at 08h07 of Day 1

Table 6.8: Concentration of phosphorus and nitrate at all network nodes at 08h07 of Day 1

	Elevation	Base demand	Phosphorus	Nitrate
Node Name	**m**	**LPM**	**mg/l**	**mg/l**
Kitchen Sink ground floor	2	0.05	8.89	0.31
Greywater toilet ground floor	2	0.50	8.76	0.31
Normal toilet ground floor	2	0.50	8.38	0.29
Shower ground floor	2	0.40	8.05	0.28
Bath ground floor	2	0.40	7.88	0.28
Sink 1 ground floor	2	0.05	7.68	0.27
Sink 2 ground floor	2	0.05	2.70	0.20
Kitchen Sink 1st floor	5.5	0.05	9.38	0.33
Greywater toilet 1st floor	5.5	0.50	9.89	0.35
Normal toilet 1st floor	5.5	0.50	9.46	0.33
Shower 1st floor	5.5	0.40	9.09	0.32
Bath 1st floor	5.5	0.40	8.90	0.31
Sink 1 1st floor	5.5	0.05	8.68	0.30
Sink 2 1st floor	5.5	0.05	8.32	0.29
Mains	2	0.00	8.30	0.29
Downstream node	2	0.00	0.00	0.00
Resvr Supply	8	#N/A	0.00	0.00
GreyRes9m	9	#N/A	10.00	0.35
GreyRes12m	12	#N/A	10.00	0.35

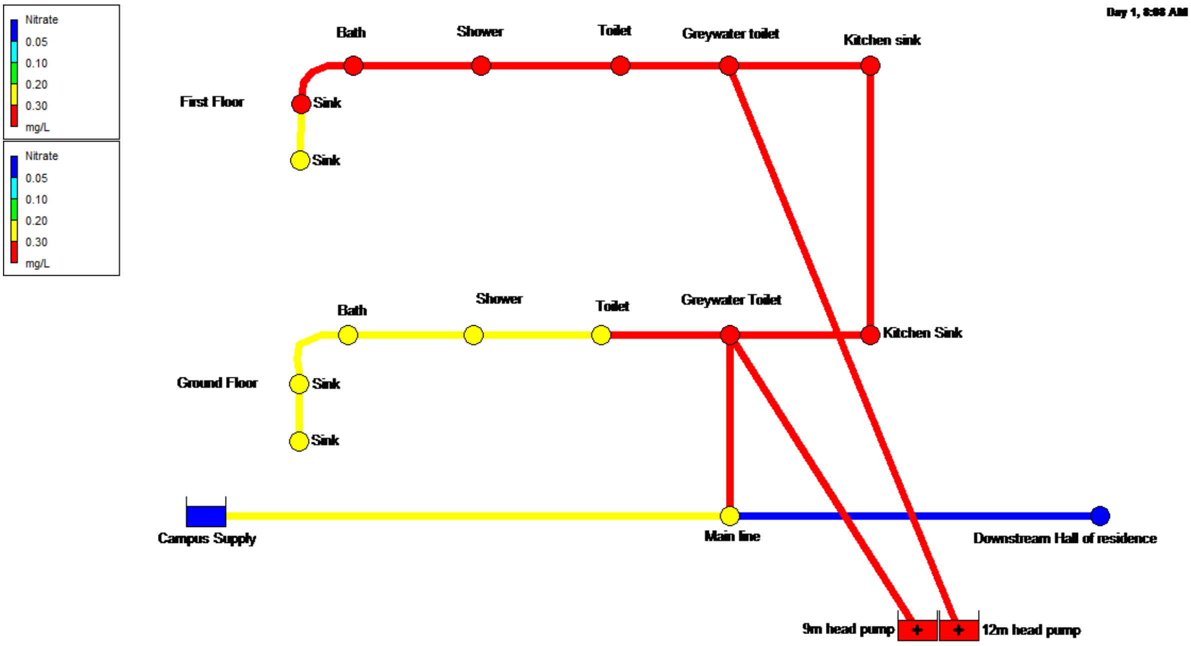


Figure 6.9: Nitrate concentrations at 08h08 of Day 1

Table 6.9: Concentration of phosphorus and nitrate at all network nodes at 08h08 of Day 1

	Elevation	**Base demand**	**Phosphorus**	**Nitrate**
Node Name	**m**	**LPM**	**mg/l**	**mg/l**
Kitchen Sink ground floor	2	0.05	8.89	0.31
Greywater toilet ground floor	2	0.50	8.76	0.31
Normal toilet ground floor	2	0.50	8.38	0.29
Shower ground floor	2	0.40	8.05	0.28
Bath ground floor	2	0.40	7.88	0.28
Sink 1 ground floor	2	0.05	7.68	0.27
Sink 2 ground floor	2	0.05	7.37	0.26
Kitchen Sink 1st floor	5.5	0.05	9.38	0.33
Greywater toilet 1st floor	5.5	0.50	9.89	0.35
Normal toilet 1st floor	5.5	0.50	9.46	0.33
Shower 1st floor	5.5	0.40	9.09	0.32
Bath 1st floor	5.5	0.40	8.90	0.31
Sink 1 1st floor	5.5	0.05	8.68	0.30
Sink 2 1st floor	5.5	0.05	8.32	0.29
Mains	2	0.00	8.30	0.29
Downstream node	2	0.00	0.00	0.00
Resvr Supply	8	#N/A	0.00	0.00
GreyRes9m	9	#N/A	10.00	0.35
GreyRes12m	12	#N/A	10.00	0.35

SCENERIO 2: Varying the time of ingestion.

Phosphorus and nitrate were injected at different times of the day (00h00, 08h00 and 16h00). Figures 6.8, 6.10 and 6.11 were compared to observe how long it took for nitrates to reach the entire network based on different injection times. The results show that when the greywater contaminant was injected at 08h00 of Day 1, it took 7 minutes for nitrate to reach the entire network (Figure 6.8). When injected at 00h00 it took 4hours 32 minutes (Figure 6.10, 6.15(a and b), and 6.16(a and b)) and injection at 16h00 of Day 1, resulted in the entire network being contaminated by nitrate 13 minutes thereafter (Figure 6.11).

In addition, Table 6.10 shows the variation in the quantity of nitrate at each node 8 minutes after injection. The table shows that nitrate reached all fixtures in 8 minutes when injected at 08h00 while injection at 00h00 and 16h00 resulted in no nitrate reaching the ground and first floor sinks after 8 minutes. As mentioned in Scenario 1, the movement of contaminants is a function of the water demand occurring adjacent to the time of injection. Since peak flow occurs between 07h00-09h00, it is expected that the contaminants, in this case nitrate, would spread to the network faster at 08h00 than at 00h00 and 16h00. The same is also true for contaminants reaching the network nodes faster at 16h00 than at 00h00.

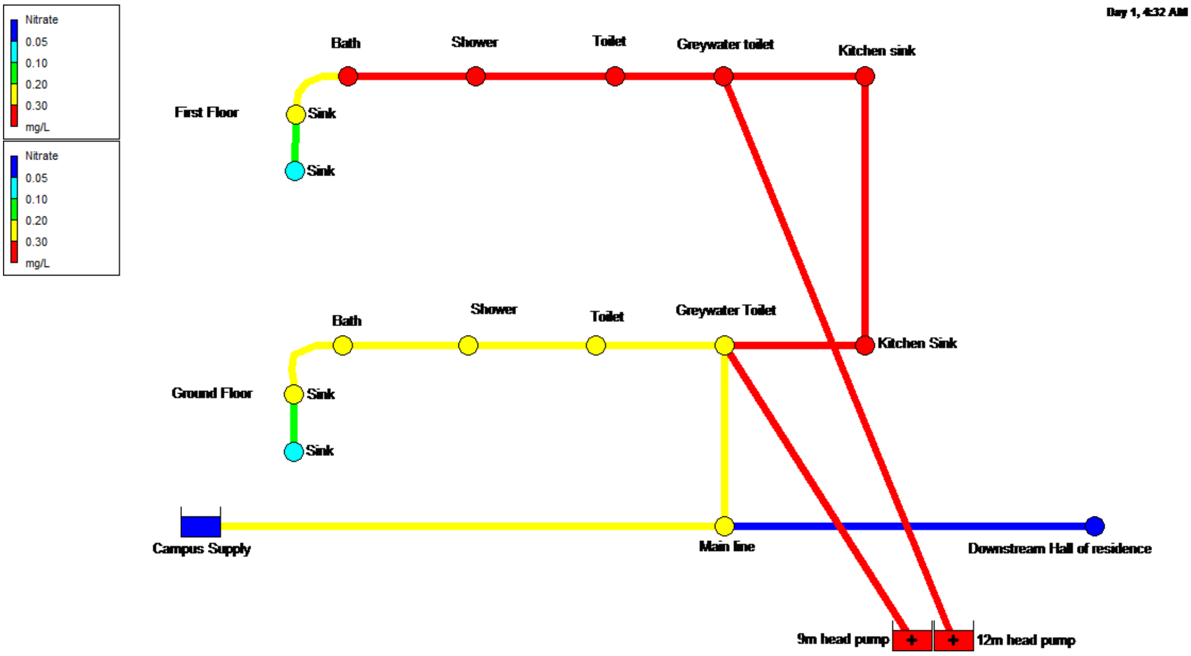


Figure 6.10: Nitrate concentrations at 04h32 of Day 1

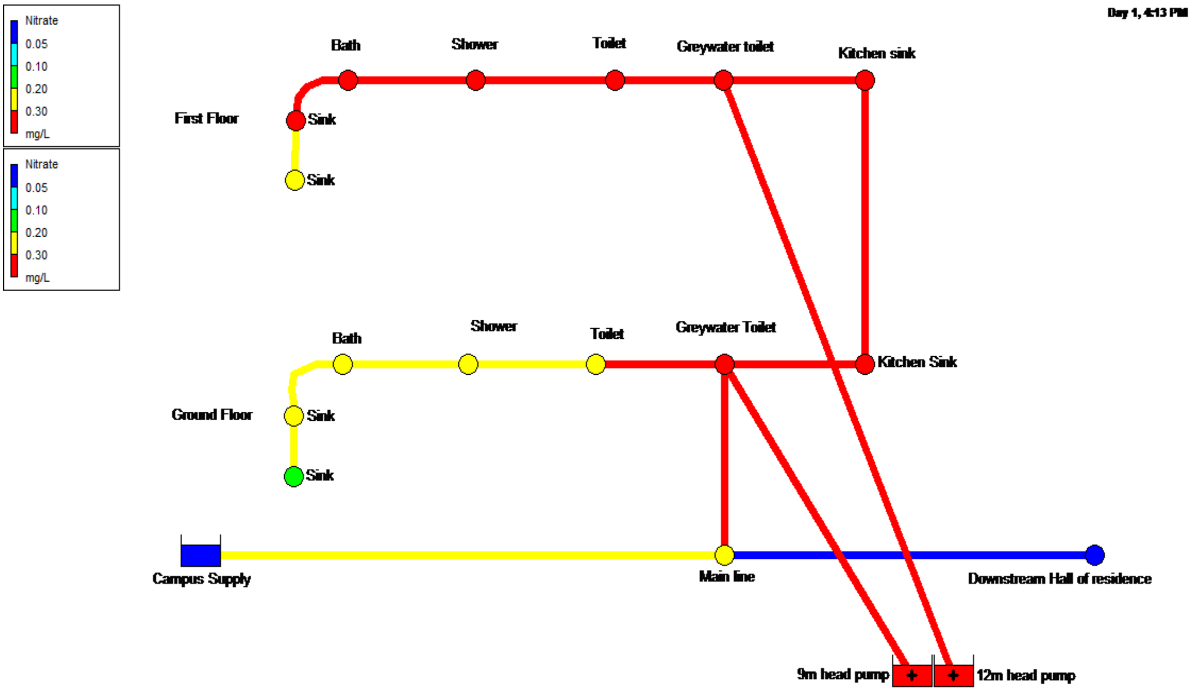


Figure 6.11: Nitrate concentrations at 16h13 of Day 1

Table 6.10: Concentration of Nitrate at all network nodes 8 minutes after injection on Day 1

	Injected at 00h00	Injected at 08h00	injected at 16h00
Node Name	Nitrate mg/l	Nitrate mg/l	Nitrate mg/l
Kitchen Sink ground floor	0.31	0.31	0.31
Greywater toilet ground floor	0.29	0.31	0.30
Normal toilet ground floor	0.00	0.29	0.29
Shower ground floor	0.00	0.28	0.29
Bath ground floor	0.00	0.28	0.28
Sink 1 ground floor	0.00	0.27	0.27
Sink 2 ground floor	0.00	0.26	0.00
Kitchen Sink 1st floor	0.33	0.33	0.33
Greywater toilet 1st floor	0.35	0.35	0.35
Normal toilet 1st floor	0.00	0.33	0.34
Shower 1st floor	0.00	0.32	0.33
Bath 1st floor	0.00	0.31	0.33
Sink 1 1st floor	0.00	0.30	0.31
Sink 2 1st floor	0.00	0.29	0.00
Mains	0.27	0.29	0.29
Downstream node	0.00	0.00	0.00
Resvr Supply	0.00	0.00	0.00
GreyRes9m	0.35	0.35	0.35
GreyRes12m	0.35	0.35	0.35

SCENERIO 3: Varying the point of injection.

The effect of varying the point of injection was studied. Due to the location of the greywater network of pipes within the UJ unit, the only possible locations for a cross-connection with a potable water pipe were just before the greywater toilets. This is because the potable water supply pipes, previously serving the toilets now retrofitted to flush with greywater, were not removed during the implementation of the greywater toilets, but simply disconnected. For this scenario therefore, varying the point of injection could only occur close to the greywater toilets. Hence 3 variations in the point of greywater injection are considered: a cross connection just before the ground floor greywater toilet only (Figure 6.12), a cross connection just before the first floor greywater toilet only (Figure 6.13), and both (Figure 6.14).

Table 6.11 shows that after 1 minutes of greywater injection for each point of injection mentioned above, phosphorus was identified only at the greywater toilet close to the point of injection. However, after 7 minutes of greywater injection, the numbers of nodes affected were then dependent on the location of the point of injection and the number of injection points (see Table 6.12).

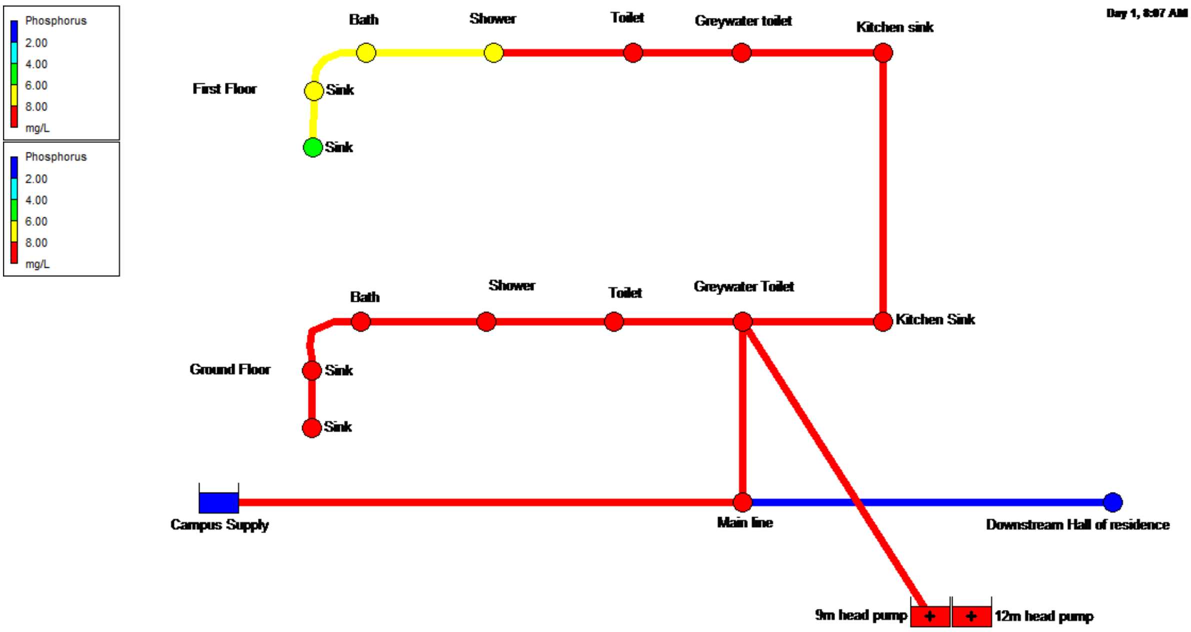


Figure 6.12: Injection of greywater just before the greywater toilet on the ground floor at 00h07 of Day 1

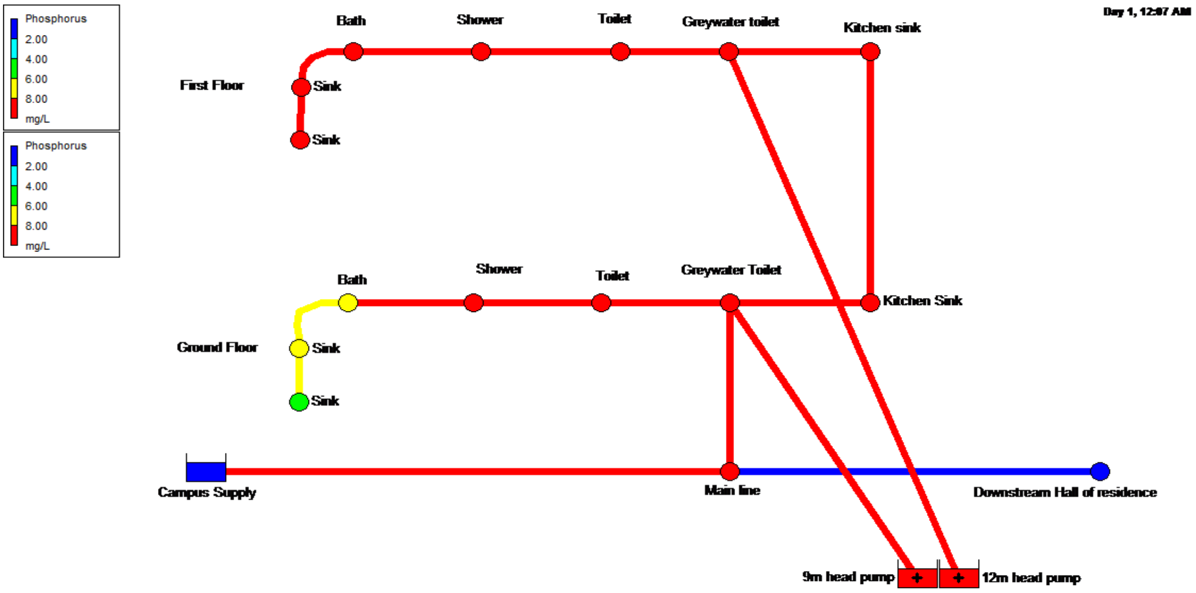


Figure 6.13: Injection of greywater just before the greywater toilet on the first floor at 00h07 of Day 1

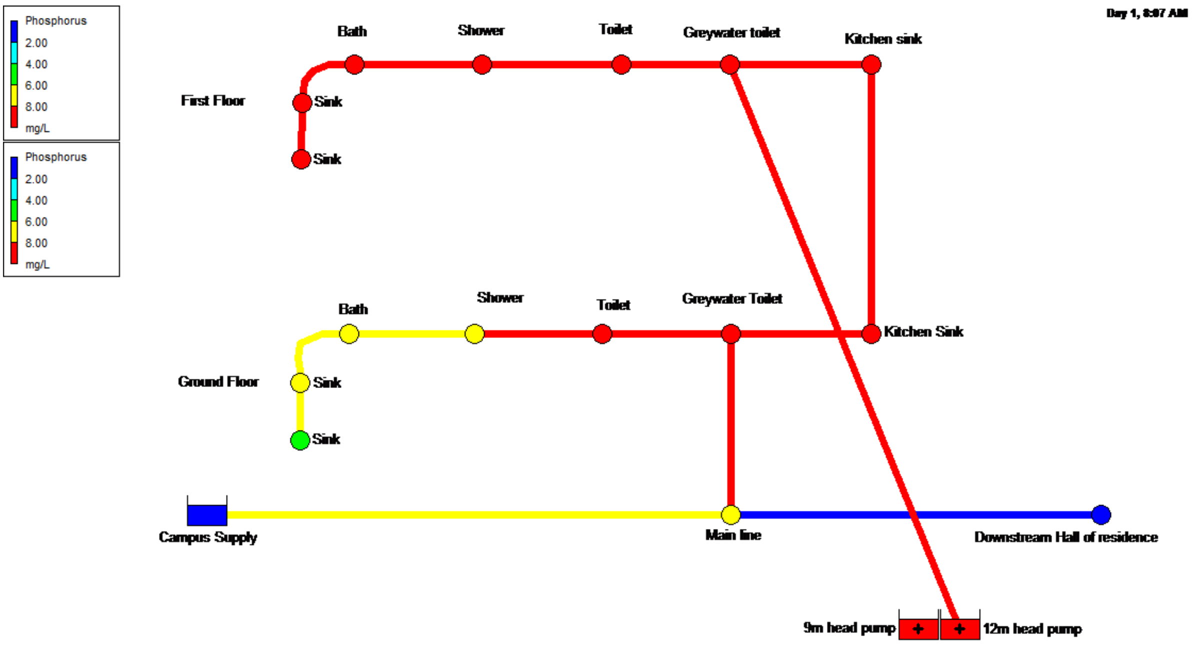


Figure 6.14: Injection of greywater just before the greywater toilet on both floors at 00h07 of Day 1

Table 6.11: Phosphorus at all network nodes based on different points of injection at 00h01 of Day 1

	Base demand	Phosphorus mg/l		
Node Name	**LPM**	**Injected on the ground floor**	**Injected on the 1st floor**	**Injected on both floors**
Kitchen Sink ground floor	0.05	0	0	0
Greywater toilet ground floor	0.50	9.88	0	2.21
Normal toilet ground floor	0.50	0	0	0.05
Shower ground floor	0.40	0	0	0
Bath ground floor	0.40	0	0	0
Sink 1 ground floor	0.05	0	0	0
Sink 2 ground floor	0.05	0	0	0
Kitchen Sink 1st floor	0.05	0	0	9.38
Greywater toilet 1st floor	0.50	0	9.89	9.89
Normal toilet 1st floor	0.50	0	0	9.46
Shower 1st floor	0.40	0	0	0
Bath 1st floor	0.40	0	0	0
Sink 1 1st floor	0.05	0	0	0
Sink 2 1st floor	0.05	0	0	0
Mains	0.00	0	0	0.05
Downstream node	0.00	0	0	0
Resvr Supply	#N/A	0.00	0.00	0.00
GreyRes9m	#N/A	10.00	10.00	10.00
GreyRes12m	#N/A	10.00	10.00	10.00

Table 6.12: Phosphorus at all network nodes based on different points of injection at 00h07 of Day 1

	Base Demand	Phosphorus mg/l		
Node Name	**LPM**	**Injected at ground floor**	**Injected at 1st floor**	**Injected at both floors**
Kitchen Sink ground floor	0.05	9.44	8.88	8.89
Greywater toilet ground floor	0.50	9.88	8.42	8.76
Normal toilet ground floor	0.50	9.46	8.05	8.38
Shower ground floor	0.40	9.08	7.74	8.05
Bath ground floor	0.40	8.89	7.57	7.88
Sink 1 ground floor	0.05	8.67	7.38	7.68
Sink 2 ground floor	0.05	8.31	4.78	5.58
Kitchen Sink 1st floor	0.05	9.01	9.37	9.38
Greywater toilet 1st floor	0.50	8.61	9.89	9.89
Normal toilet 1st floor	0.50	8.23	9.46	9.46
Shower 1st floor	0.40	7.91	9.09	9.09
Bath 1st floor	0.40	7.74	8.90	8.90
Sink 1 1st floor	0.05	7.55	8.67	8.68
Sink 2 1st floor	0.05	4.89	8.32	8.32
Mains	0.00	9.37	7.99	8.30
Downstream node	0.00	0.00	0.00	0.00
Resvr Supply	#N/A	0.00	0.00	0.00
GreyRes9m	#N/A	10.00	10.00	10.00
GreyRes12m	#N/A	10.00	10.00	10.00

SCENERIO 4: Varying the quantity of contaminant injected.

Table 6.13 presents the results obtained due to the variations in quantity of nitrate and phosphorous within the UJ network due to cross-contamination occurring at both the ground and first floor nodes situated just before the greywater toilets. Table 6.13 compares different phosphorus (5mg/l, 10mg/l and 15mg/l) and nitrate (0.18, 0.35 mg/l, 0.51mg/l) quantities at all the network nodes at 08h08 – i.e. 8minutes after injection. This is the time it took for the different quantities of each contaminant to reach all nodes within the network in scenario 1. The results in Table 6.13 show that the higher the quantity of contaminants injected, the higher the quantities reaching each fixture and consequently, the higher the risk of being infected by these contaminants.

Figures 6.15 and 6.16 show the patterns of phosphorus and nitrate concentrations at 4 selected network nodes (first floor greywater toilet, ground floor greywater toilet, sink 2 on the ground floor and sink 2 on the first floor) for scenario 4. The pattern for phosphorus infection is similar to that of nitrate. These figures represent 0.35 mg/l for nitrate and 10mgl/l for phosphorus injected at both ground and first floor nodes.

Table 6.13 Different phosphorus (5mg/l, 10mg/l and 15mg/l) and nitrate (0.18, 0.35 mg/l, 0.53mg/l) quantities injected at both floors at 08h08 on Day 1

	5 mg/l injected at cross-connection	**0.18 mg/l injected at cross-connection**	**10 mg/l injected at cross-connection**	**0.35 mg/l injected at cross-**	**15 mg/l injected at cross-**	**0.53 mg/l injected at cross-connection**
	Phosphorus	**Nitrate**	**Phosphorus**	**Nitrate**	**Phosphorus**	**Nitrate**
Node Name	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**
Kitchen Sink ground floor	4.45	0.16	8.89	0.31	13.34	0.47
Greywater toilet ground floor	4.38	0.16	8.76	0.31	13.14	0.47
Normal toilet ground floor	4.19	0.15	8.38	0.29	12.57	0.44
Shower ground floor	4.03	0.14	8.05	0.28	12.08	0.42
Bath ground floor	3.94	0.14	7.88	0.28	11.82	0.42
Sink 1 ground floor	3.84	0.14	7.68	0.27	11.52	0.41
Sink 2 ground floor	3.69	0.13	7.37	0.26	11.06	0.39
Kitchen Sink 1st floor	4.69	0.17	9.38	0.33	14.07	0.50
Greywater toilet 1st floor	4.95	0.18	9.89	0.35	14.84	0.53
Normal toilet 1st floor	4.73	0.17	9.46	0.33	14.19	0.50
Shower 1st floor	4.55	0.16	9.09	0.32	13.64	0.48
Bath 1st floor	4.45	0.16	8.90	0.31	13.35	0.47
Sink 1 1st floor	4.34	0.15	8.68	0.30	13.02	0.45
Sink 2 1st floor	4.16	0.15	8.32	0.29	12.48	0.44
Mains	4.15	0.15	8.30	0.29	12.45	0.44
Downstream node	0.00	0.00	0.00	0.00	0.00	0.00
Resvr Supply	0.00	0.00	0.00	0.00	0.00	0.00
GreyRes9m	5.00	0.18	10.00	0.35	15.00	0.53
GreyRes12m	5.00	0.18	10.00	0.35	15.00	0.53

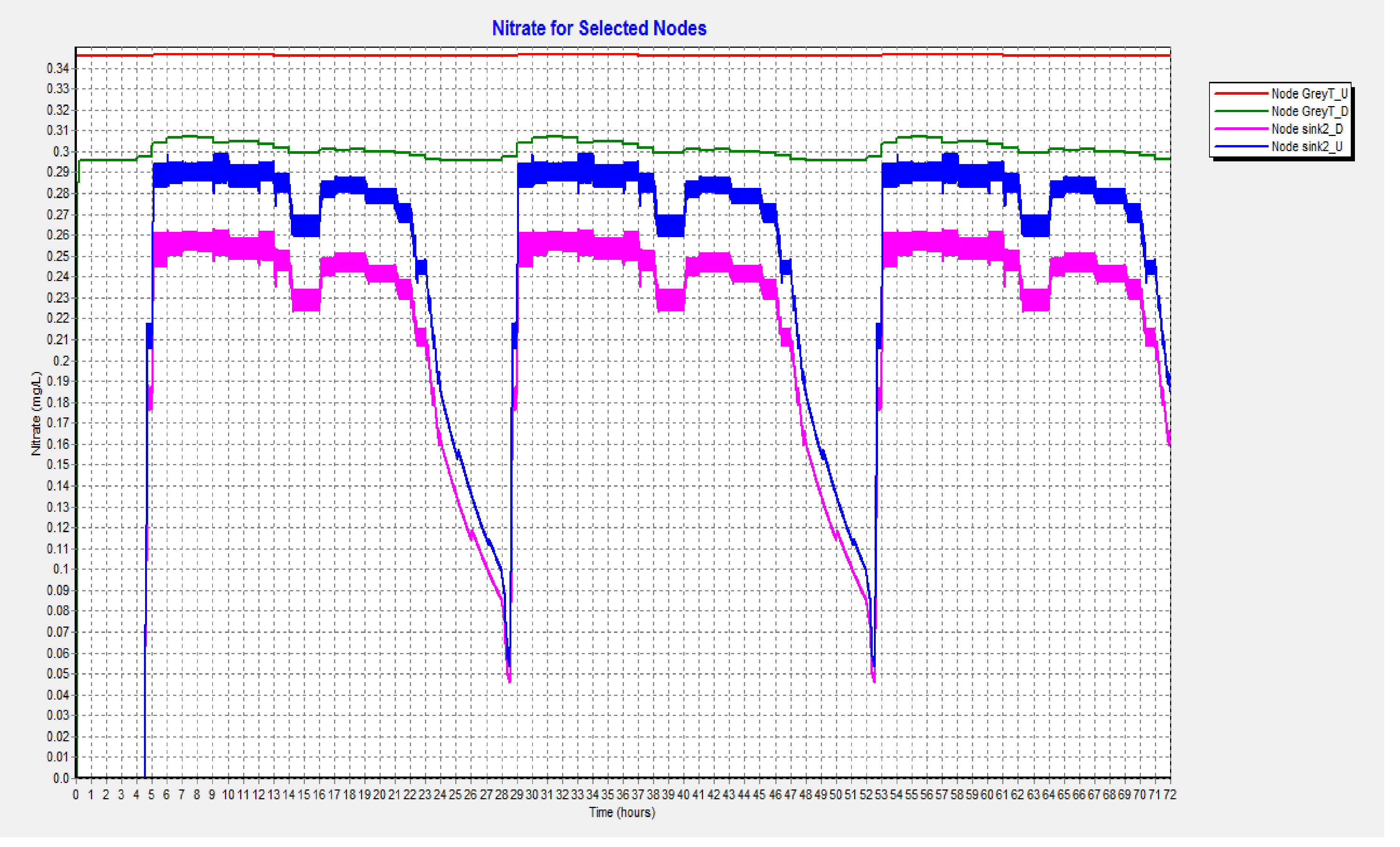


Figure 6.15a: A time series plot at 4 selected nodes when 0.35mg/l of nitrate was injected at the ground and first floor cross-connections at 00h00

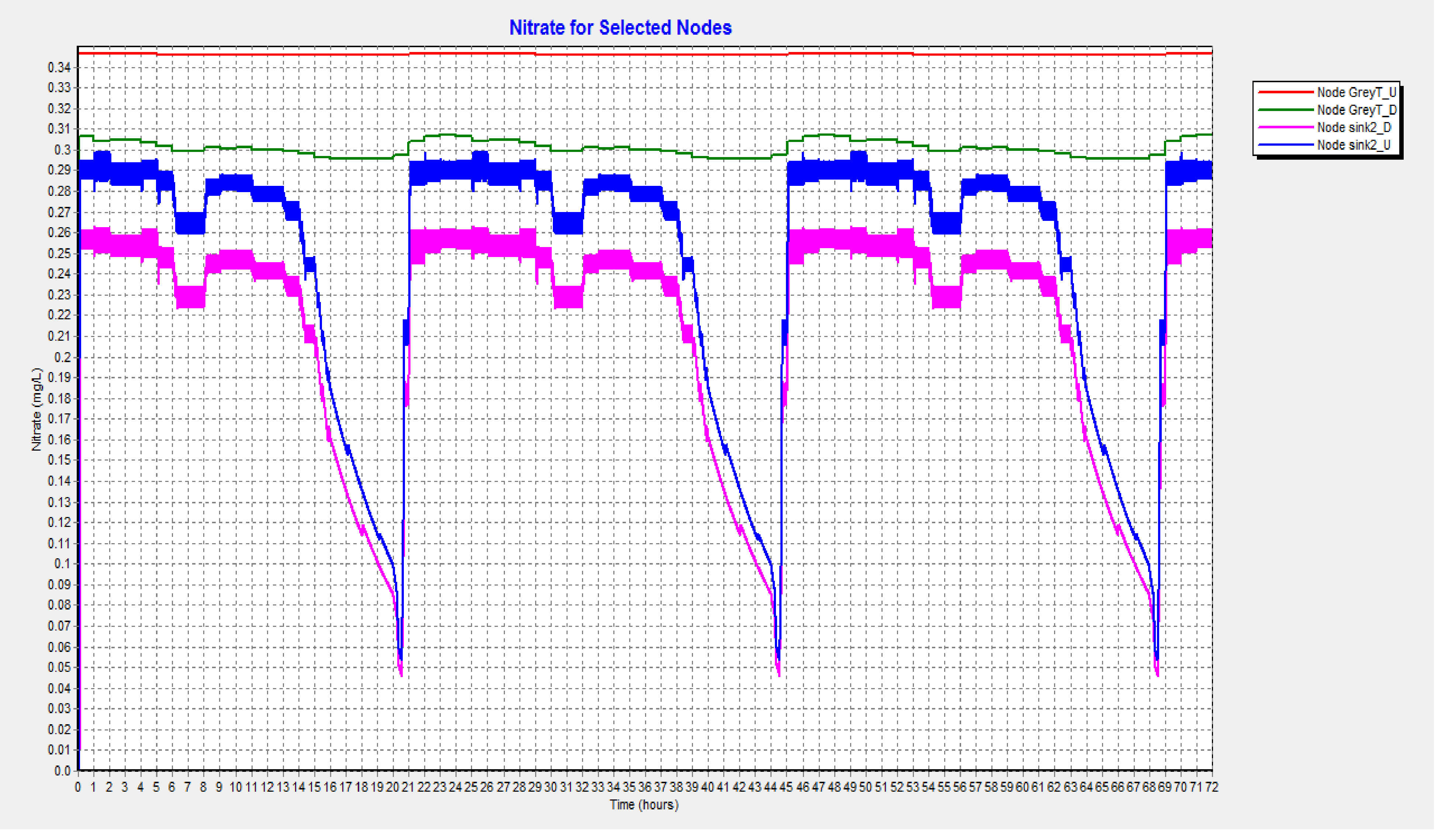


Figure 6.15b: A time series plot at 4 selected nodes when 0.35mg/l of nitrate was injected at the ground and first floor cross-connections at 08h00

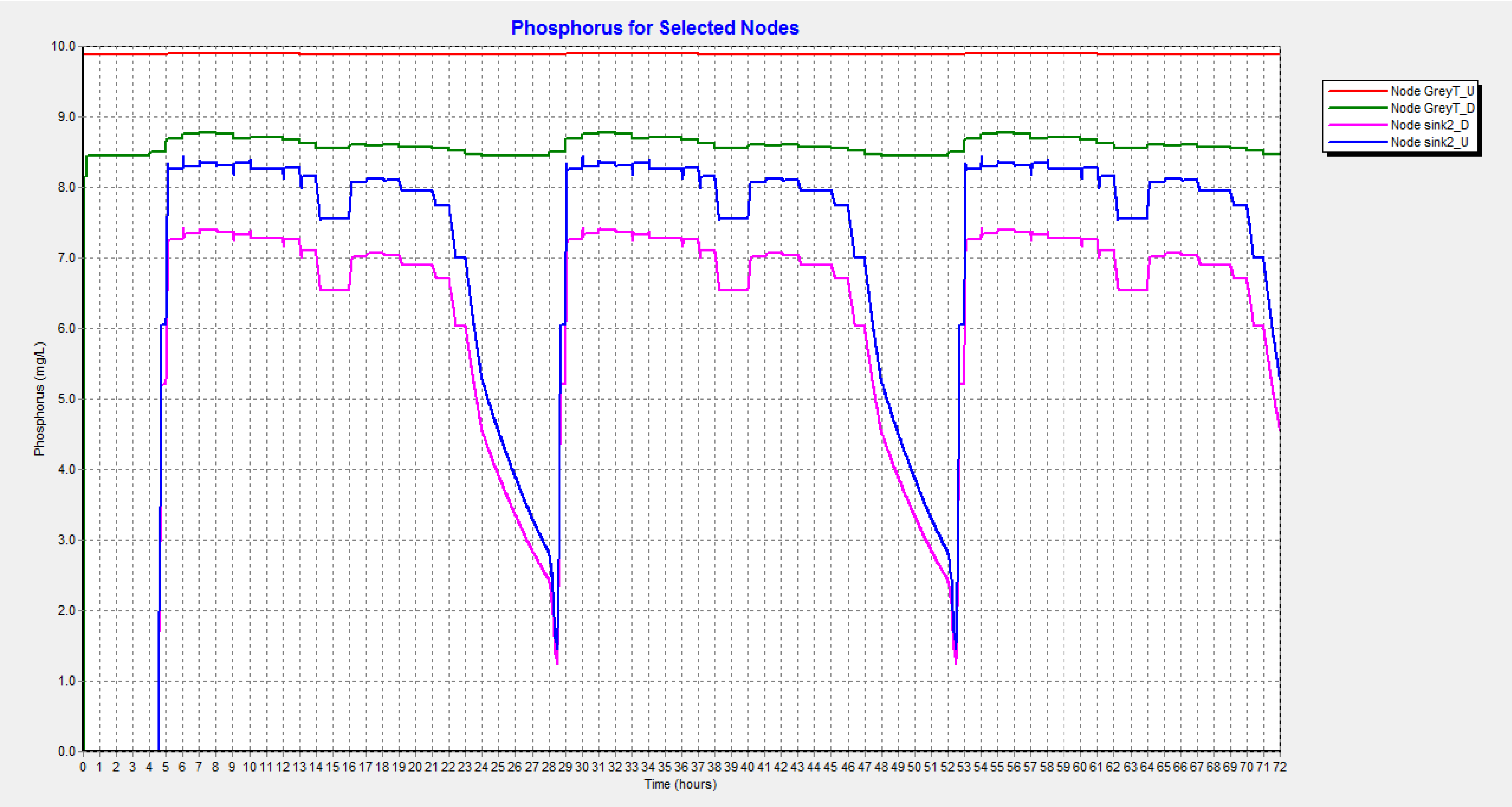


Figure 6.16a: A time series plot at 4 selected nodes when 10mg/l of phosphorus was injected at the ground and first floor cross-connections at 00h00

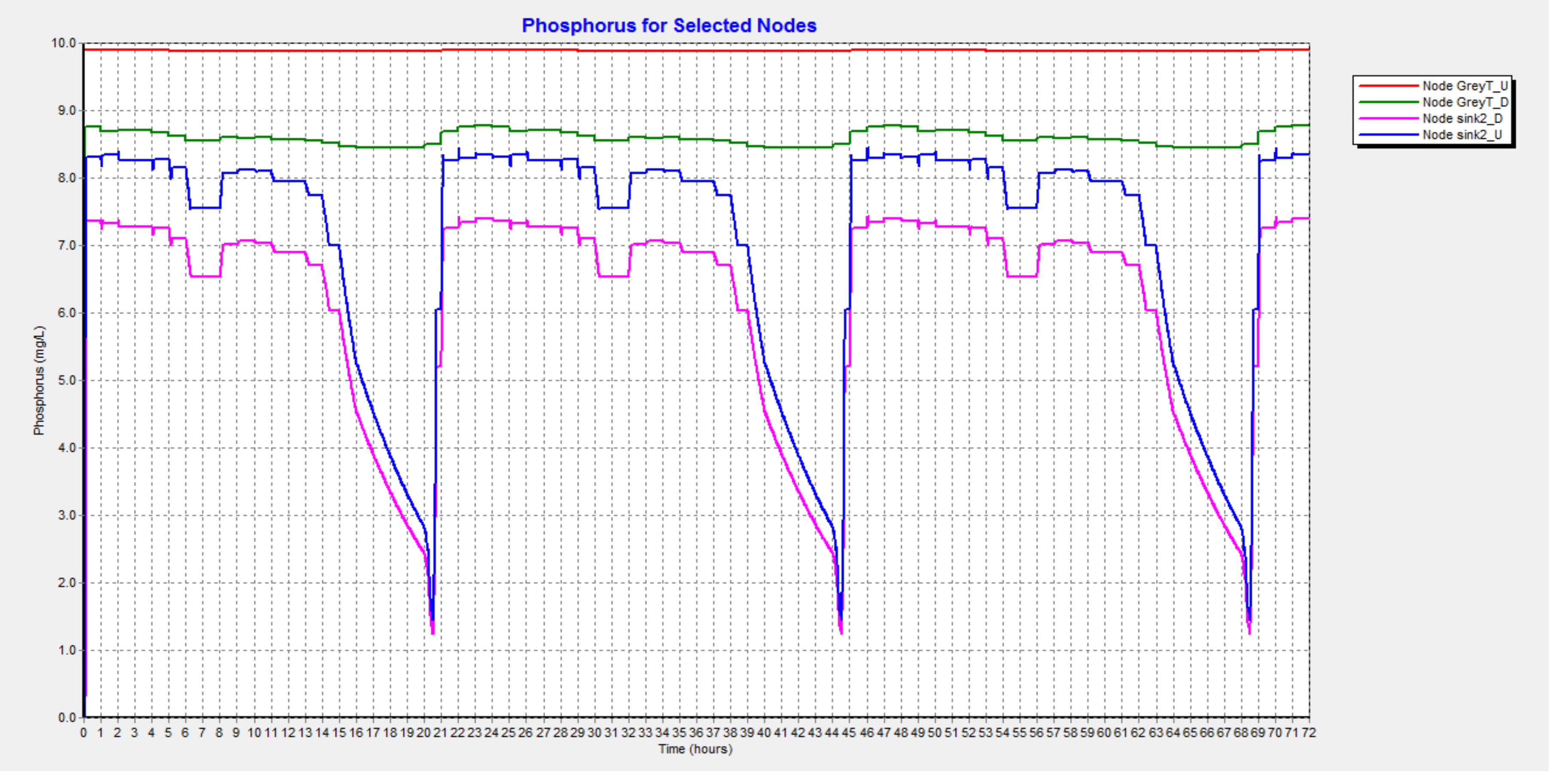


Figure 6.16b: A time series plot at 4 selected nodes when 10mg/l of phosphorus was injected at the ground and first floor cross-connections at 08h00

6.10 Summary

This exercise was undertaken in order to simulate the movement of nitrates and phosphorus within a residential potable water network and to investigate the degree of human exposure to varying quantities of these contaminants. This investigation was carried out using the EPANET-MSX programme. Due the volume of data from the simulation, the detailed results of the MSX report have been included in the Appendix E3 of this report. Key highlights from the scenarios investigated above include the following:

1. The movement pattern for phosphorus is similar to that of nitrate as can be seen in the time series (Figure 6.15 and 6.16) for both contaminants. These figures represent the injection of 0.35 mg/l for nitrate and 10mgl/l for phosphorus at both ground and first floor cross-contaminant nodes. Hence, the pattern of infection at each fixture is the same except for the difference in quantity injected for both nitrate and phosphorus;
2. It took less than 1 minute for nitrate to reach the greywater toilets when injected at 08h00. This result was compared to the real situation and it was observed that after a bell push for toilet flush, it takes less than 1 minute (btw 10-40 seconds) for the greywater to get to the greywater toilets (Figure 6.7);
3. The movement of contaminants is affected by the demand pattern of the users. Thus, if a contaminant is injected prior to or during a peak period, the contaminant is certain to reach all the water use fixtures and at a shorter space of time i.e. in minutes or seconds depending on the size of the network. When the greywater contaminant was injected at 08h00 (during the first and highest peak period of Day 1), it took 1 minute for nitrate to reach the entire network (Figure 6.8). This is in comparison to injection at 00h00 which reached the entire network in 4hour 32 minutes (Figure 6.9) and injection at 16h00 which reached the entire network in 13 minutes (Figure 6.10);
4. The quantity of contaminants measured at each fixture ranged from 0.13 mg/l to 0.53 mg/l for nitrate and 0.05 mg/l to 14.84 mg/l for phosphorus based on the smallest to the largest injections of nitrate (0.18-0.53 mg/l) and phosphorus (5-15 mg/l) expected within greywater of this kind (sieved and disinfected bath and shower greywater) injected at the 3 investigated cross-connection nodes;
5. The risk of contaminant ingestion is directly proportional to the distance from the point of injection. Results from the figures above, show that the sinks which are the furthest fixtures from the point of injection were always the least affected. Hence, the

further the fixture is from the point of injection, the less affected a person using that end use will be during a contamination event;

6. The degree of human exposure to the contaminants was directly dependent on the demand occurring adjacent to the period of ingress. In Scenario 1, over 70% of the total nitrate load was directed to the 2 toilets which flush with potable water. This was likely as a result of the proportionally larger demand for toilet flushing in comparison to other potable water uses occurring after the greywater ingress;
7. The health risk associated with the contaminant ingress in this network is dependent on the concentration of nitrate and phosphorus injected. With the injection of 0.35 mg/l of nitrate and 10 mg/l of phosphorus from the sieved and disinfected bath and shower greywater, results show that the largest concentration of nitrate within the potable network, posed an insignificant health risk according to SANS 0241 (SABS 241-2001) which specifies nitrate concentrates of higher than 10mg/l as harmful to human health. For phosphorus, no standards exist in SANS 0241 (SABS 241-2001) and hence, the results obtained for phosphorus in the simulation could not be benchmarked.

The EPANET-MSX tool presented in this section is valuable in simulating greywater contamination events within potable water piped networks. The results in the different simulation above show that the typical maximum concentrations of nitrates and phosphorus in sieved and disinfected bath and shower greywater, do not posed a significant risk to human health if ingested. However, standard precautions must be adhered to in the use of the greywater toilets and maintenance of the GWR system e.g. the use of more natural soap products that contain less chemical constituents, hand washing after toilet use, dropping the greywater toilet seat cover before flushing, and proper labelling of the greywater system.

CHAPTER 7

SUMMARY, CONCLUSION AND RECOMMENDATIONS

7.1. Thesis summary

The reuse of greywater for toilet flushing has the potential to reduce urban potable water demand used for toilet flushing, fire fighting and irrigation by between 30 - 70% (Radcliffe, 2003). GWR is one of many water management concepts with the potential to reduce urban potable water use and increase appropriate water use. Yet, there is limited GWR in several parts of the world and especially in South Africa. This is as a result of some of the risks/barriers identified in the literature and perception surveys such as the absence of regulations to guide GWR implementation and management, determination of appropriate technology, economic viability, potential risks to human health and public perceptions regarding GWR.

The aim of this thesis was to develop and implement integrated risk management in the implementation of dual grey and potable water reticulation systems in South Africa. The objectives of this study were:

1. To monitor the evolving perceptions of users towards GWR for toilet flushing in high-density urban buildings before and after the implementation of GWR.
2. To estimate toilet flushing water consumption in high density urban buildings and develop a model for predicting this demand.
3. To develop and apply a robust framework for evaluating available package plants for GWR for toilet flushing.
4. To investigate the economic viability of the implemented pilot GWR systems.
5. To model and simulate the transport of contaminants (specifically nitrate and phosphorus) within a dual grey and potable water reticulation system. In doing so, to investigate the degree of human exposure to these contaminants at various times of the day, due to varying contaminant quantities, and at different injection points.

The above objectives, and hence original contributions of this thesis were achieved in the following chapters:

The third chapter focused on identifying, assessing, and quantifying potential health risks associated with the implementation of GWR for toilet flushing and developing a framework for mitigating some of these risks. This was achieved by employing the elements of risk assessment. The integrated risk management framework developed was based on various frameworks that have been proposed in the literature i.e. The World Health Organisation (2006), The United States Environmental Protection Agency, USEPA (2005), Canada Health (2010) and the Australian guidelines, NRMMC-EPHC (2006). This chapter therefore involved documenting the different risk management frameworks listed above and identifying the similar measures employed which were incorporated into the framework developed for this study.

Chapter four reports on the social measures that were implemented to manage and therefore mitigate the risks associated with the implementation of GWR for toilet flushing at the pilot sites. These measures were: (i) the evaluation of perception surveys carried out on potential and actual beneficiaries of GWR for toilet flushing; (ii) public awareness and involvement and; (iii) an analysis of the attributes that were important to beneficiaries regarding GWR and understanding the willingness of beneficiaries to pay for some of this attributes. The above measures involved designing, administering, collecting and coding the questionnaires used to determine perceptions; regular community engagement; a review of the analytical methods available to analyse perceptions and selection of a suitable method; and modelling the factors that influence the attitudes of respondents to some attributes of greywater using conjoint analysis. The following are some of the most significant findings of this chapter: (i) The level of trust in implementing authorities at both universities was high (above 64%). There was thus a reduction in concern levels at both universities to the potential risks of GWR. The high level of trust was built as the project team regularly held awareness sessions with respondents, and conducted routine maintenance and water quality tests to ensure that the greywater systems were safe and hygienic for their use; (ii) Respondents generally viewed a pleasant smell as the most important attribute of the greywater. Second to smell was the colour of greywater. Hence, respondents were rather willing to spend about double the amount of money needed to improve the colour on the smell of the greywater.

Chapter five focused on the technical and economic measures put in place to manage and therefore mitigate the risks of failure associated with the implementation of GWR for toilet flushing. The chapter documents the development of a framework for evaluating locally available greywater treatment package plants using sustainability criteria and thus mitigating the risk of choosing the wrong system for a specific reuse application. The chapter also documents the development of a model to predict toilet flushing demand within non-residential buildings, and the analysis of the economical viability of the pilot GWR systems using cost benefit analysis. In addition to the toilet flushing estimation model and greywater selection framework developed above, the following are some significant findings in this chapter: (i) there are no simple formulas for selecting a package plant because of the trade-offs that need to be made between the three key issues i.e. technical, economics and public health; (ii) The results of the cost-benefit analysis for WITS and UJ greywater reuse systems shows payback periods of 18 years and longer than 20 years respectively. For both systems, Benefit-Cost ratios were less than 1 and NPVs were less than R0.00. These results therefore generate a net economic loss and are economically infeasible if beneficiaries are to pay the full costs of the systems; (iii) Cost is directly related to the treatment technology employed and hence, the more complex the treatment process, the more likely the package plant will be more expensive; (iv) the factors influencing toilet flushing water demand at WITS (and likely typical of academic buildings) were bulk water demand, rainfall, maximum and minimum temperature. The developed model can therefore be reliably used to estimate toilet flushing demand within the School of Civil and Environmental Engineering, WITS based on these 4 independent variables and hence, would be valuable in estimating toilet flushing demand in the event that a GWR system for toilet flushing is being planned for all toilets within the building.

Chapter six reports on a measure employed to mitigate some of the risks associated with public health and safety while employing GWR via dual reticulation i.e. the modelling of greywater contaminant transport (specifically nitrate and phosphorus) within potable water networks due to accidental or deliberate ingress. Some key results that emerged from the modelling and simulation exercise were (i) the degree of human exposure to the contaminants was directly dependent on the demand occurring adjacent to the period of ingress; (ii) based on the typical quantities of nitrate and phosphorus in shower and bath greywater which has been sieved and disinfected with chlorine, there is an insignificant immediate risk to human health from ingestion of these contaminants (SABS 241, 2001); (iii) the risk of contaminant ingestion is directly proportional to the distance from the point of injection; and (iv) the movement of contaminants is affected by the demand pattern of the users. Thus, if a contaminant is injected prior to or during a peak period, the contaminant is certain to reach all the water use fixtures and at a shorter space of time i.e. in minutes or seconds depending on the size of the network. Despite the low risks emerging from the above analysis, it is expedient that standard precautions be observed in the use of the greywater toilets and maintenance of the GWR system e.g. the use of more natural soap products that contain less chemical constituents, hand washing after toilet use, dropping the greywater toilet seat cover before flushing, and proper labelling of the greywater system.

7.2. Conclusion

This section concludes with reference to the aim and objectives of this study which validate the original contribution of this thesis:

The aim of this thesis was to develop and implement integrated risk management in the implementation of dual grey and potable water reticulation systems in South Africa. The development of the integrated risk management measure was achieved through extensive literature survey reported in Chapters 3 with the development of a robust framework employed in developing a valuable tool used to assess and manage risks relating to greywater reuse for toilet flushing. The original contributions of this thesis focused on certain technical and economic, social, and environmental risk management measures that were investigated, developed and/or implemented in Chapters 4, 5 and 6 with respect to the objectives of the study. The objectives of this study were:

1. To monitor the evolving perceptions of users towards GWR for toilet flushing in high-density urban buildings before and after the implementation of GWR. This was achieved in Chapters 4 with an increase in level of respondents' trust and confidence in the GWR implementing team, and the understanding of important attributes (i.e. pleasant smell, colour and tariff) that required critical attention.
2. To estimate toilet flushing water consumption in high density urban buildings and develop a model for predicting this demand. This was achieved in Chapters 5 under technical and economic measures with the development of a model to predict toilet flushing demand. This model (Equation 5.1) will be valuable to scientifically determine the step by step toilet flushing demand within a facility as long as bulk water and climatic data are available (i.e. toilet flushing, bulk water demand, rainfall, maximum and minimum temperatures.
3. To develop and apply a robust framework for evaluating available package plants for GWR for toilet flushing. This was achieved in Chapters 5 under technical and economic measures to risk management and it brought about an holistic and

appropriate selection approach for locally available GWR plants specifically, for toilet flushing.

4. To investigate the economic viability of the implemented pilot GWR systems. This was achieved in Chapters 5.
5. To model and simulate the transport of contaminants (specifically nitrate and phosphorus) within a dual grey and potable water reticulation system. In doing so, to investigate the degree of human exposure to these contaminants at various times of the day, due to varying contaminant quantities, and at different injection points. This was achieved in Chapters 6 and it addresses the movement of contaminants within a residential building and risks associated with greywater ingress. It also presents the use of a valuable modeling tool (EPANET-MSX) that can be used in simulating multiple greywater contamination events within potable water piped networks.

7.3 Limitations of the research

The following are the limitations of the developed risk management measures:

1. Experimental work was not carried out to characterize and understand the behaviour of chemicals in the water before the implementation of the modelling exercise. Also, the validations of the results at each node were not carried. In future, a pilot-scale distribution system simulator (DSS) could be developed so as to understand and monitor the movement and behaviour of contaminants so as to be able to compare the model's results with real life situations.
2. The willingness to pay for greywater was not compared at both pilot sites (UJ and WITS). This due to the fact that WITS it is an academic institution where students do not pay for municipal services. A comparison of both pilot sites could provide useful information in terms of similarities and difference in their choice of attributes of importance and the willingness to pay for the attributes.
3. The scientific monitoring of the impact of awareness raising activities were not carried out. If the impact could be scientifically monitored, it will be a major contribution.
4. The framework did not include the direct assessment of energy conservation and reductions in greenhouse gas emissions as part of the technology evaluation criteria. Owing to current policies on energy conservation and reductions in greenhouse gas emissions, this additional criterion is a major way of determining if a treatment technology is sustainable.

7.4 Recommendations

Listed below are a number of recommendations proffered based on the experiences garnered in this research:

a) The results presented in Chapter 5 show that the cheapest GWR system employed in both pilot sites is economically not viable. Respondents in the study conducted by Ilemobade et al. (2009a) generally expect to pay less for non-potable water reuse since the non-potable water is considered to be of a lesser quality than potable water. Hence, initial and recurrent costs can be reduced by considering the following initiatives: (i) Encouraging economies of scale in GWR by including more toilets into the GWR project. More toilets would use more greywater for toilet flushing and hence, save more potable water and significantly reduce sewage treatment costs; (ii) Incorporating the implementation of GWR into the design and construction of new buildings will significantly reduce retrofitting costs; (iii) Encouraging GWR through government incentives or subsidies especially amongst large consumers of greywater; and (iv) Many GWR initiatives, similar to the pilot projects implemented in this study, utilised electrical energy to pump the greywater to the point of use. Investigating alternative and cheaper sources of energy for the pumps would contribute to reducing recurrent costs.

b) Experiences from Chapter 4 indicate that informed and engaged beneficiaries strengthened the levels of trust and confidence bestowed on the project team. This was enhanced by providing accurate information to and involving beneficiaries from the onset of the project (i.e. prior to implementation) right through to several months after implementation. It is however expected, that even with the most comprehensive of educational programmes and assurances, there may still be potential beneficiaries who will have misgivings and be opposed to the use of greywater. Future GWR initiatives must therefore give attention to this.

c) Public acceptance of GWR has been shown to be highest for the end uses requiring the least human contact such as toilet flushing and landscape irrigation. Therefore future GWR initiatives should firstly focus on these and similar end uses.

d) It would be interesting and valuable to investigate the downstream impacts of GWR such as on sewer flows (i.e. GWR potentially reduces sewer flows and hence may negatively impact on the minimum flows expected to ensure sewage is conveyed downstream) and on sewage treatment (i.e. large scale GWR may introduce larger chemical quantities such as are used for disinfection and coagulation and hence, unduly increase the chemical loading conveyed to sewage treatment works).

e) An investigation into the monitoring of greywater quality from point of generation to point of use would be valuable to further determine the specific risk to potential users of GWR systems. Monitoring of greywater quality would also assist in ascertaining that the greywater output quality is fit for use; Regulations regarding GWR for non-potable end uses are non-existent in South Africa (Ilemobade et al., 2009a). The development of a national regulatory document or guideline would be valuable in guiding decision-making during the planning, implementation, operation and management of GWR and in the protection of human health.

f) This study attempted to develop a model that can be used to predict toilet flushing but instead of predicting it, the study could only estimate toilet flushing demand based on historical demands. It would be interesting to consider other parameters such as frequency of use, flush volume, day of the week, month of the year in future research so as to see if they can be used to develop a predictive model for toilet flushing demand.

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APPENDIX A. PERCEPTION SURVEY QUESTIONNAIRES

APPENDIX A1. PERCEPTION SURVEY QUESTIONNAIRE 1 ADMINISTERED PRIOR TO AND IMMEDIATELY AFTER THE 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** – waste water originating from showers, baths, laundry tubs and washing machines
- **Treated greywater** – greywater that has passed through some processes to remove impurities (e.g. soaps & dirt). Treated greywater can be safely used to satisfy some water requirements (e.g. toilet/urinal flushing).
- **A dual water distribution system** – separate pipes with different colours supplying drinking water and treated greywater to a building for drinking and non-drinking (e.g. toilet/urinal flushing) water requirements respectively.

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 A2. PERCEPTION SURVEY 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** – waste water 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 grey water 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 A3. PERCEPTION SURVEY QUESTIONNAIRE 3 ADMINISTERED ABOUT 7 MONTHS AFTER GREYWATER SYSTEM IMPLEMENTATION

UNIVERSITY OF JOHANNESBURG

UNIVERSITY OF CAPE TOWN
IYUNIVESITHI YASEKAPA • UNIVERSITEIT VAN KAAPSTAD

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** – waste water 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.

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 (50%)**	**1 out of 4 times (25%)**	**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**	

1. 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 A4. PERCEPTION SURVEY QUESTIONNAIRE 4 ADMINISTERED ABOUT 14 MONTHS 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 flushing and (ii) willingness to use a greywater reuse system for toilet flushing. Your responses will be confidential.

DEFINITIONS:

- **Greywater** – waste water 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.

10. 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 (50%)**	**1 out of 4 times (25%)**	**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**	

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

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

13. Current status ☐ 1st year ☐ 2nd year ☐ 3rd year ☐ 4th year ☐ ___ year

☐ Postgraduate ☐ Academic staff ☐ Support staff

14. Living in university residence? (**for students only**) ☐ Yes ☐ No
15. Gender ☐ Male ☐ Female
16. Racial category ☐ Black ☐ White ☐ Asian ☐ Coloured
17. Your current university ☐ WITS ☐ UJ ☐ UCT

Section B

18. The table below is a list of 12 different combinations of greywater attributes based on colour, odour and price (as a percentage of prices of drinking water). Kindly rank all this attributes by placing a rating from 1(least desirable) to 10 (most desirable) in this table.

S/N	**Colour**	**Odour**	**Price per M^3 (as a% of cost of drinking water)**	**Preferences**
1	Greyish colour	Odourless	50	
2	Greyish colour	Odourless	75	
3	Greyish colour	Odourless	100	
4	Greyish colour	Unpleasant smell	50	
5	Greyish colour	Unpleasant smell	75	
6	Greyish colour	Unpleasant smell	100	
7	Blue colour	Unpleasant smell	50	
8	Blue colour	Unpleasant smell	75	
9	Blue colour	Unpleasant smell	100	
10	Blue colour	Odourless	50	
11	Blue colour	Odourless	75	
12	Blue colour	Odourless	100	

Note
Greyish colour (original colour of greywater something milky with foams)
Blue colour (use of cistern blocks that changes the colour to blue)
Odourless (it can be chlorine smell or slight freshened smell)

Thank you for your time and input

APPENDIX A5. PERCEPTION SURVEY QUESTIONNAIRE CODING

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** – waste water originating from showers, baths, laundry tubs and washing machines
- **Treated greywater** – greywater that has passed through some processes to remove impurities (e.g. soaps & dirt). Treated greywater can be safely used to satisfy some water requirements (e.g. toilet/urinal flushing).
- **A dual water distribution system** – separate pipes with different colours supplying drinking water and treated greywater to a building for drinking and non-drinking (e.g. toilet/urinal flushing) water requirements respectively.

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 (1)	Agree (2)	Neutral (3)	Disagree (4)	Strongly disagree (5)
1.1	Using treated greywater for toilet/urinal flushing or garden watering will have a positive impact on the environment					
1.2	Using treated greywater for toilet/urinal flushing or garden watering will make our limited drinking water resources go further					
1.3	I am comfortable using treated greywater for toilet/urinal flushing					
1.4	I am comfortable using treated greywater for garden watering					
1.5	I am comfortable using treated greywater originating from **other** buildings for toilet/urinal flushing or garden watering					
1.6	I am concerned about people getting sick from using treated greywater for toilet/urinal flushing					
1.7	I am concerned about people getting sick from using treated greywater for garden watering					
1.8	Using treated greywater for toilet/urinal flushing or garden watering is disgusting					
1.9	I will only be prepared to use treated greywater for toilet/urinal flushing or garden watering during a drought or water shortage					
1.10	I am comfortable for a dual water distribution system to be installed where I currently reside					
1.11	**STATEMENT BELOW FOR STUDENTS & STAFF AT THE SCHOOL OF CIVIL AND ENV ENGINEERING ONLY:** I am comfortable for a dual water distribution system to be installed at the School building					
1.12	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					

2.0 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.

3.0 Age bracket	1 ☐ 15-18	2 ☐ 19-21	3 ☐ 22-25	4 ☐ 26-35	5 ☐ 36-45	6 ☐ Above 45
4.0 Current status	1 ☐ 1st year	2 ☐ 2nd year	3 ☐ 3rd year	4 ☐ 4th year	5 ☐ ___ year)	9 ☐ Undergrad *
	6 ☐ Postgraduate		7 ☐ Academic staff		8 ☐ Support staff	
5.0 Living in university residence? (**for students only**)			1 ☐ Yes	2 ☐ No		
6.0 Gender	1 ☐ Male	2 ☐ Female				
7.0 Racial category	1 ☐ Black	2 ☐ White	3 ☐ Asian	4 ☐ Coloured		

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

9.0 Your current university 1 ☐ WITS 2 ☐ UJ 3 ☐ UCT

Thank you for your time and input

Please return this questionnaire to *The assigned collection box, The Interviwer, Dr. A Ilemobade. Email:Adesola.Ilemobade@wits.ac.za.* ***OR*** *Mr. Olawale Olanrewaju. Email:Olawale.Olanrewaju@students.wits.ac.za. Cell: 079 900 7931. Fax: 011 717 7045*

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APPENDIX B: LOCALLY AVAILABLE ON-SITE GREYWATER TREATMENT UNITS FOR TOILET FLUSHING AND INTERNATIONAL GUIDELINES FOR ON-SITE GREYWATER TREATMENT UNITS

APPENDIX B2: LETTER DRAFTED TO EXPLAIN THE PROJECT AND REQUEST PLANT SPECIFIC INFORMATION USING A QUESTIONNAIRE

Date

Address

Dear Sir/Madam,

DEVELOPMENT OF A FRAMEWORK FOR SELECTING WASTEWATER 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 wastewater treatment package plants 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 wastewater treatment package plants, we would appreciate if you would provide us with details of one or more of your package plants that may be used in producing treated effluent for toilet flushing. The table below may be used as a guide. We believe this framework will be of benefit to your organisation as details of your plant(s) will be published in our final report and this will assist in the publicity of your plant(s).

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*** *– waste water originating from showers, baths, laundry tubs and washing machines*
- ***Treated greywater*** *– greywater that has passed through some processes to remove impurities (e.g. soaps & dirt). Treated greywater can be safely used to satisfy some water requirements (e.g. toilet/urinal flushing).*
- ***A dual water distribution system*** *– separate pipes with different colours supplying drinking water and treated greywater to a building for drinking and non-drinking (e.g. toilet/urinal flushing) water requirements 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="3">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>
</table>

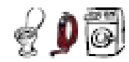
	Chemical quality	
	pH	
	Chemical Oxygen Demand (mg.ℓ-1)	
	Biochemical Oxygen Demand (mg.ℓ-1)	
	Ammonia (mg.ℓ-1)	
	Total Nitrogen (mg.ℓ-1)	
	Free Chlorine (mg.ℓ-1)	
	Phosphorous (mg.ℓ-1)	
	Microbiological quality	
	Faecal Coliform (100mℓ-1)	
	Total Coliform (100mℓ-1)	
Physical address *URL* *Email*		

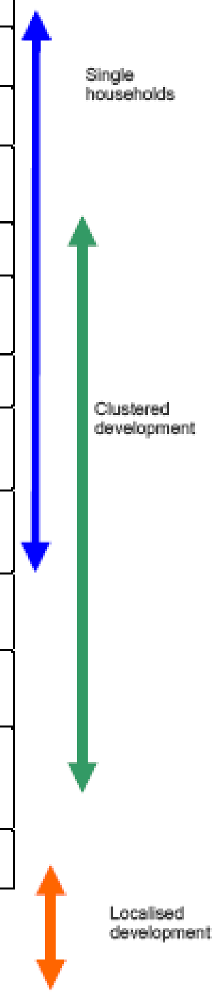
APPENDIX B3: THE SUMMARY OF WATER REUSE TREATMENT TECHNOLOGIES AND KEY ELEMENTS IN THE SELECTION PROCESS (LANDCOM'S WSUD STRATEGY (2003)

4 Summary of water treatment technologies

This chapter provides a summary of water treatment technologies. The technologies are broadly described to reflect the type of technology as identified in Figures 7 and 8.

Table 7. Summary of water reuse technologies and their key elements (the figures quoted are those supplied by the manufacturer or distributor of each technology)

Water treatment technology	Typical scale[7]	Treatment technology	Other information	Water quality suitable for[8]:	Footprint (m^2)	Capital expenditure ($'000)	Operating costs (per year)
Nubian (see page 53)	0.5 – 1.1 kL/d (2-6 EP)	Biological filtration followed by membrane filtration	Greywater treatment		3	5 + installation	Low
Perpetual Water (see page 56)	0.5 – 0.7 kL/d (2-6 EP)	Physical – sedimentation followed by adsorption	Modular greywater system		1.5	6.5 + installation	$365
Clearwater Aquacell (see page 47)	0.5 – 100 kL/d (2- 500 EP)	Membrane bioreactor	Modular system catering to wide range of scales.		1.2 – 124	13 (single house) 100 (500 EP)	$500 (6 EP) $5500 (500EP) $10,000 (1000EP)
Biolytix (see page 42)	0.5 – 10 kL/d (2-50 EP)	Natural - Humus filter situated at each household	Decentralised treatment	Subsurface irrigation	2.4 – 16	13 per house	$400
Biolytix (+UF) (see page 42)	12 – 100 kL/d (60-500 EP)	Natural - Humus filter coupled with a modular ultrafiltration unit	Combines decentralised treatment with reuse opportunities		35 – 500	30 for 50 EP	$1,200
Novasys – BIOSYS (see page 44)	1 - 150 kL/d (5-1000 EP)	Biological – fixed film bioreactor	Additional treatment required for water to be used for non-potable water	Restricted irrigation.	2	-	-
Rootzone (vertical filter – greywater wetland) (see page 41)	0.5 – 360 kL/d (2 - 1800 EP)	Subsurface wetland with a vertical recirculating filter	Land intensive treatment process	Disinfection required 	2 - 800	5 (single house) 40 (100EP)	$2,000 (100 EP0
Rootzone (horizontal wetland) (see page 45)	0.5 – 360 kL/d (2-1800 EP)	Subsurface flow wetland followed by a vertical filter	UV disinfection is required to reduce pathogen	Disinfection required 	4 – 1600	1000 (2000EP)	
WaterPac (see page 43)	2 – 10 kL/d (20-100 EP)	Biological system – primary settling followed by recirculating media filtration	Suitable for smaller communities and cluster developments with land available	Restricted irrigation	20 – 200	10 (10-20 EP) 60 (40 EP) 120 (100 EP)	$500 - $2,500
KEWT (see page 46)	7.5 – 1300 kL/d (30 -6500 EP)	Primary separation in septic tank, filtered and then evapotranspiration	Additional treatment required for water to be used for non-potable water. Suitable for developments with land available for irrigation.	Restricted or subsurface irrigation	200	30 – 50 (50EP)	-
Innoflow (see page 61)	10 – 100 kL/d (50 - 500 EP)	Onsite primary & biological treatment with centralised effluent treatment (recirculating textile filtrater)	Small diameter sewer minimises exfiltration protecting the environment. Water reuse can be achieved by including further disinfection.	Disinfection required 	160 + onsite intercept	500 (100EP) includes reticulation	$400 + periodic maintenance
Packaged Environmental	12.5 – 100 kL/d (50 - 400 EP)	Biological treatment followed by membrane filtration			60	350	$25,000 (400EP)



[7] EP is defined as "equivalent person" as 200 L/p/d. Typical operating range describes indicative operating ranges

[8] Key:  suitable for toilet flushing;  suitable for outdoor uses;  suitable for cold washing machine tap

APPENDIX B4: THE USEPA CODE OF PRACTICE FOR WASTEWATER TREATMENT SYSTEMS FOR SINGLE HOUSES (PE < 10) (USEPA, 2007).

Code of Practice: Wastewater Treatment Systems for Single Houses (P.E.<10)

APPENDIX D: EVALUATION OF Secondary Treatment SYSTEMS

Factor	Treatment Option No. 1	Treatment Option No. 2
Certification e.g. AGRÉMENT certification or other		
Construction, installation and commissioning service available		
Availability of suitable material for filter systems (soil//sand)		
Maintenance service available		
Expected life of the system		
Ease of operation and maintenance requirements		
Sludge storage capacity (m^3)		
Access requirements for sludge removal		
Design criteria*		
Capital cost		
Annual running cost /annum		
Cost of annual maintenance service		
Performance - % reduction in BOD, COD, TSS - % reduction Total P and Total N - % reduction faecal coliforms		
Minimum Standard BOD SS NH4		
Additional costs prior to commissioning (incld site improvements)		
Power requirements single phase/three phase Kw/d		

* in the case of biofilm systems the organic and hydraulic loading rates in $g/m^2.d$ and $l/m^2.d$ respectively should be quoted

APPENDIX C: FRAMEWORK ELEMENTS APPLIED TO THE USE OF RECYCLED WATER THROUGH A DUAL RETICULATION SYSTEM (NRMMC-EPHC, 2006).

Framework element and components	Activity
Element 1: Commitment to responsible use and management of recycled water quality	
Components: *Responsible use of recycled water* *Recycled water policy* *Regulatory and formal requirements* *Engaging stakeholders*	• Development of the dual-reticulation scheme involved collaboration between the water utility, the state department responsible for human health (eg Health Department — HD), the state department responsible for the environment (eg Environmental Protection Authority — EPA), the local council and the developers. • Regulatory requirements identified included the – *Public Health Act* – *Environment Protection Act* – *Water and Sewerage Acts* • Other stakeholders were – local community – plumbers and builders – general public.
Element 2: Assessment of the recycled water system	
Components: *Identify intended uses and source of recycled water*	• Intended uses included – toilet flushing – residential garden uses, car washing, etc – spray irrigation of parks and reserves (local council) • Source of water is a large metropolitan sewage treatment plant.
Recycled water systems analysis	• A catchment survey was undertaken to identify industries attached to the collection system. • The scheme included enhanced secondary treatment (with nutrient reduction), coagulation, dual-media filtration and chlorination. • Recycled water is distributed through a separate reticulation system, incorporating a 5 ML balancing storage before it reaches consumers. The system was installed in accord with *WSAA Sewerage Code Version 2.1* (WSAA 2002a).
Assessment of water quality data	• The treatment plant includes a marine discharge and results from chemical testing undertaken over a 10-year period, in accord with EPA licence conditions were available for assessment.

Framework element and components	Activity
Hazard identification and risk assessment	**Human health** Hazard identification and risk assessment for human health found that concentrations of most chemicals complied with values specified in the 2004 *Australian Drinking Water Guidelines* (NHMRC–NRMMC 2004). Microbial hazards for humans included enteric bacteria, viruses and protozoa. **Environmental performance** Hazard identification and risk assessment for the environment found the following: • The preliminary risk assessment identified groundwater, landscape and garden plants, turf and lawns, and specific soil types as potential environmental endpoints for hazards. • Phase 1of the risk assessment (preliminary screening) identified the hazards chloride, sodium, salinity, nitrogen, phosphorus and chlorine disinfection residuals, as moderate to high risks. • Phase 2 (maximal risk assessment) confirmed that only four key hazards (salinity, phosphorus, nitrogen and chlorine disinfection residuals) required preventive measure to lower the risk to acceptable levels. • Phase 3 (residual risk assessment) identified a range of preventive measures (see Element 3 below) available that should reduce the risk to an acceptable level (ie 'low' in Table 2.7, Chapter 2). **Environmental baseline monitoring requirements** A range of monitoring was identified to establish background conditions. Monitoring was initiated before commencement of the scheme, and included: • concentrations of hazards identified above (Phase 2) in soil including, sodium absorption ratio (SAR), exchangeable sodium percentage (ESP), nitrate, total nitrogen and phosphorus, pH, chloride and electrical conductivity (EC), at three depths • the salinity (EC), SAR, phosphorus, nitrogen and boron concentration of groundwater in the district • levels of groundwater and watertables in the district.

Framework element and components	Activity
Element 3: Preventive measures for recycled water management	
Components: *Preventive measures and multiple barriers*	**Human health** Preventive measures to manage risks to human health included: • trade-waste control system to reduce likelihood of toxic chemical discharges • enhanced secondary treatment to provide nutrient reduction • coagulation and filtration • chlorination • backflow prevention and cross-connection control at all irrigation sites • pipework (colour coded) and signage • an education program for householders and plumbers. **Environmental performance** Preventive measures to manage risks to the environment included: • total dissolved salts (TDS) of the recycled water entering the recycled water reticulation system kept below an average of 900 mg/L • residents advised that salinity and nutrients in water higher than in drinking water; therefore, advised to use less fertiliser, to select salt-tolerant plants and to consult with local nurseries • local council considered nutrient content when determining fertiliser requirements in parks irrigated with recycled water • educational material provided advice on how to avoid overwatering.
Critical control points	**Human health** Critical control points for human health were: • filtration (turbidity limits) • chlorination (Ct limits) **Environmental performance** A critical control point for the environment was salinity of the recycled water entering the recycled water reticulation system (TDS <900 mg/L as an average, critical limit 1200 mg/L).
Element 4: Operational procedures and process control	
Components: *Operational procedures*	**Human health** In relation to human health: • operational procedures were identified for all processes and activities associated with the system, including operation of treatment processes and auditing procedures for cross-connections • documented procedures were required to be available to all operations personnel and to be available for inspection at any time. **Environmental performance** In relation to the environment, procedures were established for irrigating parks and reserves to minimise salinity impacts, controlling nutrient application (fertiliser application), and controlling quantities of water used.

Framework element and components	Activity
Operational monitoring	**Human health** Monitoring requirements in relation to human health included: • standard wastewater plant requirements biochemical oxygen demand (BOD), suspended solids, etc • turbidity of filtered water (continuous) — *critical limit set* • disinfection (continuous) — *critical limit set* • on-site auditing of controls (signage, backflow prevention, etc). **Environmental performance** Monitoring requirements in relation to the environment included: • recycled water electrical conductivity (continuous) — *critical limit set* • pressure sensors in the reticulation system to identify pipe bursts and automatic cessation of supply if detected • visual inspection to ensure best management practice for irrigation followed and minimised leakage from the irrigation and reticulation system • visual inspection of health of plants and grassed areas • moisture sensors or other monitoring tools used to maximise irrigation efficiency • irrigation monitoring to minimise runoff.
Corrective action	**Human health** In relation to human health, corrective actions included the following: • Noncompliance with critical limits results in flow to dual-reticulation system being stopped and replaced by mains water. That is, flow stopped if: – turbidity limits (0.5 NTU average, 2 NTU maximum) not met for 60 minutes – minimum Ct (90 mg/min/L not achieved for more than 60 mins. • If cross-connections detected, flow to individual property stopped at the property boundary. **Environmental performance** In relation to the environment, corrective actions included the following: • If the target value of 900 mg/L TDS is exceeded, the continuous monitoring of EC of recycled water entering the reticulation system is reviewed and intensified. Any corrective actions possible are taken to ensure the sewage systems and treatment plant has not malfunctioned. • If the critical limit (1200 mg/L TDS) of the treated water is exceeded, then the treated water is shandied with drinking water. • If inspections reveal faults in irrigation procedures, remedial action implemented. • If inspections identify poor performance or health of plants and grass, causes should be investigated
Equipment capability and maintenance	• Online measuring devices include: – 24-hour monitored alarm systems for key devices – backup power available – variable dosing and variable control of flow rates in filtration plant.

Framework element and components	Activity
Operational monitoring	**Human health** Monitoring requirements in relation to human health included: • standard wastewater plant requirements biochemical oxygen demand (BOD), suspended solids, etc • turbidity of filtered water (continuous) — *critical limit set* • disinfection (continuous) — *critical limit set* • on-site auditing of controls (signage, backflow prevention, etc). **Environmental performance** Monitoring requirements in relation to the environment included: • recycled water electrical conductivity (continuous) — *critical limit set* • pressure sensors in the reticulation system to identify pipe bursts and automatic cessation of supply if detected • visual inspection to ensure best management practice for irrigation followed and minimised leakage from the irrigation and reticulation system • visual inspection of health of plants and grassed areas • moisture sensors or other monitoring tools used to maximise irrigation efficiency • irrigation monitoring to minimise runoff.
Corrective action	**Human health** In relation to human health, corrective actions included the following: • Noncompliance with critical limits results in flow to dual-reticulation system being stopped and replaced by mains water. That is, flow stopped if: – turbidity limits (0.5 NTU average, 2 NTU maximum) not met for 60 minutes – minimum Ct (90 mg/min/L not achieved for more than 60 mins. • If cross-connections detected, flow to individual property stopped at the property boundary. **Environmental performance** In relation to the environment, corrective actions included the following: • If the target value of 900 mg/L TDS is exceeded, the continuous monitoring of EC of recycled water entering the reticulation system is reviewed and intensified. Any corrective actions possible are taken to ensure the sewage systems and treatment plant has not malfunctioned. • If the critical limit (1200 mg/L TDS) of the treated water is exceeded, then the treated water is shandied with drinking water. • If inspections reveal faults in irrigation procedures, remedial action implemented. • If inspections identify poor performance or health of plants and grass, causes should be investigated
Equipment capability and maintenance	• Online measuring devices include: – 24-hour monitored alarm systems for key devices – backup power available – variable dosing and variable control of flow rates in filtration plant.

Framework element and components	Activity
Element 8: Community involvement and awareness	
Components: *Community consultation* *Communication and education*	• Before the scheme was commissioned, the residents were consulted extensively. An information package dealing with authorised uses, best practices for irrigation, restrictions and responsibilities was provided to all residents and to plumbers.
Element 9: Research and development	
Components: *Validation of processes* *Design of equipment*	• Before commissioning (2 months), testing was undertaken to validate the capacity of secondary treatment, coagulation and filtration to provide 5-log reduction of protozoa and 5-log reduction of viruses. This involved testing for adenoviruses, reoviruses, enteroviruses, hepatitis A, *Cryptosporidium, Giardia* and helminths. • Validation continued during the first year of operation to ensure that seasonal variations were assessed. • The capacity of the chlorination system to provide a minimum Ct of 60 mg.min/L was validated.
Investigative studies and research monitoring	• Resident satisfaction is being studied.
Element 10: Documentation and reporting	
Components: *Management of documentation and records* *Reporting*	• All operating procedures require documentation. All results, including printouts from continuous monitoring systems, must be recorded and stored. • Results must be reported on a regular and agreed basis to HD and EPA.
Element 11: Evaluation and audit	
Components: *Long-term evaluation of results* *Audit of recycled water quality management*	• Results are analysed as part of an annual audit by an independent third-party auditor. The audit also involves assessment of compliance with management requirements specified by HD and EPA. Audit reports are submitted to HD and EPA. • Results of biennial monitoring programs are assessed against the results of baseline monitoring.
Element 12: Review and continuous improvement	
Components: *Review by senior managers* *Recycled water quality management improvement plan*	• Operation of scheme reviewed by the water utility. Plans established for introduction of potential improvements identified from operating experience.

BOD = biochemical oxygen demand; Ct = product of disinfectant concentration (C, in mg/L) and contact time (t, in minutes); EC = electrical conductivity; EPA = environmental protection agency; ESP = exchangeable sodium percentage; HD = health department; NTU = nephelometric turbidity unit; PAH = polycyclic aromatic hydrocarbon; PCB = polychlorinated biphenyl; SAR = sodium absorption rate; TDS = total dissolved salts; VCH = volatile chlorinated hydrocarbons

APPENDIX D: AN OVERVIEW OF INDICATIVE REMOVALS OF MICROBIAL HAZARDS THAT CAN BE ACHIEVED USING VARIOUS TREATMENT PROCESSES AND TREATMENT LEVELS (HEALTH CANADA 2010).

Table D1: Indicative log removals of enteric pathogens and indicator organisms[a]

	Indicative log reductions[b]				
Treatment	*E. coli*	Bacterial pathogens	Viruses	*Giardia*	*Cryptosporidium*
Primary treatment	0–0.5	0–0.5	0–0.1	0.5–1.0	0–0.5
Secondary treatment	1.0–3.0	1.0–3.0	0.5–2.0	0.5–1.5	0.5–1.0
Dual-media filtration	0–1.0	0–1.0	0.5–3.0	1.0–3.0	1.5–2.5
Membrane filtration	3.5–> 6.0	3.5–> 6.0	2.5–> 6.0	> 6.0	> 6.0

[a] Adapted from NRMMC-EPHC (2006).
[b] Reductions are dependent on specific features of the process;

Table D2: Indicative log removals of enteric pathogens and indicator organisms[a]

	Indicative log reductions[b]				
Treatment	*E. coli*	Bacterial pathogens	Viruses	*Giardia*	*Cryptosporidium*
Chlorination	2.0–6.0	2.0–6.0	1.0–3.0	0.5–1.5	0–0.5
Ozonation	2.0–6.0	2.0–6.0	3.0–6.0	0.5–3.0[c]	0.25–3.0[d]
UV light	2.0–> 4.0	2.0–> 4.0	> 1.0 adenovirus > 3.0 enterovirus hepatitis A	> 3.0	> 3.0

[a] Adapted from NRMMC-EPHC (2006).
[b] Reductions are dependent on specific features of the process.
[c] Value range based on published CT tables from U.S. EPA (1999).
[d] Value range based on published CT tables from U.S. EPA (2006a).

APPENDIX E: EPANET MSX FILE (IN CD)