University of Southern Queensland

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Greywater Reuse in Urban Areas

A dissertation submitted by

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Abstract

Water recycling is increasingly being included in Australian policy frameworks and guidelines in order to help mitigate the unsustainable demands for potable water supplies in urban areas. Increased scientific knowledge, concern for the environment and the effects of global climate change has recently altered public opinion in cautious favour of water recycling initiatives. Technological advancements also now make water recycling more economically viable.

Recycling greywater (wastewater from showers, basins, laundry, and possibly kitchen) whether it be from centralised (‘third pipe’ systems) or individual reuse treatment systems can be effectively and efficiently recycled for non-potable reuse applications such as industrial, irrigation, toilet flushing and laundry washing depending on the technologies utilised in the treatment process. Greywater recycling offers reductions in urban potable water demand up to 30% - 70% (Radcliffe, 2003).

This paper explored current Australian Government policy frameworks and guidelines in order to define the main factors surrounding greywater reuse in urban areas. These factors were contextualised within an environmental framework and discussed under their broader social, political and environmental characteristics.

Suitable treatment technologies that best addressed the defined greywater reuse factors were identified and clear, standardised and sustainable greywater reuse processes for their application were also established.

An economic cost benefit analysis was then undertaken. Direct costs were identified and quantified and indirect costs and externalities were also identified. However indirect costs and externalities that effect greywater reuse were not quantifiable and their affects are still largely subjective.

Greywater reuse offers indirect benefits to public infrastructure in the form of reduced sewerage flows, reduced treatment plant size, shorter distribution systems, reduced potable water demand and can help prolong the need for additional potable water sources. Also, the economic benefits of greywater recycling in relation to potable water savings are obscured by current non-transparent and subsidised pricing mechanisms (Radcliffe, 2003).

Skilled knowledge is a main concern for the installation and maintenance of greywater treatment systems. Additionally, commercial products (soaps and laundry powders etc) affect greywater quality and can have a great effect on garden health, groundwater, soil and the type of greywater treatment technology utilised.

Generally, the long-term and broad implications of urban greywater systems are not yet fully understood and paramount to its acceptance is the protection of human health as well as community education and participation in community decision processes.

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Limitations of Use

Certification

I certify that the ideas, designs, and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

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Glossary of TERMS

Anaerobic State: Usually a chemical of biological process that has been carried out without the presence of oxygen. The anaerobic decay process produces the foul smelling and toxic gases, methane and hydrogen sulphide.

Pathogens: A living organism (usually a micro-organism) that causes disease.

BOD: Biochemical Oxygen Demand is a standard water treatment test for the presence of organic pollutants. It is carried out by testing a sample for the amount of dissolved oxygen used by micro-organisms as they feed upon organic matter. The sample is usually incubated in darkness for five (5) days – hence the reference BOD_5. This dissolved oxygen amount then provides an indication of the quantity of organic material present.

Water Sensitive Urban Design (WSUD): Integrates water cycle management with urban development. Such factors as drinking water, stormwater run-off, waterway health, wastewater and recycling are considered under a total design and/ or plan.

Potable water: Water that has been treated to drinking quality standards.

Ecological Footprint: The impact that a human settlement has as a result of its fuel, food and waste disposal needs.

COD: Chemical Oxygen Demand is the amount of oxygen consumed in the complete oxidation of carbonaceous matter in an effluent sample. The test measures the total carbon content and hence the organic content of the sample.

COD:NH_3:P ratio: Provides an indication of the nutrients available for biological treatment of wastewater. Nitrogen (NH_3) and phosphorous (P) are stated as ratios of COD.

Faecal coliforms: Are a group of pathogenic (disease-causing) bacteria that are only found in warm-blooded animals and their presence in water tests indicates the presence of human pollution.

E. Coli: Is a specific pathogen that is part of the faecal coliform group. Its presence is able to be easily and relatively quickly identified and is and indicator of human pollution.

Climate change: Is a term to describe human-induced influences on global climate patterns which include increased carbon dioxide (greenhouse effect), change in the Albedo (mean annual temperature changes), dust/ aerosol emissions (ionising solar radiation) and ozone shield depletion.

Water cycle: Describes the way water is commonly utilised and recycled by the environment on Earth.

Ecologically Sustainable Development (ESD): A concept first described in the Brundtland Report titled “Our Common Future” that was drafted in response to the United Nations International conference Nairobi in 1982. The term ESD was originally described in this report as *“…meets the needs of the present without compromising the ability of future generations to meet their own needs.”* To many the central message of ESD is that economic development and environmental conservation can be complimentary rather than mutually-exclusive goals.

Salinity: The total amount of dissolved material in water. This term is extended to water the quality in soils and saline soils contain large amounts of soluble salts which inhibit growth and development of plants.

Sodicity: Is where sodium (Na) is the major exchangeable cation in soil. Sodium can be toxic to some plants however the main effects are poor soil structure. A sodic soil becomes impermeable and poorly sorted

Filtrate: Material that is separated by the filter or filter media.

Net positive suction head: If the level of the fluid on the suction side of a pump is above the pump, then it has a net positive suction head. Centrifugal pumps generally require priming; however there is a net positive suction head available this automatically primes the pump.

Shadowing: This is the effect when suspended particles in a fluid passing through a UV disinfection chamber are large enough to shield any attached bacteria from the fatal UV rays that are emitting from the UV lamp.

Externalities: These are direct and indirect economic costs of unintended biophysical impacts that arise from human-based actions and are borne by the community.

Chapter 1: INTRODUCTION

The droughts of the early 21st Century in Australia have in part accelerated the drive towards environmental policies that embrace environmental resource planning measures such as water balance concepts that allocate finite water supplies to all environmental consumers (Radcliffe, 2003) and guidelines such as Water Sensitive Urban Design (WSUD).

These current water resource practices have evolved from the introduction of environmental discharge guidelines in the 1980's and the demand management policies of the 1990's. Current guidelines and policy frameworks now reflect another evolutionary change through the inclusion of water recycling standards in urban areas, of which greywater reuse systems can play an important role (Radcliffe, 2003).

Currently, national guidelines for wastewater reuse are being drafted as part of the National Water Initiative (NSW Health, 2004), of which greywater reuse will be included. However, many state governments have already enacted their own interim legislation and issued guidelines for greywater reuse in urban areas in response to public opinion and their own rapidly depleting water storages.

There is a general consensus from regulatory authorities that greywater reuse guidelines must continue to protect human health, as per the traditional guiding design philosophy for traditional centralised wastewater collection and treatment systems.

Identifying the likely effects and consequences of urban greywater reuse, guide the process of determining the most suitable treatment technologies. The most effective and efficient treatment systems identified then help to define and implement clear, standardised and sustainable processes for greywater reuse.

Economic factors are important for implementing greywater reuse systems however, the social and environmental costs are also very important as the current water shortages in many capital cities highlight.

The likely consequences from indirect social and environmental costs of greywater reuse as well as externalities are mostly identifiable, but largely unquantifiable at this stage, especially in economic terms. As a result any cost benefit analysis for greywater reuse systems is relatively incomplete. However there is consensus that any realisation of these costs would generally favour the economic case for greywater reuse in urban areas (Jefferson, 1998).

Chapter 2:
OBJECTIVES

Initially, an understanding of the current factors surrounding the issues of greywater and its reuse possibilities in urban environments were gained by reviewing relevant Australian and overseas policy frameworks, guidelines and their supporting reports.

The identified factors were then characterised within an environmentally sustainable framework whereby greywater recycling issues were contextualised within broader social, political and environmental factors.

The framework was then used to investigate greywater reuse technologies and identify those technologies that best address the greywater reuse factors identified.

A cost benefit analysis that incorporated broad environmental factors was then applied to those identified greywater technologies to refine the selection of the most suitable technologies that better address the greywater reuse factors.

Additionally, clear standardised and sustainable greywater reuse processes were then developed for the application of the identified greywater recycling systems in the urban environment.

Chapter 3:
GREYWATER CHARACTERISTICS

3.1 Water Use In Australia

In 2002 it was estimated that 26% of Australia's surface waters and 31% of its ground waters were fully or over utilised (National Land & Water Resources Audit) and although Australia has a large surface area to catch rainfall, just 12% of rainfall enters its rivers. The remainder of the rainfall finds its way to groundwater and wetlands, is utilised by plants and trees and is evaporated (Radcliffe, 2003).

So although it has been long-established that Australia has very low water storage capabilities by the nature of its climate, geography and topography, by 2002 Australia had fully utilised a significant amount of its water storage available and the Murray-Darling Basin is the most high-profile example of this. Here water usage has exceeded the river's water storage and the supporting catchment's requirements.

In 1996-1997, 75% of Australia's water storage was used to irrigate crops, 20% went to urban industry and household use and 5% was used by rural household and livestock use. Whilst the farming industry uses most of the water, increasing rates of urbanisation in Australia's cities has resulted in them now using the same amount of water per hectare (Radcliffe, 2003, p3).

For urban water use, 59% was used at the domestic household level. Specific water uses at the household level were also identified and are shown in table 3.1.

Components of water use in Australia's largest 22 cities		
Residential gardens	414,000 ML	20% of total urban use
Bathroom	317,000 ML	15%
Toilet flushing	244,000 ML	12%
Laundry	183,000 ML	9%
Kitchen	61,000 ML	3%
Total	**1,219,000 ML**	**59% of total urban use**

Table 3.1 (Radcliff, 2003 p3)

This table was used partly in the following cost benefit analysis for quantifying potential water use and economic savings for greywater reuse in urban areas in Australia.

3.2 What is Greywater?

Domestic wastewater consists of blackwater and greywater as shown in figure 3.1.

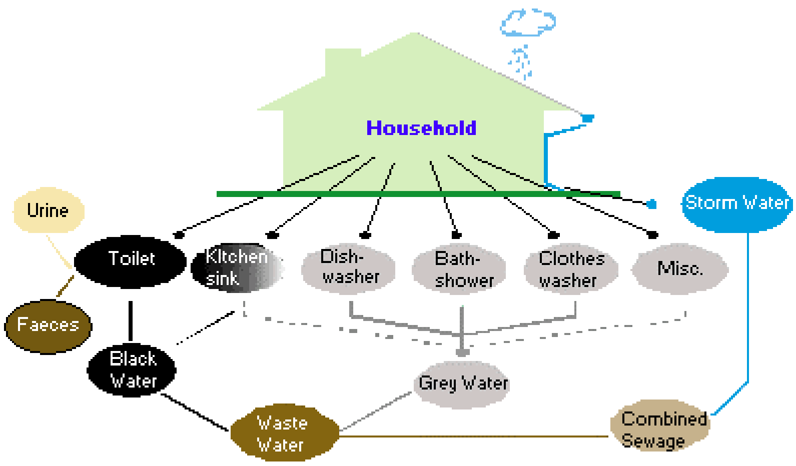

FIGURE 3.1: Constituent parts of wastewater (UNEP, 2000)

Blackwater describes the sewage toilet waste and this form of wastewater is collected via the sewer drain connection in urban areas and treated at centralised sewerage or wastewater treatment plants. Blackwater is characterised by having a very high pathogenic bacterial contamination, high organic loads and nutrients, dark in colour and foul smelling (Al-Jayyousi, 2003).

Greywater consists of other domestic sources such as the laundry and laundry sink, bath and shower wastewater. The kitchen sink and dishwasher wastewater should strictly be included with greywater; however this form of greywater usually contains relatively higher organic nutrients and higher BOD loadings (Al-Jayyousi, 2003). This in turn significantly increases the treatment requirements of greywater reuse systems and in

Australia it is included with Blackwater as this form of waste poses a higher threat to public health (Diaper, 2004).

Greywater is characterised as a dilute form of wastewater and makes up 68% of the total domestic wastewater (Emmerson, 1998). It is distinguished from blackwater by having high inorganic loads, low nutrients with low pathogenic bacterial contamination, lighter grey colour and has a sweeter smell (Al-Jayyousi, 2003). Greywater quality is highly variable depending on the household's social preferences (Al-Jayyousi, 2003).

3.3 Greywater Quality

Greywater quality is usually governed by the use of soap or soap products with water for body and laundry washing. The quality and quantity of these contaminants are highly variable and depend on the user's social and product preferences, geographical location, demographics and level of occupancy of the dwelling (Al-Jayyousi, 2003).

The organic concentration of greywater is similar to wastewater; however their chemical nature is different. Also greywater is relatively low in suspended solids indicating that the contaminants are predominantly dissolved (Al-Jayyousi, 2003), as indicated in Table 3.2 below.

Source	BOD_5 mg/L	COD mg/L	Turbidity NTU	NH_3 mg/L	P mg/L	Total Coliforms
Hand Basin	109	263	-	9.6[a]	2.58	-
Combined	121	371	69	1	0.36	-
Synthetic Greywater	181	-	25	0.9	-	1.5×10^6
Single Person	110	256	14	-	-	-
Single Family	-	-	76.5	0.74	9.3	-
Block of Flats	33	40	20	10	0.4	1×10^6
College	80	146	59	10	-	-
Large College	96	168	57	0.8	2.4	5.2×10^6

Table 3.2: Quality of greywater sources (Al-Jayyousi, 2003)

[a] Total Nitrogen.

3.3.1 Microbial

The presence of potentially harmful micro-organisms is indicated by measuring for the faecal coliform group and more specifically E. Coli bacteria. These micro-organisms indicate the presence of intestinal pathogens such as Salmonella or enteric viruses and are used as a pollution indicator or safety factor (Emmerson, 1998 p13).

A high E. Coli count in a greywater sample indicates that there is a greater chance of developing human illness from contact with greywater. However, a low E. Coli count does not imply that there are no harmful micro-organisms present. E. Coli is used as an indicator micro-organism only and other harmful micro-organisms may still be present but not measured. They include other bacteria, viruses, protozoa and Helminths (parasitic worms).

In specific studies of household greywater quality, shower water has faecal coliform counts as high as 6000 colony forming units (cfu) per 100mL (Rose et al. 1991) and bathroom water generally was found to contain up to 3300 most probable number (MPN) cfu's (Christova-Boal et al. 1995).

3.3.2 Chemical

The COD: BOD ratio of greywater may be as high as 4:1, which is higher than wastewater and is due to the low macro-nutrient (phosphorous and nitrogen) levels – refer to Table 2. To further reinforce this the COD:NH_3:P ratio for greywater has been measured at 1030: 2.7: 1 compared with 100: 5: 1 for wastewater, which also indicates relatively low values of biodegradable organic matter in greywater (Jefferson et al. 1999).

3.3.3 Physical

The likelihood of high COD:BOD ratios in greywater along with the predominant use of soaps and detergents in bath and laundry indicate a high concentration of dissolved solids such as salts. Most of these will not be removed from greywater before reuse unless treated to a relatively high standard.

Although low in suspended solids, hair and lint are common suspended solids in greywater that is collected from laundry and bathroom sources and can potentially foul treatment processes.

The use of mostly alkaline soaps and detergents can also greatly affect the pH of greywater. The diversity of the products used varies the impact on pH and this also depends on the social choices of the household. Similar to addressing the level dissolved solids, the high pH cannot be corrected without sophisticated treatment. Therefore greywater is generally discharged to the garden or park without treatment and the soil treats the greywater.

Although the quality of greywater is highly variable, the possibility of significant microbial contamination ensures that greywater reuse systems must strive to avoid, minimise or abate human contact.

The generally low nutrient loads will limit biological treatment solutions (especially for small systems) and the high dissolved solids content will require closer scrutiny of their effect within the treatment process and on the soils and environment upon which greywater is discharged (Al-Jayyousi, 2003). Suspended solids such as hair and lint pose problems for greywater reuse systems involving pumps and drip irrigation systems and must be filtered (Ludwig, 1994).

Following is a comparison of typical household wastewater and greywater (Beavers, 1995):

- 63% of BOD load;
- 39% of the suspended solids load;
- 18% of the nitrogen;
- 70% of the phosphorous;
- 65% of the wastewater flow.

The comparison of greywater with wastewater quality indicates a relatively low contamination of greywater (Beavers, 1995) and therefore lower treatment requirements. Additionally, the relatively high proportion of greywater generated shows a large potential source for water savings by reuse systems.

The main applications for greywater reuse are garden and park irrigation (external uses) as well as toilet flushing and laundry (internal) use. Household greywater systems that reuse greywater for toilet flushing and/ or laundry water must utilise a treatment process that includes coarse suspended solid removal, turbidity reduction and disinfection (Al-Jayyousi, 2003).

Chapter 4:

REVIEW OF GREYWATER REUSE PRACTICES AND GUIDELINES IN AUSTRALIA

The droughts of the early 21st Century in Australia have in part accelerated the drive towards environmental policies that embrace environmental resource planning such as water balance concepts that allocate finite water supplies to all environmental consumers (Radcliffe, 2003).

The increased scientific knowledge of the natural environment and its very complex processes has in part allowed more rigorous and accurate measurement of the human impacts upon it (Emmerson, 1998). This scientific knowledge along with increasingly identified environmental strains from human development has promoted conservation practices (Diaper, 2004).

In Australia, current resource conservation practices have evolved from the introduction of environmental discharge guidelines in the 1980's, where public emphasis was on wastewater quality and quantity. It was identified that nutrient loading from excessive wastewater discharging into Australia's rivers and streams was causing very harmful environmental problems such as poor and deteriorating water quality, loss of habitat landscape flora and fauna and pollution of coastal and marine environments. As a result "end of pipe" solutions and regulations were pursued and the user-pays principle instigated. These environmental issues are still prevalent today, however emphasis is on source control rather than the "end of pipe" (Radcliffe, 2003).

As a result State Governments recognised that poor quality sewage treatment caused most of this pollution and wastewater treatment practices were refined to reduce environmental degradation and thereby increasing or maintaining human standard of living. Regulatory bodies were set up such as Environmental Protection Authorities to advise and implement the new environmental guidelines.

In the 1990's emphasis then shifted towards demand management policies as a result of Australia's increasing growth problems – increasing standard of living and increasing population levels. As a result of acknowledging the environmental strains of these human trends ecological sustainable development principles were adopted. It became apparent that water conservation was critical in order to protect existing water stores and to abate the increasing environmental strains caused (CSIRO, 1996 pp7-11).

For the newly emerging privatised water authorities it was more economical to engage in public programs to reduce water consumption and the government regulatory authorities supported the trend (Radcliffe, 2003). Water usage began to be measured and charged more rigorously.

However, in the first decade of the new millennium advancing scientific knowledge of climate change and its acknowledged effects such as the recent prolonged droughts in Australia have in part accelerated the drive towards environmental policies that embrace environmental resource planning. This included water balance concepts that allocate finite water supplies to all environmental consumers and not just human users (Radcliffe, 2003).

Current Australian guidelines and policy frameworks now reflect another evolutionary change through the inclusion of water recycling standards in urban areas, of which greywater reuse systems can play an important role.

4.1 Development of Greywater Reuse

Greywater reuse has been utilised in rural areas where there are no centralised sewer systems for many decades in Australia and overseas. The systems used were usually simple crude designs used to irrigate the landscape (Jeppesen, 1996).

Greywater reuse systems in urban areas have been used under the regulation of plumbing codes in the United States of America since the 1990’s. This was in response to abating severe future water shortages in areas such as California and Florida (Jeppesen, 1996) and they are similar circumstances under which Australia is now legalising greywater reuse in urban areas. Likewise in Japan, but more in response to the increased rates of urbanisation and population growth, greywater reuse systems have been in use for multi-dwelling buildings since 1990’s.

Water reuse strategies in Australia were officially recognised in 1983 when a report into water reuse was initiated by the federal Department of Resources and Energy as part of the Water 2000 project (GHD, 1983). But it did not consider domestic reuse options seriously and there have been many other Federal Government inquiries since which have recommended conservation and alternative sources of potable water supplies (Emmerson, 1998).

However, in 2002 an Australian Senate Inquiry produced the National Water Policy which was focussed on wastewater reuse. As a result, in 2003 the Australian Research Council sponsored a review of water reuse in Australia by the Academy of Science and Engineering. In this report greywater was defined and its reuse options discussed.

Concurrently to these reports, some State Governments began to draft or had already introduced legislation to allow limited greywater reuse systems to be used in sewered urban areas. State Government policies and guidelines also began to build on earlier experimental greywater and wastewater reuse schemes such as the Rouse Hill residential development in Sydney in the late 1990’s, the Springfield residential development in Brisbane in early 2001 and individual household systems such as Michael Mobbs’ sustainable house project in Sydney NSW and the Healthy Home on the Gold Coast in QLD.

The promotion of wastewater reuse at policy level and establishment of technical guidelines marks a change in the traditional view of wastewater as being a waste and consequently centrally discharged to it now being recognised as a resource and a source of opportunity (Radcliffe, 2003). Indeed wastewater is now noted as the only water resource that increases with urban development and planning and design principles are beginning to embrace this as a sustainable resource to reduce the ecological footprint of urban development (Gardner, 2003).

Many authorities have included greywater reuse systems into overall water and resource planning strategies such as Water Sensitive Urban Design (WSUD) which is an integral part of overall urban design and new development planning (Melbourne Water, 2004). Under WSUD, greywater reuse systems are investigated at the on-site and neighbourhood unit levels and are seen as a tool for conserving water use along with pollution control systems that include landscape design and stormwater reuse i.e. rainwater tanks (Melbourne Water, 2004).

At the neighbourhood unit level, greywater can be collected via a stormwater drainage system, treated and re-distributed back to neighbourhood homes for garden water use. These systems are called Third Pipe systems.

4.2 Government Responses to Water Conservation and Reuse

Most Australian water authorities and policy makers have identified three (3) main viable alternatives that are available to increase potable water supplies, they are;

- Demand management – water saving;
- water reuse, and
- Alternative water supplies.

(Radcliffe, 2003)

In the 1990's demand management was pursued and now the next step in conservation measures is wastewater reuse as well as alternative water sources such as desalination plants.

As with overseas experiences, at present Australian legislation and guidelines for greywater reuse are mostly set by State Governments and seek to involve qualified trades people (i.e. plumbers), regulatory bodies (i.e. Environmental Protection Authority – EPA and water authorities) and local councils to set, monitor and administer the legislation.

However, as a result of the 2002 National Water Policy and the subsequent review of water reuse in Australia by the Academy of Science and Engineering in 2003 there are National Reuse Guidelines being drafted at present and are due to be released in 2005 (RWCC, 1993).

Legislation has been introduced by most State Governments recently and in many instances those regulatory authorities administering guidelines for greywater reuse acknowledge the legislation is legalising many existing greywater systems (RWCC, 1993).

Regulatory guidelines for greywater reuse systems mostly address health concerns. In that systems can only divert greywater from wash basin, laundry, shower and bath sources and recycle the greywater for garden irrigation with no human contact. This usually requires sub-surface irrigation systems. Additionally, some guidelines allow for greywater to be reused for laundry washing, toilet flushing and surface irrigation depending on the treatment used.

4.2.1 Queensland (QLD)

There are high profile Third Pipe wastewater and greywater reuse systems operating at the neighbourhood unit scale and these sites include Springfield, Ipswich and a portable treatment unit located in Pine Rivers Shire Council. Whilst these applications were initially experimental sites, they have been successful (Radcliffe, 2003).

Government policy and Guidelines for greywater reuse already exist only for non-sewered areas in Queensland and in 2004 legislation was proposed for greywater reuse in urban sewered areas. Along with the proposed legislation a set of guidelines will be also be introduced, similar to the guidelines for non-sewered areas. The proposed legislation is due to be passed in 2005 and public submissions are still being sought for the proposed greywater reuse guidelines (Department of Housing, 2004).

The Queensland Government conducted scoping studies since 2000 to support the present urban greywater reuse legislation and these included investigations into the economic and health effects of greywater reuse (PWC, 2000).

The proposed legislation will require local council administration, approval and monitoring of greywater reuse systems in urban areas and installation must be undertaken by approved plumbers. The Queensland EPA will issue and support greywater reuse guidelines and greywater system approvals (Department of Housing, 2004).

4.2.2 New South Wales (NSW)

The NSW Health Department set regulatory guidelines for wastewater reuse in 2000 and these included greywater reuse options for urban sewered areas for single dwellings and residential neighbourhood schemes. In 2004 interim guidelines were issued for the use of greywater reuse systems for multi-dwelling and commercial developments. The new National Reuse Guidelines due to be presented in 2005 will then supersede these interim guidelines along and the 2000 guidelines (NSW Health, 2004).

Greywater reuse schemes must be installed by qualified plumbers and system designs are subject to NSW Health Department accreditation, local water authority and Local Government approval (NSW Health, 2000).

NSW Health specifies two (2) main types of greywater reuse systems for urban use – Greywater Diversion Systems (no treatment, gravity and pump diversion devices) and Domestic Greywater Treatment Systems (stores and treats greywater). Greywater reuse is restricted to garden irrigation mainly.

4.2.3. Victoria

The Victorian Environmental Protection Authority (EPA) produced greywater reuse guidelines for urban areas in 2001. Greywater systems must be approved by the Local Government and local water authorities and designs are subject to EPA guidelines and must be installation by a licensed plumber (EPA Victoria, 2001). Melbourne Water includes its own greywater reuse guidelines as part of its Integrated Water Cycle Tools within its Water Sensitive Urban Design Policy (Melbourne Water, 2004).

Commitment to greywater reuse as part of Sate Government water saving policies is very strong in Victoria and is reflected in the current greywater reuse system rebate offered by the Department of Sustainability and Environment. The State Government Department has offered rebates of $150 for each installation of permanent greywater reuse system installed at residential properties (Melbourne Water, 2004).

The design and performance of greywater systems are subject to many Victorian State Government Acts – Water Industry Act 1994, Water Act 1989, Building Act 1993 and most importantly, the Health Act 1958 and the Environment Protection Act 1970. The relevant legal obligations are highlighted in the EPA greywater reuse guidelines and they mainly state the legal obligations of the greywater system owner/ operator with regards to human and environmental health considerations (EPA Victoria, 2001).

Similar to NSW, greywater systems are categorised into surge (no storage or treatment) and treatment systems and are restricted to mostly garden irrigation, however laundry and toilet flushing are additional reuse options with additional treatment systems (EPA Victoria, 2001).

4.2.4 Western Australia (WA)

The Western Australian Government has embraced water reuse strategies in the new millennium as tools to abate the severe water shortages facing the state. Surface water supplies have been progressively decreasing over the past few decades due to climate change and population growth and ground water supplies which are heavily relied upon are not being utilised in a sustainable way (Radcliffe, 2003).

In the late 1990's Murdoch University trialled five (5) different methods of greywater reuse for individual or multi-adjoining properties in WA (Anada et al, 1996). At the same time in 1996 the Western Australian Health Department released Draft Guidelines for Domestic Greywater Reuse in Western Australia for comment. These guidelines were then reviewed and the new Draft Guidelines for the Reuse of Greywater in Western Australia was released for public comment in July 2002 (Emmerson, 1998).

The draft guidelines produced by the Western Australian Health Department which are now in use, outlines a permit system whereby the Western Australian Health Department issues permits for greywater reuse systems subject to the approved designs described in the draft guidelines. Final approval and permit administration rests with Local Government (Department of Health, 2002).

The involvement of the Water Corporation of Western Australia (the only water authority in WA) and the Department of Environment, Water and Catchment Protection was limited to helping develop the draft guidelines with the Western Australian Health Department.

The approved greywater systems available reflect Jeppeson's designs (Jeppesen, 1996) where greywater systems were designated as primary (no storage or treatment) or secondary systems (storage and treatment). Applications range from sub-surface garden irrigation (primary systems) to spray irrigation and toilet flushing with secondary treatment in order to avoid human contact of contaminated greywater. The guidelines also allow for other non-standard technologies and processes (i.e. different filter types, natural disinfection and filtration), however all types of systems must gain approval (Department of Health, 2002).

The commitment of the Western Australian Government is reflected in its Waterwise Rebate Scheme whereby approved and permanently installed greywater reuse systems can receive a rebate up to $500 per system (WA Government, 2002).

4.2.5. South Australia (SA)

South Australia also faces potable water shortages and has committed strategies towards greywater reuse systems in 2003. Greywater reuse guidelines have been developed by the main regulatory body for wastewater reuse systems, the Department of Health (SA). All greywater systems must be approved by the Department of Health in conjunction with Local Government and those systems in sewered areas must be approved by SA Water with regards to plumbing and connections to existing drainage (SA Water, 2004).

In addition to characterising primary and secondary reuse system technologies as well as stating sub-surface garden irrigation for preferred applications, an engineer’s assessment of soils to be irrigated is required (Department of Health, 2003).

The South Australian Government has also supported various centralised wastewater reuse schemes at the neighbourhood unit scale as defined in the Reclaim Water Guidelines produced by the Department of Health Services in 1999. Mawson Lakes, Le Fevre Peninsula and Salisbury City are examples of Third Pipe effluent reuse systems at the neighbourhood unit scale (Thomas et al. 2000).

4.2.6. Australian Capital Territory (ACT)

In April 2004 the ACT Government through its "Think Water, Act Water" sustainable water resource management strategy committed to reducing 12% of the per capita potable water consumption by 2013 and 25% by 2023 (ACT Government, 2004).

The strategy identified greywater reuse as a tool to achieve this target and as such in late 2004 ACT Health in conjunction with the ACT Planning and Land Authority, Environment ACT and ActewAGL issued guidelines for greywater reuse in urban areas (ACT Government, 2004).

The ACT Planning and Land Authority's legislative authority allows it to regulate greywater reuse system design and installation. Licensed plumbers must install greywater systems and like Victoria the owners/ operators of approved greywater reuse systems are subject to public health and pollution regulations such as the Environmental Protection Act 1997 (ACT Health, 2004).

4.2.7 Other States/ Territories

Tasmania and the Northern Territory do not recognise or permit greywater reuse systems in urban areas however these areas in general do not face potable water shortages and therefore are not reliant upon water saving strategies at this stage.

Although National guidelines are being developed for wastewater reuse (including greywater reuse) in urban areas, State Governments have already recognised the water saving opportunities posed by greywater reuse. Since 2000, these policies and guidelines along with other initiatives have been implemented in order to maintain National Water Strategy responsibilities and to achieve their own resource conservation and planning goals.

Chapter 5:

FACTORS AFFECTING GREYWATER REUSE IN URBAN AUSTRALIA

Greywater comprises between 68% of total household wastewater on average (Emmerson, 1998) and presents the largest potential source of water savings in domestic residences. Most of the greywater systems proposed in urban areas are closed-loop processes. That is, greywater is managed and reused in a decentralised way within a household, neighbourhood or community (Al-Jayyousi, 2003).

Greywater systems are assessed in terms of technical feasibility, public health, social acceptability and sustainability and these are reflected in Government policy and guidelines. These criteria can be further contextualised into an environmental framework of social, political and environmental factors.

From a broad catchment resource perspective, significant opportunities and constraints of greywater reuse are;

- Availability of a non-potable water source.
- Local climate conditions.
- Development layouts and building/ landscaping designs.
- Local soil types.
- Community perceptions and concerns.

In the later part of thew 19th Century the largest increase in human life expectancy (from about 30 years of age to over 50 years of age) occurred and was directly attributed to the establishment of a reticulated potable water supply. This was the creation of our current system and few changes have occurred since (Emmerson, 1998). The centralised system prevented a significant mode of transmission for infectious disease epidemics and in urban areas this must remain the most important factor for greywater reuse design (Al-Jayyousi, 2003).

5.1 Political Factors

Public concern for the environment has evolved over the past few decades. Since the Brundtland Commission in 1989 ecologically sustainable development (ESD) principles have been progressively integrated with Government policies, planning and industry guidelines as well as water resource planning. Organisations also recognise the growing environmental concerns of the public by embracing “green” marketing and developing mission statements and corporate goals around ESD principles (Dryzek & Schlosberg, 2003).

The recent droughts in Australia have caused Governments to re-evaluate the economic costs of human development upon the environment in social terms. This along with positive public opinion has provided political support for wastewater reuse systems as part of water saving initiatives (Radcliffe, 2003). Additionally, the increased strains of population growth and urbanisation have necessitated Governments to review and investigate new ways of providing the additional water resources available to sustain future growth. Greywater has a constant supply and its reuse can provide water saving opportunities that could lead to postponement of traditional planning techniques such as building new dams and catchment diversion projects (Gardner, 2003).

Greywater reuse at individual, neighbourhood and community scales offers simpler and more cost effective solutions (Ludwig, 1999) for Government water saving initiatives as they strive for policies that encourage more sustainable use of resources.

In order to privatise their water and wastewater businesses Governments began to create favourable policy and economic conditions to attract businesses to the industry and compete (PWC, 2000). Water and wastewater assets were scrutinised and optimised as the heavily subsidised consumer prices began to increase to reflect the true cost of water supply and treatment (Radcliffe, 2003).

These economic reforms have increased the case for water reuse schemes as well. Although the water pricing process is still not transparent in Australia and determining the true cost of infrastructure for water extraction, distribution, treatment and collection as well as future planning are still not clearly defined (PWC, 2000). Water has traditionally always been subsidised by the Australian public, especially the agricultural sector which provides most of the wealth for urban Australia (Radcliffe, 2003). Whilst subsidised water supply for agricultural irrigation is a sensitive and contentious issue, in Australia's urban areas water use per hectare is the same as the agricultural sector (Radcliffe, 2003). This highlights the potential for significant water savings in urban areas.

Whilst Government policies promote and strive for profitable operation of the water authorities, the Government must also support environmental conservation policies. These policies fundamentally contradict each other and they are dualistic. Ultimately they could hinder progress towards achieving each policy's respective goals (Radcliffe, 2003).

5.2 Social Factors

Whilst there are no reported cases of human illness or disease directly attributable to greywater reuse (Emmerson, 1998), the limited studies investigating the levels of micro-biological contamination of greywater indicates the potential for human infection is high. Also, the traditional centralised sewer collection and treatment system that is currently used was successfully designed to protect human health. On-site reuse of greywater marks a departure from this centralised health-driven system and so attracts legitimate public concern.

Public health concerns regarding the potential for greywater becoming a mode of transmission for infectious diseases and viruses in higher density urban areas is a significant issue and must be addressed by greywater reuse system design.

Additionally, the sensitive public health concerns over greywater reuse systems make them vulnerable to wider and more negative publicity caused from any specific health-related accidents (Radcliffe, 2003). However, no such incidents have been reported to date (Emmerson, 1998).

Community or public support for greywater reuse systems is critical to the success of implementing policies and guidelines and is conditional upon;

- Community involvement in decision making processes.
- Public education.
- Community demographics.
- Trust in Water authorities.

(Marks, 2004)

Trust in water authorities was identified as the major factor in gaining public support and historically strong public trust has always been given to all public utilities in Australia who provide essential community services (Marks, 2004).

Many experimental community-based wastewater and stormwater reuse systems (i.e. Mawson Lakes SA, Springfield QLD and Rouse Hill NSW) are now beginning to provide historical data on the public acceptance process. Although more detailed understanding of sociological factors is still difficult to ascertain due to persisting lack of studies (Marks, 2004). However, comparisons with overseas experiences confirm the importance of sociological factors in reuse acceptance (Dillon, 2000).

There is a higher acceptance for non-potable reuse applications for wastewater (Radcliffe, 2003) and studies in the USA indicate greater acceptance as the degree of human contact decreases (Marks, 2004). Also, these studies indicated that when options for reuse are evaluated by the community, the most important factors in order of priority are;

- Human health,
- the environment,
- conservation,
- treatment costs, and
- distribution costs (mainly for third pipe systems).

(Marks, 2004)

These are similar to Australia, however greywater reuse does not attract the public caution that effluent reuse does (Radcliffe, 2003).

In the 1980's and 1990's many reuse schemes were postponed due to public opposition. Whilst there were legitimate public health concerns, the process followed by the relevant authorities proposing the schemes lacked stakeholder plans to effectively negotiate the change required (Hurlimann & McKay, 2004). Stakeholder involvement in the decision making process is identified as crucial to gaining community support and trust (Hurlimann & McKay, 2004) and communication is the most important precursor to engendering trust (Morgan & Hunt, 1994).

The effects of recent droughts in Australia early this decade related global environmental issues such as population growth, urbanisation and climate change directly to communities. This has heightened public awareness of the natural water cycle which they are part of and the environmental strains imposed by human development. This has encouraged Governments and communities to consider their actions in respect to the environmental effects imposed by them (Radcliffe, 2003).

The increased standards of living in Australia have created more attention to designing and maintaining landscapes and gardens for personal and community recreation. Also, more pressure is applied to local Governments to provide better quality recreational and sporting facilities, which requires more frequent and greater use of water for irrigation (Radcliffe, 2003).

Decentralisation of the traditional wastewater collection and separate disposal system is caused by using on-site greywater treatment systems in urban areas. As a result, reusing greywater within the same space as it is generated highlights the environmental consequences of user's social habits directly (Al-Jayyousi, 2003). Government greywater reuse guidelines also highlight and reinforce these precautions. Therefore users must scrutinise the environmental effects of the products and chemicals that they use as they become more environmentally aware and responsible for their actions. This could have a flow-on effect to manufacturers and businesses as consumer habits begin to change.

However, if greywater is used to substitute garden irrigation it is debatable whether it will actually reduce overall water consumption habits. There are no studies to investigate this area at present.

5.3 Environmental Factors

Traditionally, new water resource planning involved the development of new dams and catchment water diversion schemes. The link between the natural environmental costs (such as loss of habitat, landscape and groundwater changes) and human health from these developments was not given great consideration (Gardner, 2003). However, the recent natural disasters in Australia such as drought, fire and flooding and more direct human-induced environmental disasters such as the destruction of the Murray-Darling catchment has highlighted the vulnerability of the environment and the costs to human health as a consequence of these large projects (Radcliffe, 2003).

The importance of determining and monitoring the capacity of the environment to sustain human activity is now more widely understood and is recognised in striving to achieve more sustainable living practices. These environmental factors are encapsulated in Ecologically Sustainable Development (ESD) principles (Gardner, 2003).

The commitment by Governments to integrate (ESD) principles into public planning now ensures that factors such as resource allocation and environmental costs are considered in development processes (Sydney Water, 2002).

As a result, policies that address future water resource requirements investigate the environmental costs of new water sources such as building dams or diverting catchment water for human use and in comparison, policies that promote water saving solutions are more favourable (Sydney Water, 2002). Reusing greywater at on-site, neighbourhood or community scales can in part abate or avoid the environmental costs of new water resource projects.

By reusing greywater, households have the capacity to reduce potable water demand by 30-70% (Radcliffe, 2003) and this in turn reduces the wastewater volume to be collected and treated at wastewater treatment plants. This can then reduce the overall nutrient load during treatment and on the environment when the treated wastewater is returned to the environment.

New residential developments could then reduce infrastructure requirements by reducing sewer collection pipe capacities and sizes and treatment plants could reduce size (Emmerson, 1998). Additionally, the energy required to pump and treat the wastewater would be reduced and considering most of the energy provided in Australia is from non-renewable sources such as coal and oil, reducing energy consumption would in turn reduce the environmental strains of extracting and burning these fuels.

The higher nutrient loads and turbidity effects of polluted wastewater being returned to the environment results in immediate and significant changes to the environment it is being discharged into (Gardner, 2003). By reducing mainly the volume of this pollution the environment in principle should improve, however studies on the quality of the improvement are lacking and therefore difficult to quantify.

The reduction in potable water demand generally would contribute to postponing the requirement for developing new water sources (Hunter, 2004). This is usually quantified in terms of extending the time by which future new developments can be undertaken without an increase in public water source and headworks infrastructure.

However, whilst reusing greywater can reduce the environmental effects of potable water demand and wastewater collection and treatment on a broad scale, at the local scale its use on gardens and recreational areas presents many more issues.

Watering gardens or irrigating grounds with greywater introduces a level of pollution to the landscape which may change soil characteristics, effect nutrient availability or poison plants (Al-Jayyousi, 2003). The nature of these potential problems are mainly long-term and due to greywater reuse being only recently embraced, these potential environmentally-related on-site issues are still largely unknown as there is a lack of studies that verify them. Many guidelines promote vigilant checking of adverse environmental impacts such as soil pH and plant growth factors (Department of Health WA, 2002).

The high dissolved solids content in greywater is characterised by high COD and turbidity levels and mainly consists of salts that could increase the salinity and/ or sodicity of soils (Al-Jayyousi, 2003). A soil with high clay content can be more affected by greywater with a high salt content and as a result may become sodic and increase the likelihood of erosion as well as hinder a plant’s ability to securely anchor itself. Also a soil with high salinity can severely reduce a plants’ ability to take up water and nutrients (Singer & Munns, 1996).

Additionally, the influence of greywater-related salinity and other pollution problems in soil may also contaminate groundwater supplies and influence other geographic locations far away from the source of the pollution, thus having a much wider effect (Emmerson, 1998).

If many households within the same geographic location reuse greywater on gardens then collectively the possible adverse environmental affects described above will be more widely exacerbated if soil types and groundwater conditions were greatly affected by the pollution levels in the greywater.

However, these adverse environmental consequences are highly variable as a result of the variable quality and quantity of greywater reused, the variability of soil conditions, the variability of groundwater conditions and the variability of climatic conditions such as rainfall. These highly situational and geographic conditions make the determination of these environmental factors very difficult and may only be realised over the long term (Emmerson, 1998). Thus if a problem does occur, it may be realised when it is too late or more difficult to abate.

The relatively low levels of microbial contamination of greywater can be effectively processed by the bacteria within soil (Jeppesen, 1996). However, if untreated greywater was stored on the soil surface (i.e. ponding) or were released as droplets to the atmosphere, (i.e. spray irrigated) the high availability of oxygen could potentially increase pathogen colony numbers rapidly and substantially increase the risk of disease from human contact as well as become breeding areas for mosquitos and other vermin.

The nitrogen and phosphorous levels in greywater will generally provide essential nutrients for plants, having a positive environmental effect and may reduce or ameliorate the requirement for fertiliser on many gardens and parks (EPA Victoria, 2004), which can create adverse affects such as toxic run-off during rainfall events.

The environmental strains caused from the recent Australian droughts and the generally accepted global climate changes have altered the political and social factors that previously hindered the acceptance greywater reuse in urban areas. However, public health must be addressed and maintained to gain general community acceptance of greywater reuse as part of Government water saving policies and guidelines.

Whilst greywater reuse has positive broad environmental sustainability affects, the specific environmental consequences of its application are as yet not fully determined.

Also, although the costs of the technologies associated with greywater reuse systems have reduced considerably, further cost savings may be realised in reduced or postponed public infrastructure and if the true cost of potable water supply is realised (PWC, 2000).

Chapter 6:

URBAN GREYWATER REUSE TECHNOLOGIES AND PROCESSES REVIEW

The technologies that best address the factors that effect greywater reuse must primarily consider the biological characteristics of greywater (Al-Jayyousi, 2003) in order to ameliorate public health concerns. The level of treatment provided by greywater reuse technologies will further vary according to the system's scale and reuse applications. Treatment technologies can be best described in either user-based or technology-based terms.

The technology utilised in greywater reuse systems can be differentiated into primary, secondary and tertiary levels (Jeppesen, 1994). These can then be further characterised in terms of the number of users the greywater reuse system must support (user-defined) and by their likely reuse applications.

The main scales of use in user-defined terms are single dwellings, multi-dwellings (Jeppesen, 1994) and community-based systems (Thomas, 1997) with the general applications of greywater reuse being garden watering/ irrigation (external) and toilet flushing/ laundry washing (internal).

6.1 General Design Considerations

These main design factors are consistent with most Government guidelines as present.

Relative to wastewater greywater which is predominantly from bathroom and laundry sources is high in dissolved solids (mostly salts) and turbidity, low in nutrients and is likely to contain significant amounts of pathogens (Al-Jayyousi, 2003). The suspended solids that are present are mostly in the form of hair and lint from bath and laundry waste (Jeppesen, 1996). If greywater is sourced from kitchen wastewater it is likely to have a high BOD, high in organic suspended solids and nutrients with low pH (Jeppesen, 1996).

The reuse of greywater from bathroom and laundry sources can be relatively simple for garden watering reuse applications up to sophisticated treatments for toilet flushing and laundry applications. However, treatment for kitchen wastewater, will generally require more sophisticated technologies and processes to address the high BOD and fatty solids generated (Al-Jayyousi, 2003).

In order to primarily address the likelihood of high pathogen contamination and hence public health concerns, greywater must either be disinfected or disposed of in a manner that does not allow human contact (Jeppesen, 1996). For greywater reuse applications where disposal only involves garden watering, sub-surface irrigation systems would remove the possibility of human contact and therefore reduce the level of treatment required (CSIRO, 2004). However, if greywater reuse involved toilet flushing and/ or laundry water applications disinfection would be required as there is a possibility for human contact (Jefferson, 1998).

Finally, all greywater reuse systems must be connected to the centralised sewer collection system as a precaution. If the greywater reuse system malfunctions or if maintenance is to be carried, the system must be capable of being manually or automatically diverted to the sewer line. This would avoid an unlikely event where the greywater is not collected and disposed of which would increase the risk of human contact and threaten public health.

6.2 Technology-based Greywater Systems

Primary treatment systems are designed to convey the greywater to a garden watering or irrigation application from its source and little refinement or treatment of greywater quality occurs. However, secondary and tertiary treatment technologies offer different and varying improvements in treated greywater quality.

6.2.1 Primary Treatment Systems

These systems do not store or treat greywater and as such are best to reuse greywater for sub-surface applications.

The simplest forms of primary greywater reuse systems are best described as greywater diversion devices (Ludwig, 1994) and are the most economical.

A simple plumbing device diverts greywater in the wastewater drainage line to a sub-surface garden irrigation system via gravity without any external energy. This system does not treat the greywater and as such the sub-surface garden irrigation system must be able to cope with fouling material such as hair and lint (Ludwig, 1994). With this in consideration the irrigation pipe is usually oversized and outlets to specific sub-surface points in the garden that contain mini-leachfields. These filter the solids and allow sub-surface infiltration without greywater solids fouling or likely tree root pipe ingress. In these applications the soil treats the greywater and consideration must be given to the type and depth of soil available to complete the process without compromising the environment or public health.

FIGURE 6.1: Simple gravity diversion (Van Dok, 2004)

The diversion systems (shown in figure 6.1) are always connected to the sewer system as well as the irrigation drainage system and usually have a manual valve to divert greywater back to the centralised sewer collection system if required.

Sub-surface irrigation reuse applications avoid human contact with untreated greywater and diversion systems are simple to install and maintain, especially in retrofitting to existing dwellings (Ludwig, 1994). However, these simple systems rely upon gravity flow to apply the greywater and therefore are reliant upon favourable topographical conditions, building and plumbing designs. Also, the intermittent and relatively low flows provided by greywater sources can cause incomplete draining of the irrigation lines and cause fouling in some installations (Ludwig, 1994).

To further stabilise flows and clarify greywater a surge tank can be incorporated into the diversion gravity feed/ discharge system – as shown in figure 6.2. The surge tank is usually no larger than 100L (Ludwig, 1994) and is sealed to avoid human contact. The surge tank provides some primary clarification of the greywater solids and provides a regulated flow through the irrigation lines, thus reducing the likelihood of fouling. The relatively-low storage time is designed not to allow the greywater to enter the anaerobic state, which would increase its pathogen contamination and become foul smelling (Jeppesen, 1996).

FIGURE 6.2: Surge Tank (Van Dok, 2004)

For applications where gravity flow is not workable or mini-leachfield point irrigation is not preferred, a pumped surge tank system can be utilised (Ludwig, 1994 p17). These systems utilise external electrical energy and in order for this system to work effectively, coarse and/ or fine filtration is desired in order to prevent fouling of pumps and irrigation lines. Additionally, filtration will reduce organic loads and solids levels which will inhibit microbial growth in the greywater (Al-Jayyousi, 2003).

Coarse filtration will mainly prevent fouling of the surge tank pump and can take the form of disposable “sock” or mesh-type filters. The geo-textile and nylon sock-type filters (shown in figure 6.3) are the most efficient and low maintenance (Christova-Boal et al, 1996). These coarse filters would typically be installed in the greywater drain line when discharging into the surge tank prior to pumping. The synthetic sock filters expand as they fill-up with filtered material which maintains adequate flow and they require replacing or cleaning fortnightly on average (Christova-Boal et al, 1996). Their removal and disposal is an acceptable health risk provided adequate safety equipment is worn.

Other forms of coarse filters include disc or mesh filters that can be fitted with automatic back-washing systems. They will utilise more external energy and have high initial capital costs, however their operating costs are comparable to sock-type filters (Christova-Boal et al, 1996). On average these filters must be cleaned or will self-clean once a week and automating the filter cleaning process will simplify operator maintenance and lessen the likelihood of human contact with greywater (Christova-Boal et al, 1996). Disc-type filters operate more efficiently at coarser settings (Christova-Boal et al, 1996) and therefore are better utilised as coarse filters.

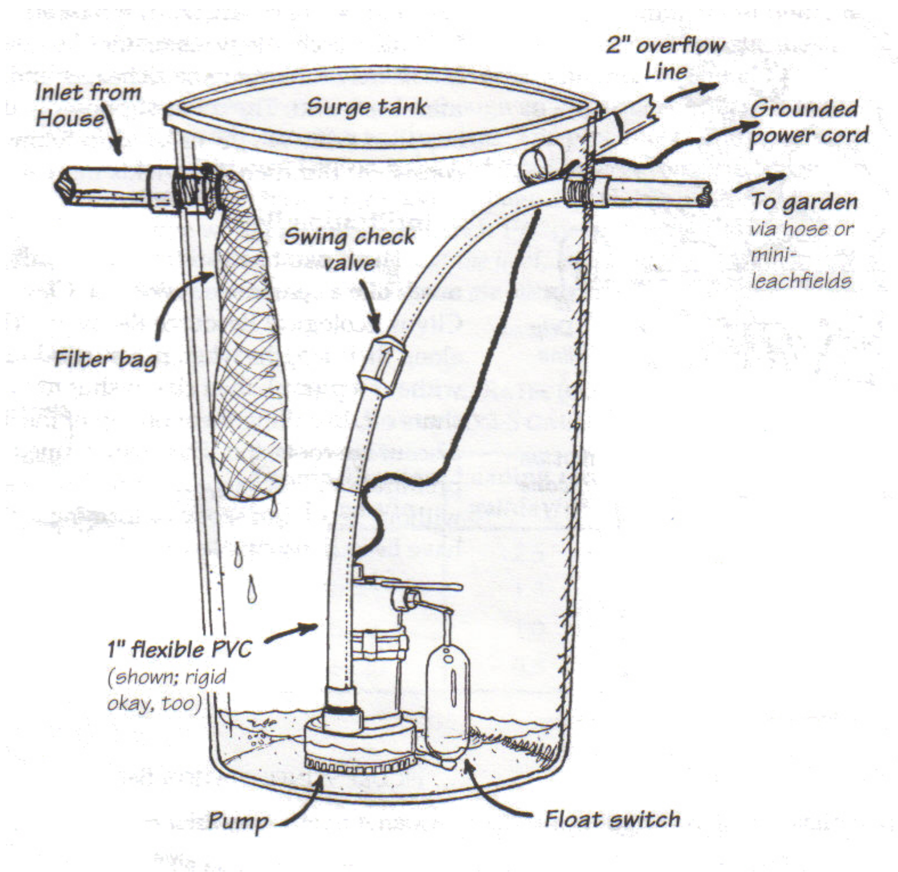

FIGURE 6.3: Primary treatment system with coarse Filtration (Ludwig, 1994)

Fine filtration is utilised primarily to prevent fouling in irrigation lines and are typically installed in-line just after the surge tank pump in before the irrigation discharge line. Therefore they mostly operate under pressure and the most common and cost effective form is a sand filter.

Sand filters will increase the pump design pressure and can also include automatic back-washing systems that self-clean and are very effective at removing finer particles that foul more intricately designed irrigation systems (Gardner & Millar, 2003). Therefore the most efficient greywater reuse applications that utilise drip sub-surface irrigation systems require finer filtration and should incorporate a sand filter as the fine filtration treatment step.

More natural forms of fine filtration such as the soil box (shown in figure 6.4) or infiltration bed (Ludwig, 1994) and the vertical swamp (Thomas & Zeisel, 1997) can be utilised, but their filtration rates and overall effect in the hydraulic design must be closely scrutinised in order to be successful.

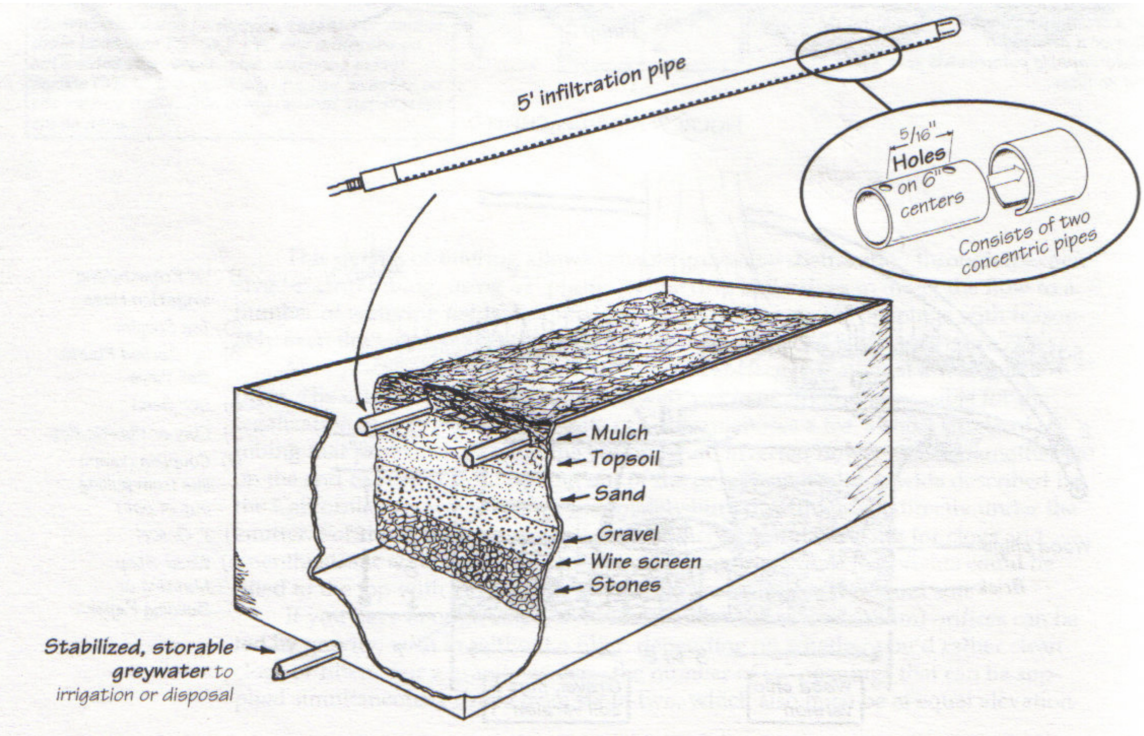

FIGURE 6.4: Soilbox design (Ludwig, 1994)

The soil box or infiltration bed can be mounted above ground or in-ground and consists of layers of gravel, sand, and a top layer of peat or mulch. In soil boxes a top layer of soil can be utilised to support plants, whilst treatment takes place lower down. As with the sand filter process, greywater is pumped or fed in via gravity at one end, through the layers of natural material in the filter and is discharged at the opposite end to other irrigation applications. Disinfection and dissolved solids clarification treatments can also take place in the soil box (Ludwig, 1994).

The vertical swamp utilises a series of relatively large soil boxes mounted vertically on a wall or similar structure. Greywater is pumped into the top box and is allowed to flow via gravity through the series of cascading soil boxes until it is collected in a sump at ground level and redistributed to other irrigation applications. Each soil box supports plants that thrive in saturated soil states, such as reeds. The vertical swamp is generally more effective for higher flows, where space is limited and where it can be mounted in areas away from human contact. The vertical cascading flow created between the soil boxes aerates greywater and further treats the greywater.

The soil boxes are natural filtration processes whereby the filtrate is broken down by the soil or mulch microbes and can also be utilised for plant growth. By supporting plant growth the filter has a positive energy balance in the process train – rather than at the end of the process, i.e. plant growth after irrigation.

For small irrigation areas or relatively lower pressure irrigation systems a submersible-type pump is most efficient. These constantly operate under a positive suction head and are also easily connected to a float-type level switch which automatically controls the pumping operation and surge tank levels (refer to figure 6.3). This lowers the maintenance required to operate and maintain the pump in service and can be mounted inside a sealed surge tank, which also dampens its operating noise.

Centrifugal pumps provide greater pressure and flow capacities for larger greywater reuse systems and must be mounted outside the surge tank. Whilst, these pumps require constant priming, they can be mounted at ground level under a positive suction head. However, a suction line must be mounted at the base of the surge tank through its wall and the surge tank level control device must be mounted separately in the surge tank. This makes the centrifugal pump set-up relatively more complex and vulnerable to ongoing operating and maintenance problems compared to using a submersible pump.

For greywater irrigation applications open-type pump impellers best suit as they are unlikely to foul (Davey Pumps, nd) if filtration fails or is limited. However, open impellor-type pumps have limited pressure requirements and may limit the size and type of irrigation system utilised – within both the submersible and centrifugal pump ranges.

However, given the relatively small land areas of most urban blocks it is unlikely that household greywater reuse systems will require pump pressures and flowrates outside the range of submersible-type pumps and it is therefore more effective to use submersible pumps generally for primary treatment systems.

6.2.2. Secondary Treatment Systems

These systems allow storage of greywater and therefore must include disinfection treatment to avoid further contamination of greywater during storage.

In order to most efficiently disinfect, the greywater must be reasonably clarified and/ or filtered and the filtration options are the same as for primary treatment systems. Sand filtration can reduce the BOD_5 and COD loadings as well as reducing turbidity (Al-Jayyousi, 2003), which aids the disinfection process.

Generally, systems that store greywater seek to maximise the greywater reuse applications available. That is, greywater is most likely to be reused under pressure for garden irrigation, toilet flushing and/ or laundry water applications.

However, these systems can be used for gravity flow garden irrigation applications as well, but this does not maximise the greywater reuse benefits available.

A typical secondary treatment system (refer to figure 6.5) will comprise a surge tank for primary clarification and diversion, a centrifugal pump that transports the greywater from the surge tank through a fine filter and an in-line disinfection system to a storage tank. From the storage tank the treated greywater can then be applied under pressure via another centrifugal pump or under gravity flow to reuse applications.

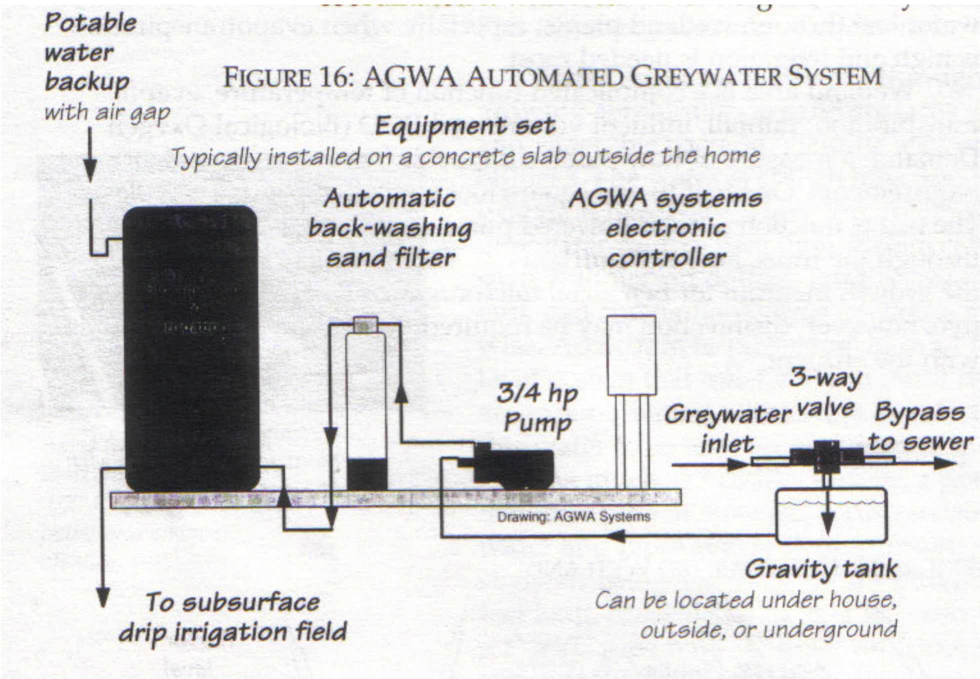

FIGURE 6.5: Secondary Greywater Treatment Technology (Ludwig, 1994)

In systems without storage the disinfection process is applied just prior to point-of-use. This ensures that the greywater is properly disinfected just prior to use, however it is only suited to disinfection technologies that do not require contact time to react with the greywater.

Also, if greywater is passed through fine filtration, but not disinfected before being stored and thus reducing pathogenic growth, during storage pathogen numbers can still significantly increase. This situation can be inhibited by using a black or dark sealed storage tank that prevents natural light and oxygen coming into contact with the stored greywater. Oxygen and natural light promote growth of aerobic micro-organisms and photosynthetic organisms such as algae to grow and reproduce. Therefore by limiting these organism's life-sustaining factors their growth rates will be reduced (Al-Jayyousi, 2003).

If disinfection does not take place before storage there is a risk of creating an anaerobic state within the greywater thereby increasing its contamination levels, however if constant source and discharge flows are provided this could be avoided. Also, if the stored greywater is to be used for toilet flushing and/ or laundry applications a larger sized point-of-use disinfection system may be required as pathogen numbers may have significantly increased during storage.

UV disinfection is a favourable technology for greywater reuse and is most advantageous for in-line operations. It does not require long contact times (just the time taken to flow over the UV lamp) and it will not adversely change the chemical structure of the greywater.

However, UV disinfection technology requires relatively low turbidity and suspended solids in order to prevent shadowing of pathogens when the greywater passes over the UV lamp (Tchobanoglous et al, 2003). Fine filtration will significantly improve the turbidity and suspended solids levels in greywater and will be further minimised after storage if microbial growth is restricted (Tchobanoglous et al, 2003). Therefore it is preferred to use UV disinfection with pre-filtration.

Using chemicals such as chlorine or bromine for disinfection would change the chemical characteristics of the greywater and would require at least twenty (20) minutes contact time (Clifford White, 1972). Further, it may react with certain waste products in the greywater and form more toxic by-products (Christova-Boal et al, 1996). Additionally, overdosing the disinfectant would adversely affect the soil and plants irrigated (Christova-Boal et al, 1996). Other forms of disinfection such as ozone and chlorine dioxide are more complex and more costly technologies and were not be considered for these reasons.

Whether applied in liquid, tablet or powder form, dosing of chemical disinfectants would also require injection and/ or monitoring/ controlling equipment in order to control the disinfection process. This would increase the complexity of the system for maintenance and operating tasks and therefore chemical disinfection was not generally accepted as a preferred disinfection process.

The preferred storage tank size would be from 200L to 500L (Ludwig, 1994) and would comprise a surge tank, centrifugal pump, sand filter, storage tank and an in-line UV disinfection unit. Figure 6 shows a similar system however the UV disinfection system is not shown and would normally be positioned in the process train after fine filtration and prior to storage.

The system can be automated incorporating automatic backwashing filters, solenoid vales and tank level and pump controls. Also an extra centrifugal pump can be utilised for pressurised reuse applications such as toilet flushing, higher pressure irrigation and laundry washing.

The storage tank in a secondary greywater treatment system can also be augmented with rainwater storage (Dixon et al, 1999). This would dilute the generally higher quality run-off water to a lessor quality however the stochastic nature of run-off supply can be alleviated by the more consistent greywater (Dixon et al, 1999). The diluted and treated greywater quality would improve and this would aid disinfection and if post-storage disinfection was utilised the combination of treated greywater/ rainwater would provide more effective internal household reuse applications.

6.2.3. Tertiary Treatment Systems

This classification includes treatment processes that further increase the quality of greywater or polish it for reuse applications. Fixed film biological rotating drums, membrane bioreactors, biologically aerated filters, activated sludge and membrane treatment systems are all included in this category.

However, only two (2) basic forms of biological treatment systems will be described. Whilst utilised on larger scales for more general effluent applications the other tertiary treatment technologies mentioned lack sufficient studies into greywater applications and current literature indicates that costs are high (Al-Jayyousi, 2003).

6.2.4. Biological Treatment Systems

This level of treatment involves utilising the biological content in greywater to reduce microbial contamination, suspended solids, turbidity and nutrients (nitrogen and phosphorous). The treatment process requires a significant level of automation and energy to power the aeration technology as well as pumps and disinfection systems. Kitchen waste may also be included in the greywater biological treatment process.

Greywater is characteristically low in nutrients and this would inhibit the efficiency of biological treatment systems for individual household systems. However, for larger greywater treatment systems that incorporate greywater from multiple households the nutrient levels would improve the overall biological treatment efficiency. Consistency in treated greywater quality can also be achieved through greater storage volumes which assist in the biological treatment process (Al-Jayyousi, 2003).

However, the consistency of biological treatment systems could vary greatly according to the types of chemicals used at greywater sources. Some substances or products used such as laundry washing products, soaps or shampoos with high amounts aluminium or zeolite could poison or hinder the biological process (Christova-Boal et al, 1995).

Basic biological systems would involve simple aeration using a blower within the storage tank for a set timeframe (batch operation) and then discharged through a UV disinfection system to point of use. The aeration process could involve a system vertical swamp type system.

Although greywater is generated frequently, the volume is variable and therefore a batch system is more effective. The process would remain the same as for secondary treatment systems prior to storage, except that fine filtration could be substituted for coarse filtration and a second primary storage tank will most likely be required to store incoming greywater generated while the batch aeration process takes place in the other storage tank.

For systems with larger or more continuous greywater flows a continuous biological system can be used. A rotating drum system can effectively process greywater by creating a fixed biological film on the rotating drum and as it rotates above and below the tank level. The organic content of the greywater remains in an aerobic state and reacts with the biofilm on the drum as it submerges and re-emerges in and out of the tank. This effectively aerates and dilutes the greywater continuously. The processing speed and process effectiveness is determined by the speed of the rotating drum (Thomas & Zeisel, 1997). However the drum must remain wet to keep its biological film active and after retention in the rotating drum tank the biologically-active greywater is clarified and stored for disinfection and then reuse application as shown in figure 6.6.

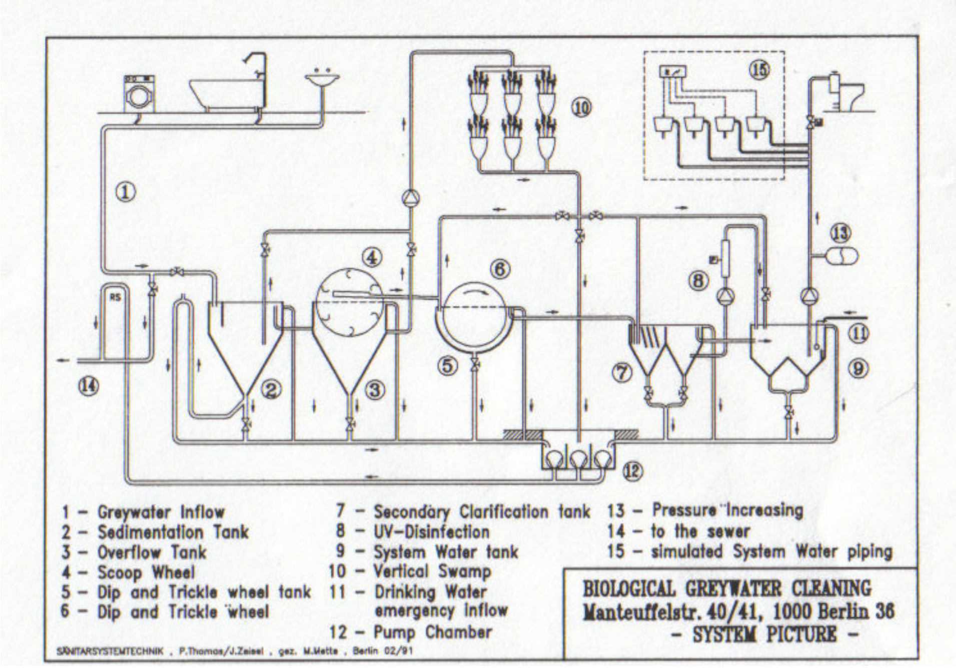

FIGURE 6.6: Rotating Drum Biological Greywater Treatment System (Thomas, 1997)

The adjustable rotating drum speed can accommodate variable nutrient levels in the greywater and the system can achieve reductions in organic loadings down to less than 5mg BOD_7/ L with loadings as little as 3g BOD_7/ m^2/ day without nutrient enrichment (Thomas & Zeisel, 1997). However, the addition of nutrients (Nitrogen and phosphorous) would improve the treatment quality (Thomas & Zeisel, 1997).

Although the relatively moderate nutrient load in greywater is considered generally positive for single dwelling garden irrigation applications, it is likely that for multi-dwellings the collected greywater would have significantly increased nutrient loads (Thomas & Zeisel, 1997). If a greywater treatment system of this scale only utilised secondary treatment processes the higher nutrient-rich processed greywater may increase the likelihood of adverse environmental effects if applied to garden irrigation.

Biological treatment systems are effective and efficient when storing and treating large greywater volumes. The initial low nutrient levels of greywater require larger storage volumes to increase organic loads, however the process is vulnerable to shock loads caused by the variable quality of greywater and toxicity of household products used (Thomas & Zeisel, 1997).

Biological treatment systems are more complex and require greater knowledge to operate and maintain. They also require a considerable amount of energy to operate and close attention must be paid to the types of chemicals used at source i.e. social preferences of the users must be scrutinised.

6.3 User-Defined Greywater Systems

The technologies used in greywater treatment systems can be further defined by the scale of their design and there are three (3) distinct scales of systems identified;

- Single dwellings
- Multi-dwellings
- Community-based systems.

Primary, secondary and tertiary treatment levels can be characterised into these identified greywater system scales.

6.3.1. Single Dwellings

This is the most popular greywater system scale in urban areas and involves on-site reuse systems designed for single households/ dwellings.

Single dwellings are more likely to have gardens requiring irrigation, which offers the greatest benefit of greywater reuse. Therefore significant reuse opportunities are available at this scale. However, the level of technological understanding by greywater reuse system operators is likely to be lower and therefore the level of sophistication of systems on these scales would generally be low as well (Jeppesen, 1996). However, ownership of the system is high (Al-Jayyousi, 2003).

The relatively low volume of greywater produced from single dwellings most benefits primary and secondary treatment designs, as biological treatment may not achieve the organic loads required to work effectively. Also other tertiary treatment systems would effectively polish the greywater to a very high standard, but at a considerably higher cost because of the relatively low treatment volumes and these would generally be above single dwelling requirements.

The level of reuse applications as well as cost budgets would be the main factors to consider in determining the most appropriate level of treatment – a primary or secondary treatment system for a single dwelling i.e. for internal and external reuse disinfection would be required.

To then determine the level of sophistication of the identified treatment, factors such as building layouts, scale of reuse and topography would be scrutinised i.e. if a pump/ pressurised system is required.

6.3.2. Multi-dwellings

These are single land parcels supporting multiple buildings or households such as a block of apartments or townhouses for typically residential, education, tourist or commercial purposes.

The characteristics of greywater from multi-dwellings include high variability in quality however this can be offset by the relatively high volumes produced (Thomas & Zeisel, 1997). The volumes of greywater produced will also be greater relative to the land or garden available for irrigation reuse applications.

For maintenance and operation the users are likely to employ a dedicated caretaker of the system, however individually each user is likely to take less responsibility or ownership in general.

Therefore parameters for a greywater treatment system would involve large volume storage to dilute varying greywater quality and a high quality of treatment with safe application to reduce public health concerns (Thomas & Zeisel, 1997).

Typically a greywater reuse system design would include storage, biological treatment, filtration and disinfection. This system will be able to have the nutrient loads required to treat and polish the greywater and can typically have a footprint (physical size) of only a car space or two. With this level of treatment other applications such as toilet flushing and laundry wash water are possible also, which improves the systems cost benefit. However, whilst the greywater characteristics are likely to improve the treatment process, costs per capita diminish as the levels of users increase in multi-dwelling applications.

6.3.3. Community-Based

Greywater treatment and reuse on this scale involves centrally collecting, treating and distributing greywater from small neighbourhoods or communities (i.e. sub-division or residential street).

The relatively large greywater flows and more consistent quality would further improve greywater treatment effectiveness at these larger scales and there will also be more land available for irrigation applications such as public parks and sporting/ recreational areas.

The biological treatment of greywater naturally clarifies and filters the greywater before disinfection and as a result utilises less energy and less space compared to other treatment processes that rely on mechanical separation/ filtration. However, collecting the greywater would require separate drainage lines in addition to sewer and stormwater systems and additional return lines for reuse distribution. This would be a significant cost and the additional plumbing would mostly suit new developments.

Therefore, at this scale it is more efficient and effective to treat the total effluent produced (blackwater and greywater) from the community and reuse it for non-potable applications. Less plumbing and drainage is required, hence less development cost and the concept can be retrofitted to existing systems i.e. existing sewer lines can be utilised. Also nutrient loads are higher and this will help the biological treatment process.

6.4 Greywater Reuse Applications

The general applications that are most economically feasible and best reflect public health concerns are garden watering and irrigation for external reuse and toilet flushing and/ or laundry washing for internal reuse.

6.4.1. Garden Watering/ Irrigation (External) Reuse Applications

All levels of greywater treatment technologies - primary, secondary and tertiary systems can be utilised for garden watering which are relatively small areas or irrigation which refer to larger areas such as parks.

The different levels of treatment systems are determined mostly by the scale of use and landscape-based factors such as topography, climate and building type.

When small-scale garden watering is desired as per most household applications, a simple greywater diversion or primary treatment system will suffice and the watering system utilised will be a sub-surface system in order to prevent human contact with untreated greywater. If the topography of the land and building design is favourable, gravity discharge to the sub-surface irrigation system may be possible otherwise a pressurised pump system would have to be employed, which would also require filtration to prevent the pump from shortening its service life. The choice of filtration, if desired at all will also be determined by the choice of irrigation system employed.

If simple greywater diversion or surge tank control under gravity flow is desired, then the only adequate reuse application is a sub-surface irrigation system – which is the most efficient form of irrigation. This type of system would utilise a relatively large diameter irrigation tube (25-100mm) to carry the untreated greywater to key locations in the garden where sub-surface mini-leachfields or leaching chambers disperse it within 200mm of the sub-soil surface (Ludwig, 1994) and is shown in figure 6.7. Sealed distribution boxes may also be incorporated in the irrigation distribution lines.

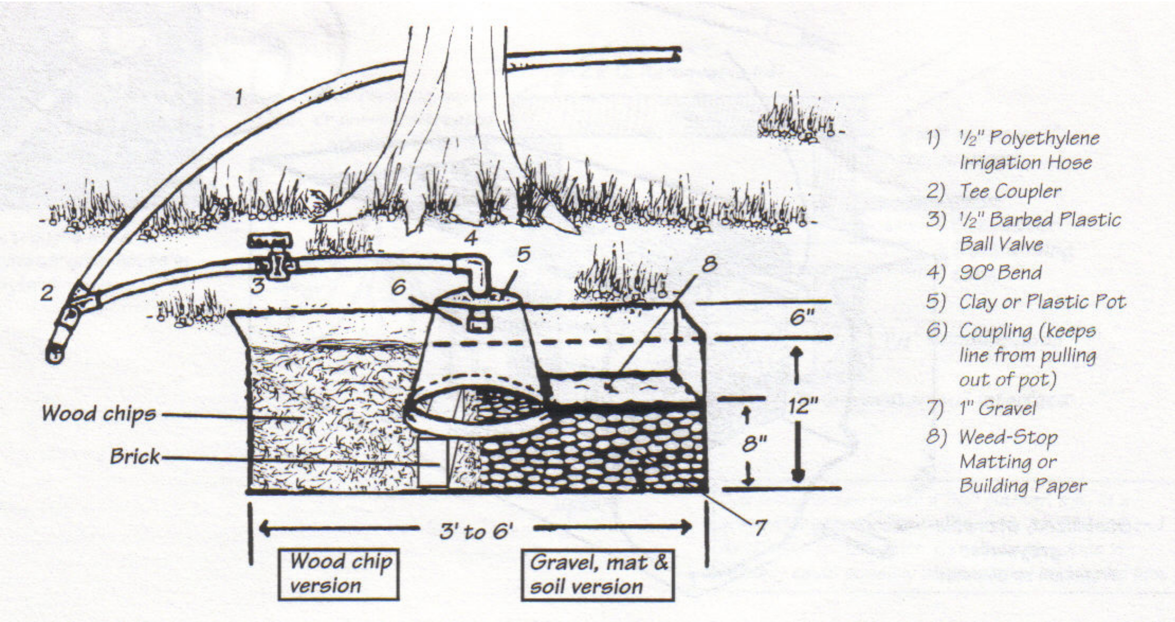

FIGURE 6.7: Mini-leachfields (Ludwig, 1994)

Key design parameters of basic irrigation systems are;

- Use large irrigation tubing to avoid solids build-up within the system.
- Ensure that the sub-surface discharge points (mini-leachfields or leaching chambers) adequately disperse the greywater and not hinder flow or allow tree root and vermin ingress.
- Ensure that there is adequate static head to allow gravity flow of the system without allowing the system to “back-up” at the point of use i.e.

ensure that there is enough height difference between the point of greywater generation and discharge to overcome the friction losses in the irrigation system.

(Ludwig, 1994)

If the topography and/ or building design of the area identified for greywater reuse is unfavourable for gravity flow, then a pressurised system will be required that includes a submersible pump located inside a sealed surge tank with automatic float level control and coarse filtration to protect the pump (Ludwig, 1994).

If an irrigation system with wider dispersion or lawn irrigation is desired then a drip feed system can be utilised. However this system has high pressure losses and is vulnerable to fouling at the dripper outlets. Therefore for this type of irrigation a pump and fine filtration system is required and this would involve coarse filtration, a pump and then a sand filter process. The sand filter would be located in-line after the pump and is shown in figure 6.8 (Ludwig, 1994).

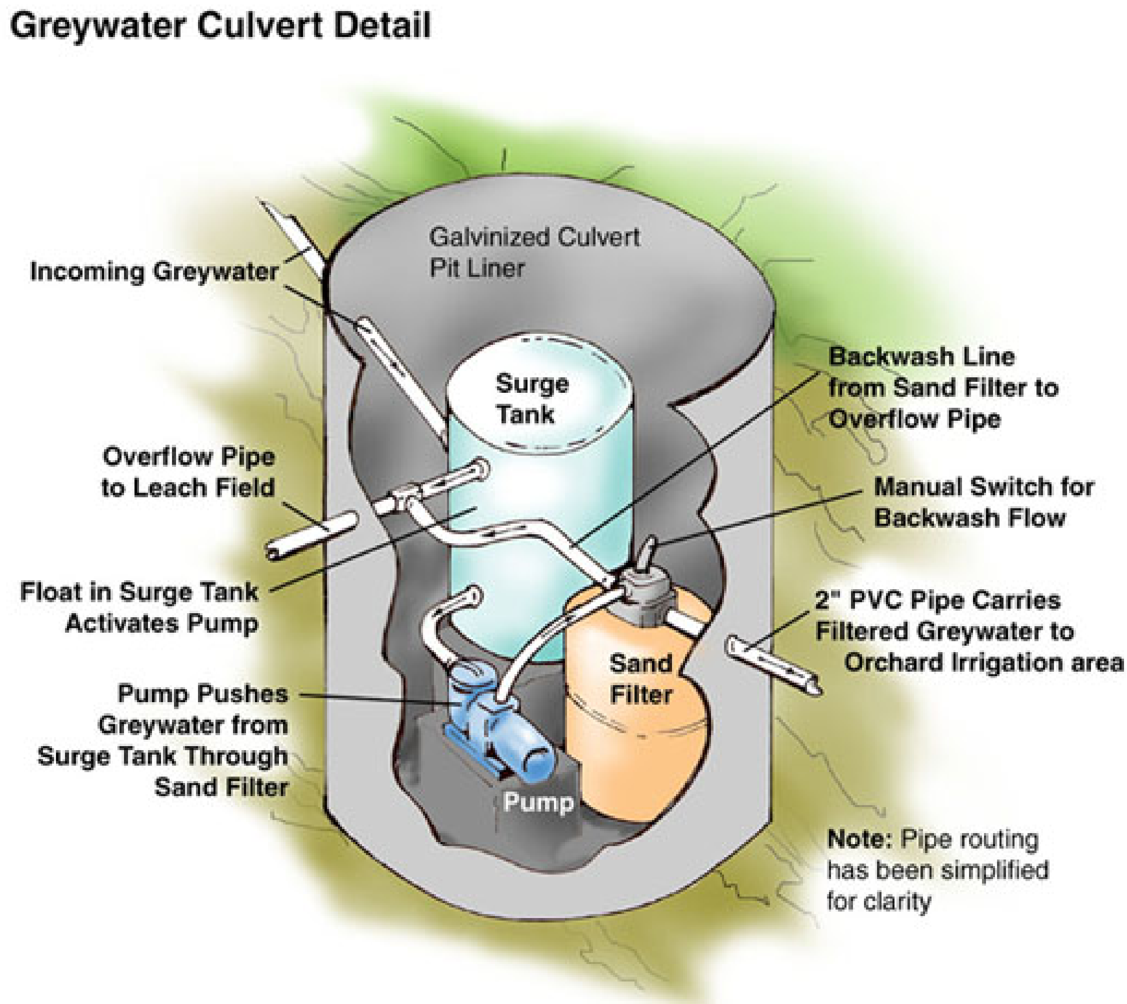

FIGURE 6.8: Greywater Treatment Sand Filter Arrangement (Ludwig, 1994)

If surface dripper or spray system is desired the greywater must be disinfected and this would involve locating an in-line UV disinfection system after the sand filter.

If large-scale irrigation is desired, then greywater storage may be required that will in turn require filtration and disinfection – hence a secondary treatment system would be a minimum standard. It is also likely that the irrigation system will be required to be pressurised, therefore requiring pumped discharge. Also with secondary treatment systems spray irrigation systems may be possible.

Large-scale irrigation applications of greywater reuse may also utilise combined rainwater/ greywater storage systems. Whilst these systems lower the quality of rainwater (Dixon et al, 1999), they compliment their respective storage capacities when utilised for irrigation purposes.

Rainwater storage depending on climate will mostly be variable and unpredictable, where as greywater is relatively constant and predictable. The dilution of polluted greywater with relatively clean rainwater will aid the filtration, pump and disinfection (if required) processes and hence improves the quality of the treated greywater and the equipment service life.

6.4.2. Toilet Flushing/ Laundry Washing (Internal) Reuse Applications

Due to the high likelihood of human contact with these reuse applications, disinfection is required, therefore secondary and tertiary systems are applicable.

However, for laundry washing it is more desirable to lower the turbidity (i.e. dissolved solids - salts) and neutralise the pH of the greywater during the treatment process. A tertiary treatment system would provide this higher reuse quality, but the costs are higher and mostly suits multi-dwelling scales where these higher costs can be shared.

Greywater reuse for toilet flushing offers significant water savings, however if a greywater reuse system requires upgrading to a secondary treatment level only for this purpose (i.e. only require a primary system for garden watering), it can be cost inhibitive.

An alternative from using or upgrading to a secondary greywater treatment system is to use a combined handwash/ cistern system (Ludwig, 1994). This is a proprietary product and is used extensively in Japan. It is shown in Figure 6.9 and involves locating a wash basin that is supplied by mains water and located directly above the toilet cistern. It is an integral part of the cistern structure and the greywater waste from the wash basin drains directly into the cistern storage to be used for the next toilet flush. The cistern also uses the mains to top-up if the washbasin greywater does not fill the required flush storage.

FIGURE 6.9: Combined handwash/ cistern system.

Effective and efficient greywater treatment systems designed to Government regulations and guidelines can be utilised for single and multi-dwellings. The variety of treatment processes available allow site specific determining factors such as topography, soil, climate and building designs a well as different cost budgets and reuse applications to be accommodated. Single dwelling greywater reuse systems are most adaptable for retrofitting to existing building sites.

Biological treatment processes can be more effectively utilised for multi-dwelling greywater reuse systems and the occupants of these dwellings generally do not have as much demand for garden watering/ irrigation. However, kitchen waste can be included and the quality of the treated greywater produced from biological treatment can be applied for toilet flushing and laundry applications in addition to irrigation.

Maintenance is critical to ensuring that public health is kept a priority concern. Whilst all greywater treatment processes include a sewer overflow/ diversion system to guard against treatment and public health failure, all of the greywater reuse systems defined require regular maintenance to operate efficiently and effectively for the applications they are designed.

To alleviate this key concern, maintenance should be carried out by trained operators on a regular basis. The scope of this task would include greywater treatment system and irrigation system maintenance as well as inspections of irrigated areas to ensure adverse environmental impacts are noted and acted upon if required. This could be undertaken in the form of a periodic contract with a specialist or experienced greywater system supplier that operates within the Government policies and guidelines.

Chapter 7:
URBAN GREYWATER REUSE SYSTEMS COST/ BENEFIT ANALYSIS

The recent strong growth in Government policies and guidelines for greywater reuse in urban areas indicate that the financial implications of greywater treatment systems provide greater environmental and social benefits. However, treatment technologies are now more economically feasible and after considering the appropriate Government and regulatory guidelines as well as scrutinising the practical and technical implications of greywater treatment systems, costing the identified benefits finalise the process of determining the feasibility of greywater reuse systems in urban areas.

By decentralising greywater treatment to on-site, water and wastewater asset managers can transfer risk and financial obligations onto households. Whilst these may have cost benefits, treatment plants may lose economies of scale and increase costs (PWC, 2000). These costs are still very difficult to determine and there are many other indirect costs and savings that arise from on-site greywater treatment and reuse in urban areas. These were not considered, but will be discussed later.

Cost savings for the Cost Benefit Analysis (CBA) were benchmarked against the calculated potable water cost savings of reusing greywater for the individual household applications such as garden watering, laundry washing and toilet flushing. The flows generated by these applications were determined from average city household wastewater flows of 586 L/day (Radcliffe, 2003). Since greywater makes up 68% of the average wastewater flow (Emmerson, 1998), the average urban greywater was determined to be 400 L/day/ household.

This figure was then used to determine the individual household usage flows from average percentages as shown in table 7.1.

Household Application	**% of Greywater**	**Volume (L) per day**
Bathroom	25%	100
Toilet Flushing	20%	80
Kitchen Waste	5%	20
Garden Watering	34%	136
Laundry	16%	64
TOTAL:	**100%**	**400**

Table 7.1. (Radcliffe, 2003)

These flow volumes were then converted to costs by determining the annual usage and applying the true cost of potable water supply in Queensland (PWC, 2000).

The cost of potable water supply in Australia is still publicly subsidised with little transparency appearing in the price determination process (Radcliffe, 2003) and the true cost of potable water supply will vary greatly around Australian cities. In Queensland the true cost of potable water supply is estimated to be $2.50 per Kilolitre (PWC, 2000). Further, this CBA did not consider discount rates and assumed likely future potable water cost increases will move towards the estimated true cost of supply.

Additionally, this CBA assumed a service life for the capital equipment utilised in primary and secondary treatment systems of ten (10) years. The relatively low capital costs involved, short service life and widely varying payback periods diminish the requirement to apply discount rates.

For tertiary treatment systems the long payback periods indicate the application of discount rates might not have a significant effect. However when scrutinising the scale of economy for the number of dwellings per treatment system size and the relatively higher capital costs, the application of discount rates might become a critical factor, but they were not applied to this CBA.

For primary treatment systems, maintenance was assumed to be undertaken by the household or system owner and hence no labour cost was noted. However for secondary treatment systems qualified maintenance specialists were assumed to carry out the identified maintenance work quarterly at $50 per visit and for tertiary treatment systems a dedicated operator and maintenance contractor was assumed to control the process.

Irrigation costs were not included in the CBA as it was assumed that these landscaping costs were most likely to be installed regardless of the irrigation water source.

Energy costs were determined using a standard rate of $0.15 per KWh, however in general, energy costs were minimal as primary and secondary systems predominantly operate intermittently and the equipment used have relatively low energy demands.

The costs identified in the CBA reflect the tasks, equipment and processes shown and typical primary, secondary and tertiary treatment systems that were previously identified in Chapter 6 have been analysed and summarised in table 7.2.

Treatment Level	**Source**	**Materials/ Major Components**	**Capital Cost**	**Energy Usage**	**Operation and Maintenance Requirements**	**Operating Cost**	**Water Saving KL ($) Per year**	**Applic's**	**Payback Period Yrs**
Primary [1] *(Diversion)*	Laundry	Diversion Valve	$40	None – gravity fed	Minimal maintenance of valve	None	23 ($58)	Garden watering	< 1 (OK)
Primary *(Gravity Surge tank)*	Laundry	Surge tank	$50	None – gravity fed	Annual tank clean	None	23 ($58)	Garden watering	< 1 (OK)
Primary *(Pressurised Surge tank)*	Laundry	Surge tank Submersible Pump PVC Pipe Coarse Filter Installation	$520	0.3 [2] KWh/ KL	Annual tank clean Annual pump clean Fortnightly coarse filter clean Annual coarse filter replacement	$23	23 ($58)	Garden watering	15 (Beyond service life)
Primary *(Pressurised Surge tank)*	Laundry Bathroom	Surge tank Submersible Pump PVC Pipe Coarse Filter Installation	$550	0.3 [2] KWh/ KL	Annual tank clean Annual pump clean Fortnightly coarse filter clean Annual coarse filter replacement	$23	50 ($124)	Garden watering	6 (OK)

Table 7.2: Cost Benefit Analysis.

Treatment Level	**Source**	**Materials/ Major Components**	**Capital Cost**	**Energy Usage**	**Operation and Maintenance Requirements**	**Operating Cost**	**Water Saving KL ($) Per year**	**Applic's**	**Payback Period Yrs**
Primary *(Pressurised and Fine Filtered Surge tank)*	Laundry Bathroom	Surge tank Submersible Pump PVC Pipe Coarse Filter Sand Filter Installation	$800	0.3 [2] KWh/ KL	Annual tank clean Annual pump clean Fortnightly coarse filter clean Quarterly Backwash Annual coarse filter replacement	$23	50 ($124)	Drip Feed Garden watering	8 (OK)
Secondary [1]	Laundry Bathroom	Surge tank Submersible Pump PVC Pipe Coarse Filter Storage Tank Sand Filter UV Disinfection Installation	$5,500	7.2 KWh/ KL	Annual tank clean Annual pump clean Fortnightly coarse filter clean Quarterly Backwash Annual coarse filter replacement Quarterly UV lamp clean Annual UV lamp replacement	$370	60 ($150)	Garden Irrigation Toilet Flushing	Never

Table 7.2: Cost Benefit Analysis (continued).

Treatment Level	Source	Materials/ Major Components	Capital Cost	Energy Usage	Operation and Maintenance Requirements	Operating Cost	Water Saving KL ($) Per year	Applic’s	Payback Period Yrs
Tertiary [1] *(Aeration)*	Laundry Bathroom	Surge tank Pumps PVC Pipework Coarse Filter Storage Tank Air Blower UV Disinfection Installation Automatic Control	$6,500	0.6 KWh/ Day/ (for min. daily requirement of 2400L)	Annual tank clean Annual pump clean Fortnightly coarse filter clean Annual coarse filter replacement Quarterly UV lamp clean Annual UV lamp replacement Annual blower maintenance	$390	60 ($150)	Garden Irrigation Toilet Flushing Laundry	Never

Table 7.2: Cost Benefit Analysis (continued).

[1] (Diaper, 2004 p12)

[2] (Gardner et al, 2003)

Chapter 8:
FINAL EVALUATION OF COST/ BENEFIT ANALYSIS

The Cost Benefit Analysis (CBA) undertaken benchmarked greywater the capital equipment, maintenance and operating costs of greywater reuse systems against the savings in average urban household potable water uses. These are direct costs, which can be determined accurately given the average urban usage figures (refer table 7.1).

However, a more complete CBA would also consider indirect costs and externalities and these were not included. Whilst there is acknowledgement of them having an effect (Emmerson, 1998 and Gardner, 2003), quantifying them in economic terms cannot be accurately determined. But it is clear that net savings would result from these indirect costs (PWC, 2000). These benefits then would reduce the payback periods of the greywater treatment systems identified in the CBA.

Additionally, the estimated true cost of potable water supply in Queensland was used as a benchmark, not the current subsidised cost. The subsidised cost of potable water supply to a household is relatively low (1.4% to 1.8% of average household income in 1994) compared other costs of living such as food at 10% and videos at 0.5% (Emmerson, 1998). However adjusting potable water supply charges is politically sensitive as they are viewed as basic costs of living.

Following from the Hilmer Report (Hilmer, 1993), the federal Government's National Competition Policy (NCP) requires all significant government businesses to operate as a minimum at full cost pricing unless it is in the public best interest not to do so (National Competition Council, 2003).

Under the NCP any new water schemes must include all capital and infrastructure costs, operating and maintenance costs, a rate of return and a tax equivalent allowance in the price of water. Additionally, all existing schemes must include the costs of operation and maintenance as a minimum. However, this policy is not adhered to in many instances and State and local Governments are able to mitigate the effects of this policy by offering consumer subsidies (PWC, 2000). For example the Council of Australian Governments (COAG) can offer community service obligation payments to cover increases in water charges (PWC, 2000).

However, COAG has endorsed a pricing policy that offers tiered water supply charges that are volume-based, which will reward water-saving households by keeping charges to a minimum for low consumption (PWC, 2000). Gold Coast City Council were one of the first authorities to implement this in 2004 as is designed as a water saving strategy.

8.1 Direct Costs

From the CBA, primary treatment systems with gravity flow irrigation reuse offer the most cost effective greywater reuse processes for single dwellings. However, if topography or building design is unfavourable, a pressurised system will be relatively uneconomical unless both bath and laundry greywater can be processed. This will offer greater water saving benefits but payback periods will be greater.

Tertiary treatment systems offer greater water saving benefits as treatment quality is improved and wider reuse applications are possible, however the costs are expensive and must be shared amongst multi-dwelling users to derive favourable cost benefits.

The greatest benefit of tertiary treatment systems with their more sophisticated processes is realised when they are utilised for large multi-dwelling purposes and the relatively higher capital and operating costs can be aggregated amongst the users.

Whilst the CBA did not investigate these systems, a previous study for a biological rotating drum-type system found a break even point between the capital and annual operating costs and the annual water savings at 130 users (Thomas et al, 1997).

Hence these systems can be analysed financially by defining the number of users required to provide the greatest benefit for the lowest cost.

8.2 Indirect Costs

Indirect costs arising from on-site greywater reuse include;

- Delayed/ reduced water structure municipal head works.
- Reduced water extraction, storage, treatment, distribution and disposal costs.
- Reduced municipal power consumption (Griffiths, 2003).
- Reduced infrastructure economies of scale.

(MacDonald, 2004)

With the exception of the last indirect cost, savings in these indirect costs would be realised by greywater reuse in urban areas. Indeed, many regulators are defining their water saving strategies by the amount of future capital and replacement infrastructure that can be postponed due to the effect of water saving policies such as greywater reuse in urban areas (Sydney Water, 2002). A study previously noted that Brisbane City Council could realise wastewater treatment savings up to $42 million per year if greywater reuse systems were initiated in urban areas (Jeppesen & Solley, 1994 p102).

Power consumption of sewer collection systems can be very high and for new community developments if wastewater flows can be reduced significant savings in power costs can be achieved (Griffiths, 2003).

Additionally, most water authorities and local councils charge sewer discharge fees and this could be reduced if greywater reuse reduces sewer flows. Further, some studies promote two-tiered approaches to pricing of potable water supply and wastewater collection (MacDonald, 2004), whereby a flat fee is charged for asset management and another fee is charged for consumption. The consumption fee would include costs for additional energy, treatment and maintenance of supply and collection. This pricing mechanism is designed to better reflect the true cost of supply and collection of potable water and wastewater whilst rewarding water saving behaviour such as reuse schemes, which would improve the cost benefit of such systems.

8.3. Externalities

These are costs that arise as a result of unintended human-based actions on the biophysical environment (MacDonald, 2004), which in this case mainly include unintended environmental costs at critical steps in the hydrological cycle. These include;

- Habitat and aesthetic changes in catchment areas where new water sources are planned or unsustainable water extraction, storage and distribution is undertaken.
- Pollution from wastewater discharges to the biophysical environment.
- Salinity, sodic soils, high nutrient loads and ground water contamination as a result of greywater irrigation.

On-site greywater reuse would have a positive effect on the first two points as it would result in less potable water usage and less wastewater treatment. However, the relatively undetermined environmental effects of prolonged irrigation of greywater might adversely affect the irrigated environment. Although, the higher nutrient loads in greywater might benefit plant growth and thus reduce fertiliser usage and improve environmental outcomes.

Accounting for these costs could be reflected in a charge that is best included in existing potable water supply and wastewater collection pricing frameworks. The temporal environmental changes and the increasing scientific awareness of human impact on the environment make such a charge highly variable (MacDonald, 2004).

For such a charge a two-tier approach is also proposed whereby the first tier reflects known environmental costs based on existing infrastructure and the second would reflect future relatively-unknown impacts (MacDonald, 2004). These charges would also be incremental - increasing with increased volume usage and this approach would reward reuse applications and hence improving the cost benefit of greywater reuse systems.

Chapter 9:
CONCLUSIONS

Reusing greywater from laundry, bathroom and wash basin sources in urban households for garden watering/ irrigation, toilet flushing and laundry washing applications can on average reduce potable water demand by 41% and this can vary from 30% - 70% (Radcliffe, 2003).

Paramount to acceptance of greywater reuse is the protection of human health. This is reflected in the emerging Government policies and regulatory guidelines that include greywater reuse as part of overall water saving and broader sustainable living strategies. Critical to implementing these policies and hence promoting greywater reuse is community education of the water cycle and participation in decision processes.

Costs of greywater treatment systems are a significant factor, however it should be noted that the current centralised system of flushing toilets, sewerage collection and wastewater plants did not replace nightly soil collections for economic reasons, but rather for public health concerns (Jones et al, 1993 p268). Similarly, greywater reuse should be viewed not only in terms of its economic performance but its more significant social and environmental benefits of contributing towards sustainable development and sustainable resource use.

For individual domestic greywater systems the most efficient and effective technologies involve simple diversion and in-line surge tanks with coarse filtration for sub-surface garden watering and irrigation purposes only. More sophisticated systems that involve storage, UV disinfection, fine filtration and pump treatment processes offer greater economic value when utilised for toilet flushing, laundry washing and garden irrigation applications.

Tertiary treatment systems such as biological processes are most efficient and effective for multi-dwelling applications where more favourable scales of economy and greywater quality can be reached by connecting many users to a system.

However, skilled knowledge is a main concern for the installation and maintenance of these more sophisticated secondary and tertiary treatment greywater systems in order to protect human health. Additionally, commercial products (soaps and laundry powders etc) affect greywater quality and may have a significant effect on plant health, groundwater quality and soil type as well as the type of greywater treatment technology utilised.

Determining the direct benefits of greywater reuse systems can be benchmarked against potable water savings costs. However, these results rare at best very conservative as the true cost of potable water supply is still obscured by non-transparent and subsidised pricing mechanisms.

Greywater reuse also potentially offers indirect benefits to public infrastructure in the form of reduced sewerage flows, reduced treatment plant size, shorter distribution systems, reduced potable water demand and deferring additional potable water sources and extraction infrastructure. However, these are largely unquantifiable at this stage.

Generally, the long-term environmental factors and externalities associated with urban greywater reuse are not yet fully understood either.

Chapter 10:
FURTHER STUDY

10.1 Economic Costs

Further study is required into identifying and quantifying the significance of indirect costs and externalities that result from greywater reuse in urban areas. Although many are identified in the CBA conducted, there may be additional costs and they must be quantified in order to be realised.

Analysis of these costs would complete the full cost benefit analysis and form a suitable basis for a framework to pass these costs back to consumers.

10.2 Environmental Costs

The prolonged application of garden watering and irrigation with greywater on relatively-small urban blocks may have significant environmental effects. These have been broadly defined and their likely effects described, given the high variability of land topography, geography and climate.

However, the relatively-new acceptance of greywater reuse in urban areas has resulted in a deficiency of long-term studies and therefore an incomplete understanding of the long-term environmental consequences of greywater reuse.

10.3 Social Factors

Greywater reuse is generally described as a resource conservation strategy by Governments and regulators. However, if greywater is used to supplement current potable water demands and applications, will it result in consumer behaviour changes in demand management, which is also the goal of resources conservation? Work should be undertaken to characterise and determine the changes in potable water consumer behaviour and the effect of greywater substitution.

10.4 Water Pricing

Work should be undertaken to investigate the “scarcity value” of water. Generally, the real value of water is above the basic costs of supply, distribution and treatment and this is due to the scarcity value and opportunity costs of water.

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Appendix A:
PROJECT SPECIFICATION

University of Southern Queensland
Faculty of Engineering and Surveying

ENG4111/ 2 Research Project
PROJECT SPECIFICATION

FOR:	Mark Wiltshire
TOPIC:	GREY WATER RECYCLING SYSTEMS IN URBAN AREAS.
SUPERVISOR:	Ernest Young
PROJECT AIM:	To produce a Grey Water Recycling System which addresses the past and present concerns of on-site recycling in urban areas.

PROGRAMME: **Issue B, 19 March 2004.**

1. Investigate current Australian practices and relevant guidelines.
2. Investigate why GWRS are not being presently used in urban areas in the following broad categories;
   - (i) Social - Public perception/ willingness to pay.
   - (ii) Political - Costs/ the 'green ticket'/ public health
   - (iii) Environmental - water conservation/ garden ecology/ health
3. Develop the technically most suitable grey water treatment system.
4. Conduct preliminary cost/ benefit analysis.
5. Refine preliminary cost/ benefit analysis.
6. Project applications for grey water recycling and waste water recycling.

As Time Permits;

6. Conduct a pilot study.
7. Further study - Other technical options/ EIS/ LCA/ Other applications.

AGREED: ______________ (student) ______________ (supervisor)

(dated) 10 / 5 / 04