Faculty of Engineering and Surveying

Investigation on Reuse Potential of Laundry Water for Household Garden Irrigation in Toowoomba

A dissertation submitted by

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Abstract

As water consumption demands have increased together with shortage in rainfall during last few years, the crisis in water supply become apparent in many regions across Australia, including Toowoomba. More efficient use of other resources as valuable as water should therefore be encouraged. One feasible resource is greywater, which has been reused widely for toilet flushing and garden watering in many nations around the worlds such as Japan, USA, Singapore and Hong Kong. The reuse of greywater in individual households in Australia can contribute towards the reduction in water consumption and wastewater volume discharged into treatment systems. Laundry water is one of components in greywater which is considered to be less polluted than many other wastewaters. In addition, laundry water usually contains many essential nutrients for plant growth. Therefore, laundry water may be reused for garden irrigation without treatment. If feasible, this practice would provide a cost-effective solution to conserve water and improve soil nutrients. This paper focused on determining the quantity and quality of laundry water generated from a Toowoomba household. The results would be used to evaluating the reuse potential of laundry water for lawn and garden irrigation without treatment. The impacts of laundry water application on human health and soil properties were also taken into account in this paper.

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Prof G Baker

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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

Anaemia is a disease resulting in a deficiency of red blood cells, which can lead to a lack of oxygen-carrying ability, causing unusual tiredness.

Cryptosporidium is one type of enteric protozoa and a parasitical pathogen on an infected host. Outside of the host, they persist as dormant stages.

Diarrhoea is a disease causing frequent discharge of watery faeces from the intestines, sometimes containing blood and mucus.

Enteric Pathogens are gastrointestinal organisms spread by contamination of foods mainly of animal origin and among people who may be carriers.

Giardia is one type of enteric protozoan pathogens which are parasites on an infected host. Outside of the host, they persist as dormant stages.

Hepatitis is inflammation of the liver caused by a virus or a toxin.

Meningitis is an infectious disease characterized by inflammation of the tissues that surround the brain or spinal cord. Symptoms include headache and stiff neck and fever and nausea.

Mole is a SI base unit that measures the amount of substance

Osmosis is referred to transfer of a liquid solvent through a semipermeable membrane that does not allow solutes to pass. The direction of transfer is from the area of higher concentration of the material transferred to the area of lower concentration.

Paralysis is referred to the loss of the ability to move a body part.

Poliovirus is one type of enteric viruses which can be found in faeces. They are all parasites that require the infection of host cells of a suitable host to replicate. They usually have a narrow host range; hence without suitable infected host they can self-replicate and remain in water as inactive particles.

Salinity is referred to damaging levels of salts in solution inhibit the growth and development of plants

Sodicity is referred to high exchangeable sodium percentage (a relative proportion of Na to Ca and Mg) in soil, causing deterioration in soil structure.

Spirit level is a tool for determining whether a surface is horizontal. It consists essentially of a slightly bent transparent tube containing some alcohol with a small bubble in it. The position of the bubble within the tube indicates whether the instrument is horizontal.

Abbreviation

BOD stands for Biological Oxygen Demand. It is a measure of the concentration of organic matter in wastewater.

CFU is Colony Forming Unit, which is a measure of population of microbial concentration in a sample

EC is an abbreviation of electrical conductivity in dS/m. It is used to measure total dissolved solids in liquids or soil solutions.

SAR is Sodium Adsorption Ratio. For liquid, it measures the relative concentration of sodium (Na) ions in the liquid compared to calcium (Ca) and Magnesium (Mg) ions. For soil, it measures the relative concentration of exchangeable ions in the soil instead.

TCC is Toowoomba City Council

TDS is Total Dissolved Solids, representing all inorganic salts dissolved in the liquid or the soil solution.

TSS is Total Suspended Solids

Chapter 1

INTRODUCTION

1.1 Background

Australia is the second largest user of domestic water per capita in the world just after United State America although it is one of the world's driest continents on the planet (Hutcheon 2005). With increasing population and reduction in rainfall frequency as a result of climate change, water is becoming a limited resource. Recent low rainfall conditions across eastern Australia and the associated draw down on many cities' water supplies have forced authorities to introduce mandatory water restrictions to limit urban water use. In 2003, city councils in Sydney, Melbourne, and Canberra applied approximately 12-17% water reduction as temporary or permanent restrictions in order to preserve supplies during the current drought conditions as well as to accommodate the future population expansion (Brennan & Patterson 2004).

Water availability and quality have become critical issues facing all Australians. In the current political climate, water conservation is widely adopted and reuse is a necessity. As pressure on water supply increases, wastewater reclamation and reuse have become increasingly important sources for meeting the current water demand. A significant number of Australian water reuse projects have been carried out in the last decade with great expenses. Although many of these projects have largely been fragmented trials and observations of localised value with little synthesis, they importantly contribute to the development of reuse guidelines and practice (CSIRO 2002).

The reuse of greywater for garden irrigation is one of major focuses in the current water recycle projects with the aim to reduce the pressure on the potable water consumption. Greywater is defined as domestic wastewater that is significantly different from blackwater. Greywater is referred to the domestic wastewater discharged from laundry, bathroom and kitchen, and the term 'grey' is used to imply that if this water is stored for a while, it will turn grey (Marshal 1997). Black water, on the other hand, originates from flushing toilet and expected to contain significant amount of urine, faecal matter and toilet paper. In some situations, greywater may exclude wastewater from kitchen sinks and dishwashers as these discharges are highly contaminated with solid wastes containing organic matters.

Greywater reuse for urban and rural irrigation is attractive to the public in comparison with other types of wastewater. The reuse of treated greywater is common in many places across Australia and around the world. However, this practice is constrained by the high treatment costs. Meanwhile, the potential economic benefit of increasing water supply with direct reuse of greywater (i.e. without treatment) is an attractive option for many Water Authorities.

1.2 Greywater Reuse Option for Toowoomba City

Toowoomba is located in South East Queensland region about 120 km west of Brisbane with population of more than 90000 people (TCC 2004). The city is facing the potential shortage in water supply due to the insufficient rainfall amount in dam catchments to replace water consumed in homes and businesses. The City Council, in early 2005, has enforced level 3 water restrictions to all residential households since Toowoomba's three water supply dams have been below 40% of their capacity. Under level 3 water restrictions, no lawn is permitted and garden watering with drip irrigation is only allowed with in certain time (see Appendix B). Council estimates level 4 Restriction will be in place in August or September 2005 as levels fall to 30% (The Chronicle 2005). These water restrictions, to some extent, will affect the annual Carnival of Flowers as well as the habit of garden city where many people love to grow flowers in their own yards.

Toowoomba City Council is aware of the reuse of domestic greywater for garden irrigation as a potential strategy to reduce fresh water demands, with cost as a possible barrier. Greywater can be recycled in three ways such as the centralised treatment of wastewater which is piped back to individual houses; onsite treatment and reuse systems; and direct greywater reuse (SECITARC 2002). The first two practices are sometimes not preferable due to the highly costs associated with greywater treatment. Meanwhile, direct greywater reuse is currently illegal in many Australian states including Queensland. However, some Australian water authorities have allowed the direct greywater re-use under strict regulations to reduce fresh water consumption (Brennan and Patterson 2004). Direct re-use of greywater from low contaminated source, such as laundry or bathtubs may be feasible option to overcome economic, environmental and public health barriers. However, when wastewater is used as a substitute for fresh water supplies, significant public health, social, legal, economic and institutional issues related to direct greywater reuse must be addressed and carefully evaluated. Information on these issues is scarce; hence appropriate research on direct greywater re-use is necessary to assess its feasibility as well as to develop re-use guidelines and practice.

1.3 Terminology

Greywater recycling systems can be classified in two groups including primary greywater system and secondary greywater system. The first system directly reuses virtually untreated greywater without storage or treatment except coarse screening and filtration may be employed to remove hair, lint and coarse particles. The latter system allows greywater to be treated for toilet flushing and garden irrigation. According to *guidelines for the use and disposal of greywater in unsewered areas* (DNRM 2003), the secondary standard level of treatment plus filtration and pathogen reduction is usually recommended for this system.

The source of greywater for reuse in this study is the laundry source where the degree of pollution is considered to be much lower than other sources such as those discharged from kitchen and blackwater. Direct reuse of laundry greywater means that untreated effluents will be diverted for garden watering by subsurface irrigation.

1.4 Study Objectives

The study aimed to identify the quantity and quality of greywater from laundry source in order to evaluate the feasibility of reuse of untreated laundry water for irrigation in Toowoomba Region. The objectives of this study are:

- Review trends, policy regulations and the public health issues associated with greywater reuse in Australia
- Determine the amount of laundry wastewater in the households of different size and characteristics by using a flow-splitting device which applies the volume reduction principle
- Identify chemical and microbiological quality of laundry wastewater and determine the contamination as affected by the household characteristics
- Determine the effects of increasing storage time on the laundry water's quality and
- Discuss the potential impacts of untreated laundry water on soils in Toowoomba region.

The experiments for this study will be done on laundry water component of greywater collected from Toowoomba residential households. Therefore, the study will directly relate to the potential reuse of laundry wastewater in Toowoomba. However, the results of the study will also serve as reference information for future research and practices associated with greywater reuse.

Chapter 2

OVERVIEW ON GREYWATER REUSE IN AUSTRALIA

2.1 Introduction

Greywater reuse has been employed around the world in many countries and areas where water resources are limited. United States of America (USA) and Japan are two world leaders in reusing greywater as a water conservation strategy (Jeppensen 1995).

USA has been practising greywater reuse for a long period, predominantly for irrigation of gardens and lawns. Greywater reuse in USA were regulated in 1989, but more than a decades ago, a survey of California County Health Officials found that tens of thousand of unapproved systems were already operating across the entire country (Milne 1979, Jeppensen and Solley 1994 cited in May-Le 2004). Until 1998 the direct reuse of untreated domestic greywater for subsurface irrigation was permitted in 24 western states of America and the increasing numbers of other states are following this trend to reuse greywater, particularly under water supply crisis (Emmerson 1998).

Japan, where potable water is subject to shortage, has been intensively applying treated greywater for toilet flushing, landscaping or ornamental ponds and fountains. The onsite biological treatment systems are installed at office buildings or occupancy dwellings to treat discharged greywater before reusing it (Emmerson 1998).

Other countries such as Singapore and Hong Kong, which have limited fresh water resources, are also considering greywater as a valuable resource to reduce pressure on fresh water demand. Hong Kong is almost lacking in natural water resources while Singapore depends heavily on neighbouring Malaysia for water supply. The expensive potable water can be conserved by treating greywater for toilet flushing, and also for potable purpose again if under good purification (Lu and Leung 2003).

In Australia reuse of greywater is a relatively new idea. Regulations and guidelines have only been developed recently, and still under modification in some states or are not existent in the others (see also Section 2.3). It follows that the practices of greywater reuse in some states are still illegal Meanwhile the public have increasingly acknowledged the benefits of greywater reuse, particularly laundry water for garden/lawn watering and have been looking for cheap and safe options to conserve water with this type of on-site reuse.

2.2 Public Perception on Greywater Reuse in Australia

Public perception and acceptance are recognised as the key elements of success for any development scheme that has a potential to change a community's way to live (May-Le 2004). Same principle applied to greywater reuse scheme, the level of support and opposition of the public play a vital role in successfully finalising the greywater reuse option as the practicable water conservation strategy.

The degree of public acceptance to a wastewater reuse scheme varies depending on the reclamation purposes and public perception on health safety associated with the wastewater reuse. The studies in USA and Australia have shown that the participants of the surveys express their greatest opposition to the reuse of water for potable purposes, but seem to accept other purposes in which level of human contact with reclaimed water is low (Table 2.1). Interestingly, the reuse of recycled water for home lawn and garden irrigation purposes attracted little opposition from the public.

Table 2. 1: The degree of opposition from respondents (in percentage) to specific uses of recycled water in different surveys (adapted from Po et al. 2003)

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

Similar results have been also been obtained by studies specific to greywater reuse in many Australian states. In fact, reusing domestic greywater particularly from laundry and bathrooms for garden irrigation has received the most favourable support from public. The social surveys indicated that around 40% of residents in Melbourne were interested in reusing bathroom or laundry greywater for lawn and garden watering (Christova-Boal et al. 1995). In Western Australia, 85% of community support reuse of household greywater as an alternative source of the water for irrigation, while public acceptance of greywater reuse for lawn irrigation was 99% in South Australia (Radcliffe 2004).

From the general public's viewpoint greywater reuse is perceived to be less complex than recycling sewage; hence, there are fewer health issues and less treatment required for this waste. It is possible that public are more willing to accept greywater reuse than many health authorities. Greywater reuse seems to raise considerable public interest because of its merits as a conservation measure of water. However, proponents often underestimate potential health, environmental and aesthetic impacts of greywater reuse due to limited availability of relevant information on the reuse of greywater (SECITARC 2002). As a result, it prevents people from being aware of the potential health and environmental risks so that they can take precautions to minimise and eliminate those risks.

2.3 Water Authorities' Perception on Greywater Reuse

While the public are more willing to accept greywater reuse, the water authorities and regulation bodies show more cautions on regulating the reuse of greywater. There are two possible factors that attribute to greater caution of water authorities than that from the public. These include the high levels of awareness on possible health risks and the high cost involved in treating greywater to a safe level before reuse. Indeed, different from public perception, government groups and water authorities have clearly recognised the potential hazards associated with greywater and are treating the issue of its reuse or recycle very cautiously since public health safety are their duty. In term of economic reason, the present costs incurred by the Water Corporation in treating wastewater for reuse far outweigh any costs incurred by householders when they install a device to simply diverse untreated greywater on their gardens (May-Le 2004).

2.4 Legislation, Regulations and Guidelines

As with other types of sewage, greywater that is treated from a centralized plant to standard level can be reclaimed. However, greywater reuse at household level in sewered areas in many Australian states is currently not allowed or is only permitted with constrained regulation.

In *Guidelines for the use and disposal of greywater in unsewered areas* (DNRM 2003), greywater is considered as a component of domestic sewage having the same regulatory requirements for sewage treatment apply. Therefore, reuse of greywater is currently not permitted in sewered areas in Queensland. However, Boyle (2004) announced that Queensland State Government has recently decided to legalise the domestic use of greywater in sewered areas and has begun work on draft legislation for Code of Conduct. According to Marshall (1997), regulators has also realised significant direct greywater reuse already occurs in Australia and are working towards recommending specific reuse techniques that would reduce health and environmental pollution risks.

In other states, legislation also requires the discharge of all wastewater to a sewer in sewered areas. Exemptions from the requirements are allowed only with the appropriate permissions from proper water regulatory authorities. In Victoria, direct reuse of untreated domestic greywater on gardens without treatment does not require permits; however, it is only allowed during the drought period when freshwater water supply is under pressure (Radcliffe 2004). In New South Wales and South Australia, direct greywater reuse are permitted in both sewered and unsewered areas; however, the installation of on-site treatment system may be required if greywater discharge originates from kitchen sinks and requires storage or is applied as surface-irrigation (Brennan & Patterson 2004). Secondary greywater system is sometimes required if the reuse of greywater is allowed in some areas. Again, the local authorities determine specific regulations on greywater reuse. The current state guidelines for the practice of greywater reuse can be summarised in the table 2.2.

Even though many states have tried to establish their guidelines on greywater reuse, they are inconsistent and are not adequate to form a scientifically based national water recycling guidelines (Brennan and Patterson 2004). Indeed, the guidelines for using potable water in various areas, such as residential, commercial, industrial and agricultural sectors, are well established. Moreover, there are also well-developed guidelines for recycling of treated wastewater for agricultural uses. However, procedures and standards for reclamation of treated and untreated greywater are not adequately known. The guidelines for wastewater reclamations, including greywater reuse, have been only developed recently in some states and still require significant amendments, or are non-existent in other states (Appendix C). In fact, there is little scientific data available to develop comprehensive guidelines for greywater reuse (SECITARC 2002).

Table 2. 2: Variation of State Regulation of Greywater in Australia 2003 (adapted from Brennan & Patterson 2004)

State	Method	Regulation
NSW	Diversion*	Diversion of greywater from the bath, shower or laundry without storage or treatment generally does not need approval; however, Hasting Council (NSW) permits the use of greywater from washing machines inly during periods of water restrictions
	Storage**	Permitted with treatment via a domestic greywater treatment system (DGTS) that provides collection, storage, treatment, and disinfection. Approval by local authorities.
Victoria	Diversion	Method does not need council's septic tank permit but approval is needed to alter the sewer connection, may only be used for subsurface irrigation.
	Storage	Permitted with treatment via a domestic greywater treatment system (DGTS), which provides collection, storage, treatment and disinfection. Output may be used for surface or subsurface irrigation. Environment Protection Agency is the approving authority
Queensland	Sewered areas	Greywater reuse is prohibited, must discharge to sewer (DNRM 2003)
	Unsewered areas	Greywater is considered sewage and comes under Onsite Sewerage Code; only when treated to secondary standard can it be reused
South Australia	Primary treated	Greywater must be disposed of subsurface, while surface discharge requires treatment and disinfection. Greywater systems are considered alternative on-site wastewater system and require approval before installation
Western Australia	Bucketing	Permitted without regulation
	Primary treated	Must be distributed in below ground trenches
	Secondary treated	Application by microdrip or spray irrigation; requires approval from WA Heath before installation (20/30/10 for BOD5, TSS and FC)
*greywater diversion devices (GDD) either by gravity flow or through pump diversion (that is not a storage tank) ** performance guidelines are set for the DGTS for BOD, TSS and FC		

Guidelines provide users of recycled water with best practice advice on planning, design and management of water recycling schemes (Queensland EPA 2001). Therefore, the key to overcome the barriers to greywater reuse is to formulate guidelines for safe usage. That is, more scientific information associated with greywater reuse from appropriate research is needed. Otherwise, the uncertainty about acceptability of greywater reuse will continue and a valuable resource will continue to be wasted.

2.5 Greywater Reuse Cost

Treatment cost is always a major barrier to the success of any water recycle strategy. Many investigations on water recycling have shown that the requirement to treat greywater to standard level as other wastewaters like blackwater or industrial discharges will usually result in very high costs.

The costs for treated greywater reuse are much higher than the price at which the consumers currently have to pay for potable water. It is true that the contamination level in greywater, except from kitchen sinks, is usually lower than other wastewaters; therefore, less treatment is required to purify this wastewater to standard level, even to drinking water. However, the treatment of greywater for reuse purpose is seen not to be cost-effective due to its low influent flow. Gomboso and his colleagues (1998 cited by Newell et al. 1999) estimate that cost of treated greywater use from a centralised treatment plant can be as high as AU$9.89/kL. Meanwhile, the maximum unit cost for drinking water supply is approximately $1per each thousand litres or $1/kL (Table 2.3). Hence, there will be no driving force for consumers to buy treated greywater since the cost supply of drinking water is significantly lower. It again confirms the reason why the water authorities are less willing to carry out greywater reuse scheme with centralised treatment.

Table 2. 3:Price of water to consumers in selected towns and cities* (adapted from Brennan and Patterson 2004)

Town water supply	Tariff (step 1)	Tariff (step 2)
Sydney Water	$0.98/kL	
NSW combined	$0.65/kL	
Armidale Dumaresq	$0.70/kL per first 200 kL each month	$0.88/kL for 201-500kL and $1.15 all excess each six month
Narrabri Shire Council	$0.33/kL	
Riverina Water County Council	$0.65/kL for first 125 kL per quarter	$0.70 all excess over 125 kL per quarter
Hasting Council	$0.85/kL	
Brisbane City	$0.85/kL	
Toowoomba City	$0.60/kL	$1.00 all excess over 125 kL**

*These prices are set by the authorities outside of the market mechanism
** (Wruck, TCC, 2005, personal communication).

The option of installing onsite treatment system for treating greywater before reuse on garden/lawn irrigation also faces a similar economic barrier. Wiltshire (2005) found that the onsite secondary or tertiary treatment systems are not cost-beneficial to householders in comparison with simple diversion system (Table 2.4). Indeed, the installation and operation costs of high functioned treatment system significantly outweigh the water saving costs resulted from greywater reuse. Since the payback period is never achieved, house owners are not economically willing to accept such greywater reuse system although they may highly support the greywater reuse scheme. A social survey conducted in Melbourne suggests that people are only willing to invest in a greywater reuse system if the payback is less than 4 years (Christova-Boal et al. 1995). Only simple greywater reuse systems, which diverse untreated greywater for garden irrigation are economically feasible at household level. The solution is to use discharge from low contaminated source, such as bathtub or laundry water, and reuse it with care so that the human health risk are minimal.

Table 2. 4: Cost Benefit Analysis for Different Greywater Reuse System (adapted from Wiltshire 2005)

Treatment level	Materials (Capital cost)	Operation and maintenance (Operating costs)	Application	Payback period*
Primary (Diversion)	Diversion valve ($40)	• Non-energy consumption • Gravity fed • Minimal maintenance of valve • Cost ($0)	Garden watering	< 1 year
Primary (Surge tank)	Surge tank ($50)	• Non-energy consumption • Gravity fed • Annual tank clean • Cost ($0)	Garden watering	<1 year
Primary (Pressurised surge tank)	Surge tank Submersible pump PVC pipe Coarse filter Installation ($520)	• Energy consumption • Annual tank and pump cleaning • Fortnightly coarse filter cleaning • Annual coarse filter replacement • Cost ($23)	Garden watering	< 6 years
Primary (Pressurised and fine filtered surge tank)	Surge tank Submersible pump PVC pipe Coarse filter Sand filter Installation ($800)	• Energy consumption • Annual tank and pump cleaning • Fortnightly coarse filter cleaning • Annual coarse filter replacement • Quarterly backwashing • Cost ($23)	Drip feed garden watering	< 8 years
Secondary treatment	Surge tank Submersible pump PVC pipe Coarse filter Sand filter Storage tank UV disinfection Installation ($5000)	• Energy consumption • Annual tank and pump cleaning • Fortnightly coarse filter cleaning • Annual coarse filter replacement • Quarterly backwashing for sand filter • Quarterly UV lamp cleaning • Annual UV lamp replacement Cost ($370)	Garden watering Toilet flushing	Never
Tertiary treatment (Aeration)	Surge tank Submersible pump PVC pipe Coarse filter Air blow Storage tank UV disinfection Installation Automatic control ($5000)	• Energy consumption • Annual tank and pump cleaning • Fortnightly coarse filter cleaning • Annual coarse filter replacement • Annual air blower maintenance • Quarterly UV lamp cleaning • Annual UV lamp replacement Cost ($370)	Garden watering Toilet flushing Laundry	Never

Chapter 3

LAUNDRY WASTEWATER REUSE

3.1 Beneficial Uses of Laundry Water for Garden Irrigation

People are increasingly recognising the potential benefits of reusing greywater, particularly laundry water for lawn/garden irrigation, as it encourages water conservation, nutrient recycling and increases soil productivity. Marshall (1997) claims that reuse of greywater can conserve fresh water supplies in natural system such as lakes, rivers and groundwater. In addition, phosphorus, nitrogen and potassium in laundry wastewater are beneficial to plants. Using effluents in agriculture puts the nutrients onto soils where they can be taken up by plants, simultaneously reducing or eliminating the need for fertiliser inputs.

The use of greywater on the garden not only would conserve overall fresh water consumption, but it would also reduce the volume of wastewater entering treatment system. Sharman (1993) concluded that direct greywater reuse for garden irrigation diverts the low-pollutant load from a septic tank in unsewered areas and reduces hydraulic loading entering sewerage. That would allow the septic tank and treatment plant to function more effectively due to the low risk of shock hydraulic loads.

An overseas case study in 1997 (Al-Jayyousi 2004) demonstrates that the poor in Tufileh, Jordan who have some access to land can measurably reduce poverty in terms of both economic and social dimensions by reusing greywater for their garden irrigation. Each family in project areas was able to reduce its food expenditure by consuming its garden product and selling surplus. In addition, they could also save costs from freshwater bills and fertilizer supply on soil. These savings will be put back into the reuse schemes to enhance the quality of greywater recovered for unrestricted irrigation of higher value and faster growing crops.

3.2 Quantity of Laundry Wastewater for Garden Watering

The quantity of laundry wastewater generated in each household varies depending on the characteristics of the household such as numbers and age of occupants, personal habits and lifestyles.

The types of washing machine available also affect the volume of the effluent. Indeed, the development of efficient washing machines has reduced the volume of wastewater consumed in front loading washing machines in comparison with top loading machines. Typically, a top-loading washing machine uses 120-190 litres/load while a front-loading washer requires about 55-90 litres per load (Ferguson et al. 2003). According to Australian Bureau of Statistics (ABS 2003), for houses connected to mains, 87.5% have top-loading washing machines and 7.9% with front-loading washing machines. Brennan and Patterson in their study (2004) concluded that only half of the washing machines in current use are likely to be replaced in the next five years when the age of the machines exceeds their life service of 10-15 years. Therefore, significant amount of laundry wastewater is available in the residential communities due to the high proportion of top-loading washing machines.

If the laundry water can be used on garden, it could save lot of fresh water from consumption. For example, average annual water consumption for a typical house in Toowoomba is approximately 240 kL/year and 35-40% of the domestic water consumption is attributed to lawn and garden watering (Wruck, TCC, 2005, personal communication). That is, each household of three-bedroom dwelling in Toowoomba uses 240 litres per day as an average to water its garden. Meanwhile, typical washing machines in Australia may generate 94-139 litres/house/day (Radcliffe 2004). Hence, laundry water reuse could possibly provide nearly half the amount of irrigating water needed in each household.

3.3 Quality of Laundry Water for Garden Watering

Laundry water is quite different in its quality from the potable water. It contains many substances, such as boron and phosphate, and the water is often alkaline and saline. The detergents used for washing clothes comprise of phosphorus, ammonia, organic nitrogen and boron in varying quantities. The suspended solids such as lint, hair and dirt are commonly present in laundry effluents. Laundry greywater may contain urine and faeces from babies' nappy washing, food scraps from kitchen towel and napkin washing, soil, hair, detergents and other cleaning products (Casanova et al. 2001).

Reusing greywater for gardens may detrimentally alter the properties of soil and gradually kill plants sensitive to phosphorus, particularly Australian native flora. Many of these contaminants are classified as plant nutrients and if disposed to waterways or groundwater may cause environmental damage and toxicity to animal and human through consumption. The microbiological contamination in laundry water also raises concern on the risk of human infection by bacteria, viruses and other infectious pathogens.

3.3.1 pH

pH is the negative $\log_{10}$ of the hydrogen ion concentration of a liquid indicating whether it is acidic or alkaline. Laundry wastewater is considered highly alkaline. The high pH of washing increases the ability of detergents to remove stains (Patterson 1999). Excessive addition of alkaline wastewater to soil could increase in soil pH, which may be detrimental to plant growth even though most soils have a buffer capacity to resist pH changes. Soil properties also change when the soil pH changes, depending on the intensity of variation in the soil pH (Singer & Munns 2002). If the soil pH is too high, Fe, Zn and Mn may become immobilized by precipitation, chelation with humus or association with oxide clay minerals (Myers et al. 1999). Alkaline soils have severe problem related to Fe deficiency. Moreover, in wastewater treatment employing biological processes, pH must be controlled within a range favourable to particular organisms involved (Sawyer et al. 1994). Hence, pH characteristic of laundry greywater is very important to evaluate the applicability of laundry wastewater for watering the backyard gardens.

3.3.2 Nitrogen

Nitrogen (N) is a very essential plant nutrient because all plants need to take up a substantial mount of nitrogen during their lifecycle. Indeed, N is required to form chlorophyll, proteins and many other molecules essential for plant growth (Kamprath 1999). Even though some plants can acquire N from atmosphere, most plants obtain N as ammonium (NH_4^+) and Nitrate (NO_3^-) ions from the soil solution. Hence, irrigation with nitrogen rich effluents is beneficial to soils and plants. Nitrogen added in excess of the plant's uptake can be easily leached; hence, it will not interfere with soil nutrient balance (Myers et al. 1999).

However, leaching of N to the groundwater is one of primary factors limiting the re-use of effluent, containing high N concentration. Nitrate is the dominant form of N leached into groundwater and nitrate in drinking water has adverse effects on human health (ANZECC 2000). Algal growth or eutrophication problem is also associated with runoff with high concentration of nitrogen into surface water bodies. For these reasons, information on nitrogen is needed for wastewater quality analysis.

3.3.3 Phosphorus

Phosphorus (P) is another important nutrient for most physiological processes in plants and P deficiency severely affects plants' growth. Phosphorus is usually a limiting factor to the growth of plants as many Australian soils are deficient in phosphorus. Major quantity of P is kept in sedimentary rocks for considerable periods before it is only released to soils during erosion and weathering of rocks (Miller 2004). Phosphorus occurs in water and in soil solutions mainly as phosphates. Most phosphate compounds in soil have a low solubility and only a small amount of soluble phosphate in soil is available for use by plants (Miller 2004).

Phosphorus is used in laundry detergents as a builder and deflocculating agent (Ferguson et al. 2003). The amount of phosphorus in laundry wastewater varies depending on the types of detergents used. Phosphorus is present in wastewater almost solely as orthophosphate, condensed phosphate such as pyro-, meta- and other poly phosphate and organic bound phosphate (APHA 1998, Miller 2004). Total phosphorus measured in mg/L of water or wastewater represents the total mount of these phosphates. Patterson (1999) found that the P concentration in laundry wastewater can be lower than 5 mg/L and as high as 53 mg/L for non-phosphate detergents (labelled with NP) for phosphate based detergents (labelled with P) respectively (Table 3.1).

Irrigation with laundry greywater could increase the amount of available phosphorus in soil for plant uptake; in particular, laundry wastewater discharge associated with the use of phosphate-based detergents. However, potential problems could occur from excess P loading when drainage occurs, which could contaminate groundwater and may cause eutrophication through erosion of P-rich topsoil and a discharge of dissolved P in runoff to surface water bodies. With respect to soil nutrients, however, Myers et al. (1999, p67) states "Irrigation with effluents containing phosphorus in excess of plant requirements is beneficial to phosphorus availability and soil's phosphorus in long term".

Table 3. 4: Concentration of Phosphorus and Sodium in laundry Detergents (Patterson 1999)

POWDER LAUNDRY DETERGENTS	Phosphorus Concentration Level (*)	Sodium Concentration Level (**)	LIQUID LAUNDRY DETERGENTS	Phosphorus Concentration Level (*)	Sodium Concentration Level (**)
AWARE ENVIRONMENT CONC	Low	Moderate	**Aura (P)**	Moderate	Low
BIOZET (NP)	Low	Low	**Australian Earth(P)**	Low	Low
BIOZET WONDERFUL (P)	Very High	High	**Australian Earth conc.**	Low	Low
BUSHLAND (NP)	Low	High	**Blitz conc. (NP)**	Low	Low
CASTLE EXCEL (P)	High	Very High	**Bushland (NP)**	Low	Low
CASTLE EXCEL CONC (P)	High	Moderate	**Cold Power (P)**	Very High	Low
COLD POWER (P)	Very High	High	**Drive conc. (P)**	High	Low
COLD POWER MATIC (P)	Very High	High	**Dynamo (P)**	Very High	Low
COLD POWER ULTRA CONC(P)	Very High	Moderate	**Dynamo conc.(P)**	High	Low
DRIVE ENZYME POWER (P)	Very High	Moderate	**Earth Choice**	Low	Low
DRIVE POWER CONC (P)	Very High	Moderate	**Envirocare Plus (P)**	Moderate	Low
DUO CONC (P)	Very High	Moderate	**Greencare (NP)**	Low	Low
DYNAMO CONC (P)	Very High	Moderate	**Home Brand**	Low	Low
ECO-WISE WASHING SODA	Low	Low	**Mountain Economics**	Moderate	Low
EXTRA BLUE CONC	Low	Very High	**Biozet conc. (NP)**	Low	Low
FAB (P)	Very High	Moderate	**Omo Liquid (P)**	Very High	Low
FAB CONC (P)	Very High	Moderate	**Omo Micro conc. (P)**	High	Low
GOW'S BIOCLEAN (P)	Moderate	High	**Savings**	Low	Low
TRINATURE HERBAL CONC	Low	Very High	**So Gentle**	Low	Low
HOMEBRAND (NP)	Low	Very High	**Surf (P)**	High	Low
HURRICAN BIODEGRADABLE	Low	Very High			
HURRICAN SUPPER CONC (NP)	Moderate	Moderate			
LOVE 'N' CARE CONC (P)	High	Moderate			
LUXPURE SOAP FLAKES (NP)	Low	Low			
MOUNTAIN	Moderate	Moderate			
OMO (P)	Very High	Moderate			
OMO MATIC LOW SUDS (P)	Very High	High			
OMO MICRO CONC (P)	Very High	Low			
OMO SENSITIVE (P)	Very High	Moderate			
PLANET ARK ULTRA CONC	Low	Moderate			
RADIANT XL CONC (P)	Very High	Moderate			
SAVING CONC (P)	High	High			
SAVINGS (NP)	Moderate	Very High			
SPREE (P)	High	Moderate			
SPREE CONC (P)	Moderate	Moderate			
SURF (P)	High	Moderate			
SURF COLD WATER CONC (P)	High	Moderate			
TRINATURE HERBAL CONC	Low	Very High			
WHITE TULIP TABLETS (P)	High	Low			

Levels of Phosphorus and Sodium are measured from a single full washing load (150L).

(*) Phosphorus Concentration Level: Low (<0.8 mg/L); Moderate (0.8-12 mg/L); High (12-30 mg/L); Very High (>30mg/L).

(**) Sodium Cocentration Level: Low (<115 mg/L); Moderate (115 - 230 mg/L); High (230-460 mg/L); Very high (>460 mg/L).

The Phosphorus and Sodium Concentration Levels are classified based on the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC 2002)

3.3.4 Sodium and Sodium Adsorption Ratio

Sodium (Na) is detrimental to plant metabolism, soil structure and soil hydraulic conductivity. High concentration of Na is toxic to certain plants since it can build up in the soil gradually. Sodium concentration at high level reduces the plant's ability to take up water from the soil (Little 2001). Continual addition of sodium decreases the soil's hydraulic conductivity, possibly leading to poor drainage. Singer and Munns (2002) explain that high concentration of Na in low salt concentration soil allows soil colloids, such as clay and humus, to disperse into individual hydrated particles instead of remaining flocculated. In addition, when cationic exchange occurs, these hydrated particles may bond into a waterproof barrier and clog the soil's pores (Gayman 1994).

Laundry detergent formulations usually have high content of sodium salts as an agent that assist the manufacturer in processing operation (Patterson 1999). High Na content of household product for laundry and cleaning detergents is, therefore, a primary source of soil failure. The term "soil failure" in this study refers to the change in soil structure in which soil particles disperse, reducing soil pore space and eventually leading to surface sealing and poor drainage. The study of Robert Patterson (as stated by Gayman 1994) describes the inevitable consequence of continual addition of sodium into soil reducing the soil's ability to treat and absorb domestic wastewater. Physical flooding, blockage of soil pores and death of aerobic organisms may cause further problems with continual discharge of laundry water as soil becomes impermeable.

Most detergent manufacturers usually do not provide packaging information on the relative proportion of Na contained in their laundry products, although low sodium products are available (Patterson 1999). His study has reviewed the sodium content in some common laundry powders and laundry liquids available in Australian market (Table 3.1). Interestingly, some of the detergents labelled with no added phosphorus still have very high concentration of sodium. The lack of information to consumers restricts their choices of environmental friendly products.

The sodium adsorption ratio (SAR) is used as an indicator in order to determine sodicity hazard of irrigation water on soils. In fact, only exchangeable sodium concentration in soil, which is formed from Na ions in water, leads to soil problems (Singer & Munns 2002). SAR is a measure of the relative concentration of Na ions compared to Ca and Mg in solution, but weighted according to their relative charge.

$$\text{SAR of water} = \frac{[Na]}{\sqrt{[Ca]+[Mg]}} \tag{3.1}$$

$$[Na]\ (\text{mmol/L}) = \frac{Na\ (\text{mg/L})}{22.99} \tag{3.2}$$

$$[Ca]\ (\text{mmol/L}) = \frac{Ca\ (\text{mg/L})}{40.08} \tag{3.3}$$

$$[Mg]\ (\text{mmol/L}) = \frac{Mg\ (\text{mg/L})}{24.32} \tag{3.4}$$

Where

$[Na]$: Concentration of Na in water

$[Mg]$: Concentration of Mg in water

$[Ca]$: Concentration of Ca in water

1000 mmol (millimole) = 1 mol (mole)

Myers et al. (1999) suggest that effluent with an SAR of 3 or more has the potential to cause increased soil sodicity.

3.3.5 Total Dissolved Salt and Electrical Conductivity

Total dissolved salt (TDS) and electrical conductivity (EC) are two commonly used measures of salinity in water and wastewater. TDS is a measure of all inorganic salts dissolved in solution in milligram per litre, whereas EC is a measure of a solution's ability to conduct electricity and is measured in microSiemens per centimetre (µS/cm). According to Myers et al. (1999), EC is proportional to the concentration of TDS and TDS is often estimated from EC by the following equation:

$$TDS(\text{ mg/L}) = 640 \times EC(dS/m) \qquad (3.5)$$

$$1 \text{ dS/m} = 1000 \text{ } \mu\text{S/cm} = 1 \text{ mS/cm}$$

High salt concentration in wastewater applied to soil will lower the total water potential of soil and will affect water and nutrient uptake by plat roots. To absorb water from a saline soil solution, the plants must exert more energy to increase the solutes concentrations inside its root cells compared to those of soil solution outside root as a result of osmosis (Singer and Munns 2002). Eventually, plant growth is inhibited by high energy consumption to regulate osmotic component of water potential. In addition, high ion accumulation inside plants may reach toxic level, which is detrimental to plants. Therefore, irrigation with highly saline effluent on soils may reduce plant productivity or, in extreme cases, kill crops and native vegetation.

3.3.6 Biochemical Oxygen Demand

Biochemical oxygen demand (BOD) is a measure of the concentration of organic matter. The BOD test is widely used to determine the pollution strength of domestic and industrial wastes in terms of the oxygen that the waste will deplete if discharged into natural watercourses in which aerobic conditions exist (Sawyer et al. 1994). BOD_5 is the test that indicates the amount of oxygen required by microbes to break down organic compounds in 5 days.

Organic matter in laundry greywater could arise from food residues and human wastes, for example, when kitchen towels, children clothes and babies' nappies are washed. The higher the concentration of the organic matter present in wastewater, the faster is the depletion of dissolved oxygen (DO) in water bodies, leading to the development of anaerobic conditions. Accordingly, excessive organic matter in wastewater in general and laundry water in specific might be a source of offensive odours during the microbiological decomposition of organic matter. Moreover, high amount of organic matter may clog irrigation equipments and soil channels, reduce water infiltration, permeability and aeration, and induce anaerobic conditions, which could limit root growth (Myers et al. 1999).

3.3.7 Boron

Elevated levels of boron (B) may arise in laundry greywater due to presence of borate in bleaches and some detergents. Boron is considered as a plant micro-nutrient which plants require in very small amounts for their growth and physiological functions, such as aiding calcium and carbohydrate metabolism in plants (Richards 1954). Most soils provide adequate amounts of this nutrient naturally. According to Queensland EPA (2003), there are no risks to human health from boron in recycled water, but some plants could be sensitive to boron as concentrations only slightly higher than those considered beneficial can cause severe injury or death to plants. According to Richards (1954), most plants could tolerate up to 1.0 mg/l of B in irrigation water and only B tolerant plants can cope with up to 4 mg/l (Table 3.2).

Table 3. 5: Relative Tolerance of Plant to Boron (adapted from Richards 1954)

Tolerant	Semi tolerant	Sensitive
Asparagus	Sunflower	Pecan
Palm	Potatoes	Black walnut
Sugar beet	Cotton	Navy bean
Garden beet	Tomato	Plum
Alfalfa	Sweet pea	Pear
Gladiolus	Radish	Apple
Broad bean	Field Pea	Grape
Onion	Ragged Robin rose	Cherry
Turnip	Olive	Peach
Cabbage	Barley	Apricot
Lettuce	Wheat	Thornless blackberry
Carrot	Corn	Orange
	Milo	Avocado
	Oat	Grapefruit
	Zinnia	Lemon
	Pumpkin	
	Bell pepper	
	Sweet potatoes	
	Lima bean	

* Tolerance within a group decreases from top of the list to the bottom

3.3.8 Heavy Metals and Trace Elements

Accumulations of heavy metals and trace elements in the soil may become toxic to plants. However, irrigation with laundry water is unlikely to present a serious risk of this type of problem as the concentrations of heavy metals and elements in laundry water are generally very low. Two studies on greywater reuse in Victoria (Christova Boal et al. 1995) showed no significant concentrations of heavy metals in greywater although elevated levels of aluminium and iron were found in some samples. It is suggested that unusual high levels of aluminium, zinc and iron present in greywater could be due to the leaching of these ions from plumbing and storage materials. Hence, systems associated with greywater collection, storage and reuse should be constructed from non-corrosive materials, for instance plastic or fibreglass. The concentrations of heavy metals in laundry wastewater are reasonably satisfactory when compared with the guidelines of water quality required for irrigation (Table 3.3). Therefore, irrigation with laundry wastewater is unlikely to result in soil contaminations with heavy metals.

Table 3. 6: Typical Heavy Metal Values of Laundry Greywater

	Heavy Metal Range of Laundry Greywater		Guideline of water quality for irrigation[c]	
Parameter (mg/L)	Study 1[a]	Study 2[b]	Long-term trigger values (long term use - up to 100 years)	Short-term trigger values (short term use - up to 20 years)
Aluminium (Al)	< 1.0 - 21	< 1.0 - 44	5	20
Arsenic (As)	0.001-0.007	< 0.0001-0.007	0.1	2.0
Cadmium (Cd)	< 0.01	< 0.01- 0.05	0.01	0.05
Copper (Cu)	< 0.05- 0.27	< 0.05- 0.49	0.2	5
Iron (Fe)	0.29- 1.0	< 0.05- 4.2	0.2	10
Selenium (Se)	<0.001	< 0.001	0.02	0.05
Zinc (Zn)	0.09- 0.32	0.1- 11	2	5

[a] Christova -Boal, Eden & McFarlane (1995)

[b] Christova -Boal, Lechte & Shipton (1995)

[c] Australian and New Zealand Guidelines for Fresh and Marine water quality (ANZECC 2000)

3.3.9 Potential Microbial Infection from Laundry Water Reuse

Both direct and indirect risks of human infection arise from the presence of microbial pathogens in wastewater, laundry water in this case, which is used for irrigation. Many organisms found in wastewater including protozoa, viruses, bacteria and helminths may cause the infectious diseases of humans. According to Queensland Guidelines for Safe Use of Recycled Water (Queensland EPA 2003), these pathogens can give rise to range of diseases, such as vomiting, diarrhoea, respiratory illness, anaemia, hepatitis, meningitis, paralysis and eye and skin infections. Myers (1999) specified that these risks are affected by a number of factors including the amounts of faecal contamination, the types and infectiousness of pathogen, the nature and level of treatments, the potential for human exposure to the effluent, the method of irrigation and types of plants grown. Any risks from irrigating ornamental trees are dramatically lower than those associated with irrigating crops for human consumption. In addition, risks of human infection are also lower where the human contact with reused wastewater is minimal.

Several types of protozoa are found in faeces and are responsible for many severe sicknesses in human. According to Rose (1986), protozoa have a single-cell structure and are able to produce a cyst which enhances their survival in wastewater. Marshall (1997) claims that the majority of diseases associated with reuse of domestic water are due to enteric protozoa excreted from human intestines, for instance, *Giardia* and *Cryptosporidium*. However, these types of pathogens seem not to be a great concern associated with laundry water reuse. In fact, the study on residential greywater reuse in Arizona (Water CASA 1998) showed that no *Giardia* and *Cryptosporidium* are detected in any greywater samples and no illness associated with these protozoan parasites are self-reported by residents who directly reused greywater for their garden irrigation by several methods including surface irrigation, below ground, soaker hose, bubblers and other means. Although the study analysis represents a microbial quality of the combined greywater from all household sources including kitchen, bathroom and laundry, the study implies that laundry wastewater may be free from the enteric protozoa.

Enteric viruses are another intestinal pathogens found in recycled water, but in a small proportion. Haas et al. (1999) explain that viruses are present in water as inactive particles due to the lack of ability to self-replicate outside the host organism. These enteric viruses can be commonly detected in faecal contaminated water, and most viruses of interest in recycled water only affect humans because the widespread use of vaccine in developed nations like Australia, which has eradicated the wild type of *Polioviruses* (Ward et al. 1993 stated by Toze 2004). Accordingly, only human faecal contamination of water needs to be of any concern for viral infection of human.

Bacteria are the most common types in microorganism kingdom. The numbers of bacteria are always found in everyone's intestine including healthy people, since they are part of the normal flora in human body (Fegan et al. 1998). According to Feachem et al. (1983), during carrier states, person will be excreting the pathogenic bacteria without showing disease symptoms. Therefore, many pathogenic bacteria are often present in human faeces and can widely transmit to others persons through faecal contamination.

Helminths are also common intestinal parasites found in wastewater, including nematodes, tape worms, round worms, hook worms and whip worms. According to Toze (2004), some of these helminths require an intermediate host to ingest human faeces for development while the others are capable of causing human infection via the faecal-oral route without intermediate hosts. This means that the risk of helminths infection to humans is also strongly correlated with the faecal contamination of water.

3.3.10 Indicator Organisms

Pathogens in wastewater may be significant in quantities and types. The identification of each pathogen type would require large numbers of samples and many different media and methods, which would be very expensive and time consuming. Hence other organisms which are present in larger numbers whenever the pathogen is present; more resistant to treatment and environmental stresses than pathogen; easy to detect and numerate, are considered as good indicators for the presence of pathogens (Fegan et al. 1998).

Coliform is a family of bacteria that is always present in soils and in all types of water and wastewater, even in high quality drinking water. The coliform group of organisms survives better in water environment than other pathogens; hence, coliform groups are commonly used as an indicator of water quality (Davis and Cornwell 1998; Hammer 2004). Commonly, there are three ways of using coliform groups to indicate the quality of water. First, the test of total coliform bacteria indicates the cleanliness of the water supply to judge the adequacy of disinfection. The next common indicator group is thermotolerant (or faecal) coliform bacteria, which are a subset of total coliform and are used to indicate possible faecal contamination of water. Finally, a test for *Escherichia* coli (E. coli) confirms recent contamination of water by the faeces of humans and warm-blooded animals (NSW Health 1996).

Some genera of coliform group detected in total coliform test are not of faecal origin and are capable of reproducing outside the intestine in the environment where the enteric pathogen may not be present (Hammer 2004). Hence these groups of bacteria do not fit the criteria as a good indicator. The use of faecal coliforms can overcome this problem. Thermotolerant *Klebsiella* and *E. coli* are considered to be the type of faecal coliform which are thought to be exclusively faecal in origin and distinguished from other coliforms by their ability to produce gas from lactose at 44.5^{o}C (Fegan et al. 1998). However, according to Cabelli and his colleagues (1983), the thermotolerant *Klebsiella*, in fact, may not be exclusively originated from faeces and *E. coli* is traditionally the best bacterial indicator of faecal contamination. Hence, the faecal coliform test may show greater level of colony forming unit (cfu) than that of *E. coli* test. Despite not ideal indicators, most laboratories are using coliforms and faecal coliforms as indicators of water quality.

Chapter 4

PROJECT METHODOLOGY

4.1 Population Trend in Toowoomba

Toowoomba has a population of approximate 100,000 residents which is mainly distributed over three family types that includes couple with children, couple without children and single-parent family. According to Toowoomba City Council (TCC 2004), total number of families in Toowoomba is 21932, of which 42.8% are couple families with children; 37.3% are couples families without children; 17.6% are lone parent families and 2.3% are classified as other families (Table 4.1).

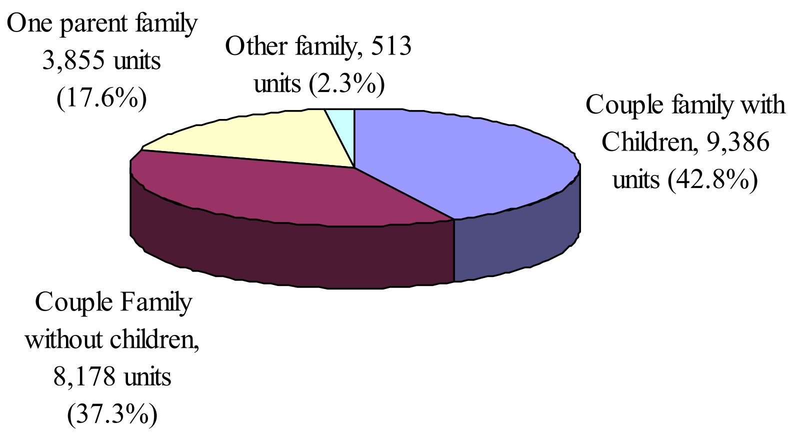

Figure 4. 5: Proportion of Family Types in Toowoomba

In order to evaluate the reuse potential of laundry wastewater in Toowoomba, the magnitude of laundry water use in Toowoomba needs to be determined. The "laundry waste use", in this study, refers to the quantitative and the qualitative characteristics of discharged laundry wastewater from the cloth washer in each household. The volume of laundry wastewater generated by individual homes largely depends on the types of washing machine, household sizes and wading habits. Meanwhile, the quality of laundry wastewater reflects the washing manner and characteristics of a household. The laundry samples from Toowoomba households were collected and analysed in order to establish the picture

4.2 Synopsis of sampling and measurements

The methodology selected for this study is briefly described in figure 4.2:

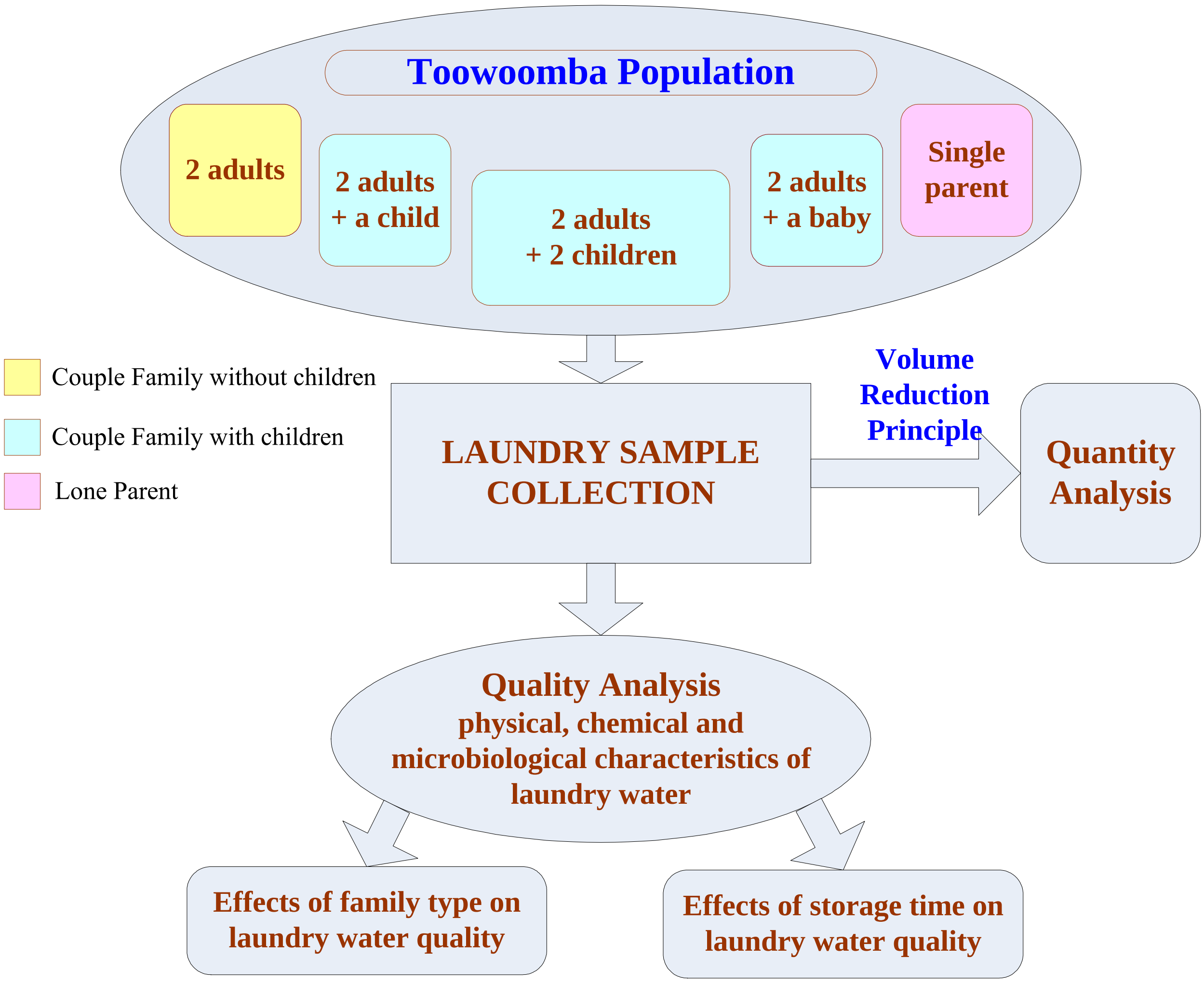

Figure 4. 6:Flowchart of Study Methodology

As shown in this figure, five family types were selected for this study comprising varying family structure:

1. Two adults (2A)
2. Two adults and a child (2A + C)
3. Two adults and 2 or more children (2A + 2C)

4. Two adults and a baby (2A +B)
5. Single parent (1A + C)

Adult people were considered to be people over 18 years old, child from 2 to 18 years old and baby less than 2 years old. A single parent family includes only one adult and a child.

Since it is almost impossible to collect data associated with laundry water use from all households in Toowoomba, a small scale Laundry Water Use Survey was carried out over one month to collect laundry samples and associated information on laundry water use for quantity and quality analysis (also see Section 4.4). Three resident families from Toowoomba city were used to represent each family type. Each resident family involved in this survey could be categorised in one of three dominant family types: couple with children, couple without children and one-parent family that accounts for 97.3% of total families in Toowoomba. Therefore, the group of families used in the study was a good representation of the Toowoomba population.

4.4 Survey Methodology

The request for volunteer participants for this survey was broadcast in the regional ABC radio channel in Toowoomba and via email messages. Three households for each of five family types were selected randomly from the respondents and laundry wastewater samples were collected from each household twice (n = 30). The figure 4.3 shows the map of all households involved in the collection of laundry water samples and related information.

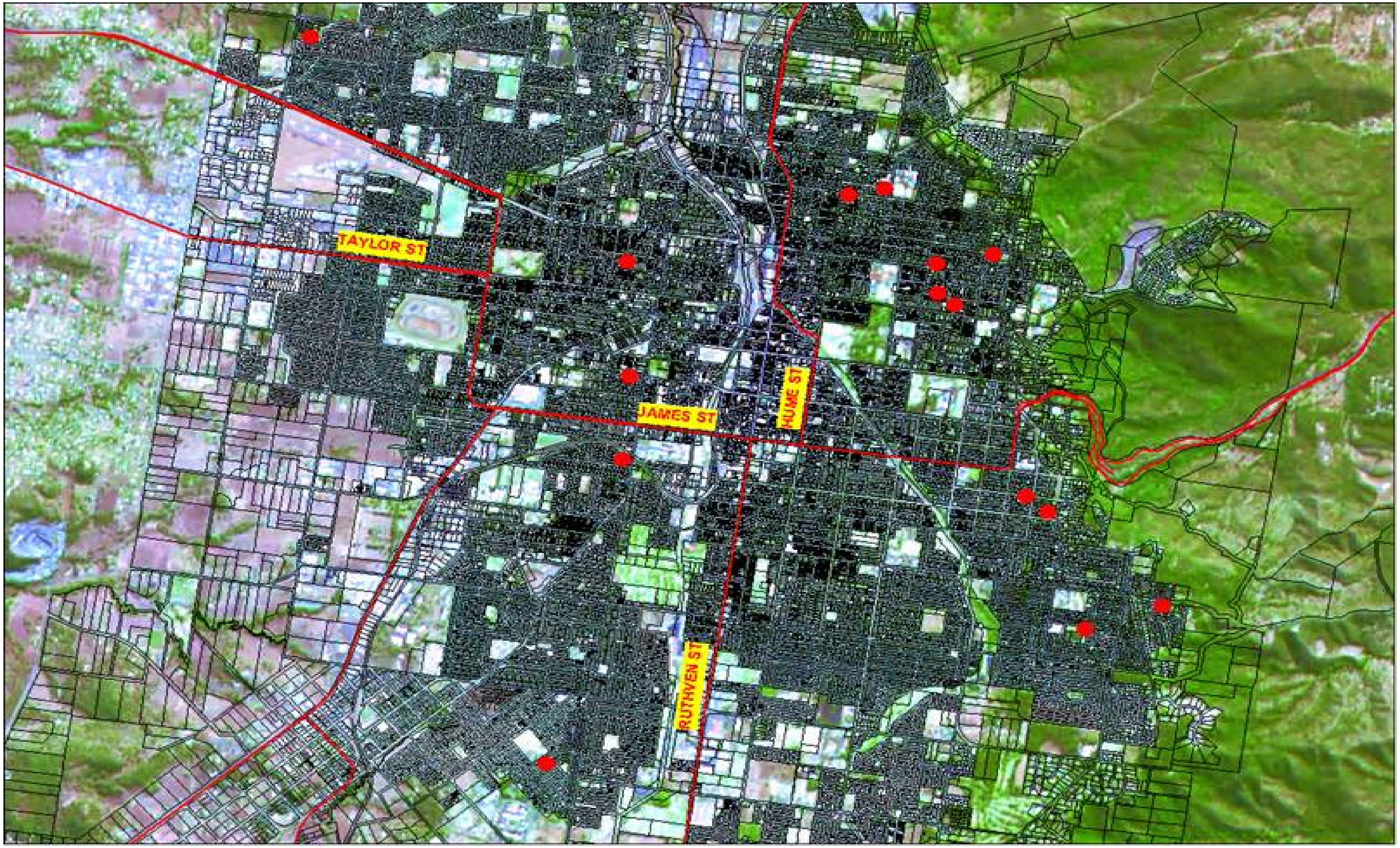

Figure 4. 7: Map of Toowoomba showing appropriate location of households that participated in this study

The precise location of each household was recorded with a portable GPS unit and eventually inserted into GIS database of Toowoomba map using MapInfo programme.

The all data collection took an approximately one month from July to August 2005. It includes three procedures:

- Collection of general information on occupants, washing machines, types of detergents and washing frequency via survey forms from all volunteer participants (Appendix D),
- Collection of water samples from laundry washing machine with sampling kits (Appendix E), and
- Analysis of the laundry water samples in laboratories

Approximately eight to ten samples were collected every week. The survey forms and sampling kits were sent to the participating houses. Each sample kit includes a 25 L plastic drum, a flow splitting device, hoses and sticky tapes. All parts of the sampling kit were sterilised with chlorine and dried under sunlight to avoid contamination and its effect the samples. On a typical sample collection scenario, the sampling kit was connected with the outlet of the washing machine. A laundry sample was collected in a 25 L drum with the flow splitting device. This device used the on volume reduction principle to assist sample collection and estimation of total laundry water discharge. This principle is discussed in detail in section 4.5.

Each laundry water sample in 25 L drum was further subsampled in 500 mL sterile plastic bottles for chemical and biological analysis and 1 L bottles for cation analysis. All processes associated with sample transport and storage was based on Australian and New Zealand Standard (AS/NZS 5667: 1998). Water samples were kept at $4^{o}C$ in dark containers during transport and storage until they were processed in laboratories. The samples were analysed within 24 hours of collection to avoid any change in concentration of indicator organisms of biological water quality. Analyses of pH, EC, total suspended solids (TSS) and Biochemical Oxygen Demand in 5 days (BOD5) were performed in the water and wastewater laboratory of University of Southern Queensland. For the other analysis (cation, phosphorus, nitrogen and faecal coliform analysis), same subsamples were sent to the wastewater analysis laboratory at Mount Kynoch, Toowoomba.

4.5 Measurements of Laundry water quantity

4.5.1 Need for the Development of Flow Splitting Device

The amount of laundry water generated by individual households depends largely on the household size and washing habits. Since there is no available information on the quantity of laundry water generated by households of Toowoomba, the study was designed to include this information. The quantity of laundry water potentially for reuse available by an individual household could be determined by multiplying average amount of laundry water discharged per wash by the number of washes per week. Information on average number of washes in each household per week could be obtained by the questionnaire. Information on the quantity of laundry water generated per wash was estimated by measuring the sample volume of the total discharge amount from a washing machine.

Quantitative measurement of total laundry water discharge in a single wash can be performed in several ways. First, the total amount of laundry water could be measured by directly capturing the total outflow from the washing machine. However, it requires the large container of about 200 L in capacity since a washing machine can generate from 55 litres to 190 litres of water per wash, as mentioned in the earlier sections. The alternative method was to use z flow meter to measure flow rate. However, water meters are not always accurate and would also human attendance during the operation of the washing machine to record the discharge over time. Hence, these methods were not feasible due to undesirable demand on resources and some degrees of the operational inconvenience.

A flow splitting devices was designed to overcome the above problems. This device aided the measurement of laundry water quantity by using volume reduction principle. It divided the discharge from the washing machine into two parts at the predefined split ratio. The small portion of the discharge was collected in a 20 L plastic container while larger component of the discharge was directed to the sewer. The volume of laundry water in the bottle was used to quantify the total laundry discharge using the known split ratio.

4.5.2 Theoretical Concept for the Design of the Flow Spitting Unit

The flow splitting unit was designed to ensure that the small sample represented the quantity and quality of the total laundry water discharge. A T-section with different outlet diameters relating to the flow split ratio was used to achieve this purpose (Figure 4.4 and Appendix F). The sampling outlet had a smaller orifice (hole-diameter A_s) compared with the wasting outlet (hole-diameter A_w). The relationship between the split ratio and the outlet of diameters is theoretically a combination of the Bernoulli and Continuity equations. In order to use those two equations in their simplified forms, the flow was assumed to be one-dimensional, steady, irrotational, nonviscous and incompressible and assumed to have a uniform velocity across the flow section (Nalluri and Featherstone 2001).

Bernoulli's Equation may be stated as:

$$Z_1 + \frac{p_1}{\rho g} + \frac{V_1^2}{2g} = Z_2 + \frac{p_2}{\rho g} + \frac{V_2^2}{2g} \qquad (4.1)$$

The continuity's equation as

$$Q_{ideal} = V_1 A_1 = V_2 A_2 \qquad (4.2)$$

Where Z_1: elevation at point 1 (m)

Z_2: elevation at point 2 (m)

p_1: pipe pressure at point 1 (Pa)

p_2: pipe pressure at point 2 (Pa)

V_1: flow velocity at point 1 (m^2/s)

V_2: flow velocity at point 2 (m^2/s)

Q_{ideal} : discharge in ideal situation where no energy loss occurs (m^3/s)

ρ : Density of a fluid (kg/m^3)

g: gravitational acceleration (m/s^2)

A_1: cross section area of pipe 1 (m^2)

A_2: cross section area of pipe 2 (m^2)

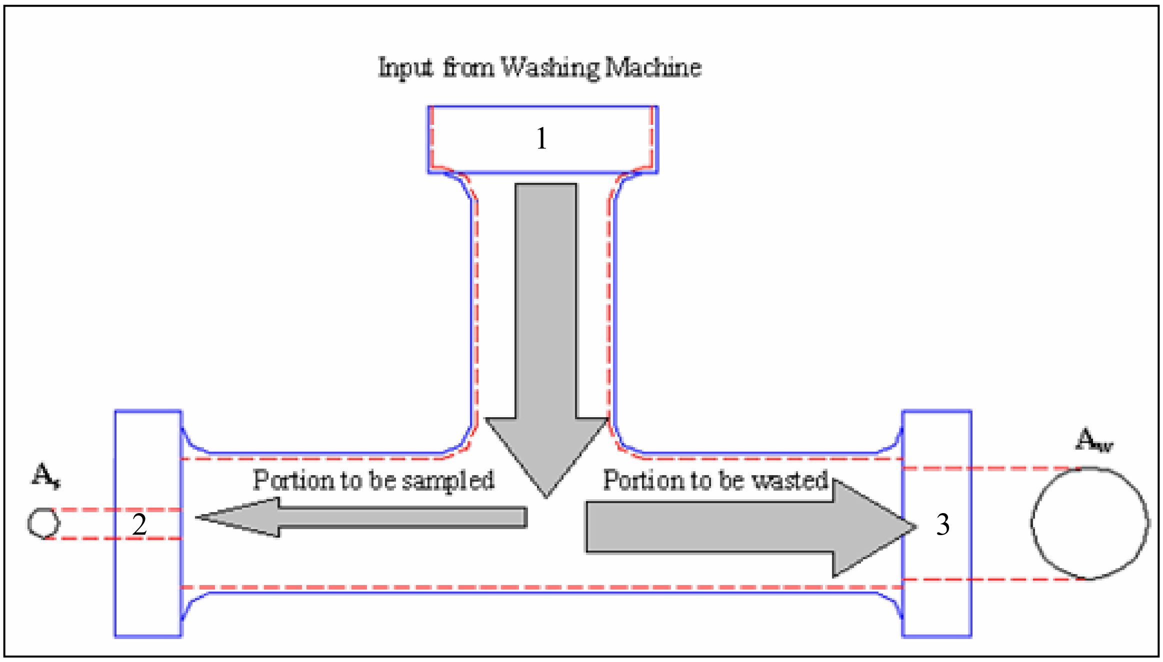

Figure 4. 8: The T-sectioned flow splitting unit with different outlet diameters

Applying Bernoulli's equation (4.1) between inlet (point 1) & sampling outlet (point 2), and between inlet (point 1) & wasting outlet (point 3), we get:

$$Z_1 + \frac{p_1}{\rho g} + \frac{V_1^2}{2g} = Z_2 + \frac{p_2}{\rho g} + \frac{V_2^2}{2g} \qquad (4.3)$$

$$Z_1 + \frac{p_1}{\rho g} + \frac{V_1^2}{2g} = Z_3 + \frac{p_3}{\rho g} + \frac{V_3^2}{2g} \qquad (4.4)$$

Where Z_1: inlet elevation (m)

Z_2: sampling outlet elevation (m)

Z_3: wasting outlet elevation (m)

p_1: pressure at inlet (Pa)

p_2: pressure at sampling outlet (Pa)

p_3: pressure at wasting outlet (Pa)

V_1: flow velocity at inlet (m^2/s)

V_2: flow velocity at sampling outlet (m^2/s)

V_3: flow velocity at wasting outlet (m^2/s)

A_2: cross section area of sampling outlet (m^2)

A_3: cross section area of wasting outlet (m^2)

If both outlets of the unit are maintained at the same atmospheric pressure, and the T-section is placed horizontally to have similar outlets elevations, Equations (4.3) and (4.4) may be combined to give:

$$\frac{V_2^2}{2g} = \frac{V_3^2}{2g} \qquad (4.5)$$

$$V_2 = V_3 \qquad (4.6)$$

Using this in equation (4.2) for discharge corresponding with volume:

$$\frac{Q_2}{A_2} = \frac{Q_3}{A_3} \qquad (4.7)$$

with d_2 and d_3 are diameters of sampling and wasting outlets respectively, then:

$$\frac{Q_2}{d_2^2} = \frac{Q_3}{d_3^2} \qquad (4.8)$$

Because of the existence of jet contraction and energy loss at the orifice, the actual discharge through the orifice is related to the theoretical discharge by the discharge coefficient C_d as follow:

$$Q_{Actual} = C_d \times Q \qquad (4.9)$$

Hence, for discharge through point 2 (sampling outlet) and point 3 (wasting outlet) with respect to discharge coefficients C_{d2} and C_{d3}

$$\frac{Q_{2-Actual}}{Q_{3-Actual}} = \frac{C_{d2} \times Q_2}{C_{d3} \times Q_3} = \frac{C_{d2} \times d_2^2}{C_{d3} \times d_3^2} = \text{Split ratio} \qquad (4.10)$$

Equation 4.9 shows that the split ratio is directly proportional to the square of the outlet diameters. In addition, the split ratio is also affected by the flow Reynolds number and sharpness of the orifice edge of which the discharge coefficient is a function (Chadwick and Morfett 1998). Therefore, the split ratio for each unit is determined through the calibration in which repetitive tests under the same controlled set of conditions are taken to obtain a stable ratio. In each calibration process, a known volume of water was poured into the washing machine. Then both wasting and sampling flows of discharge were captured and quantitated to obtain the split ratio (Appendix 9).

4.5.3 Evaluation of Device Performance

The flow split device was connected to the outlet of the washing machine in such a way that the split ratio remained stable. First, it was necessary to maintain the T-section perfectly horizontal with a spirit level and strong glue tape so that the outlets were at the same elevations. In addition, relatively large pipes and fittings were used to connect the sampling outlet to the storage containers while the wasting outlet was freely directed to the sewer. This criterion helped to maintain the atmospheric pressure at both ends of the T-section.

There are some errors inherent with assumptions relating to the design. According to Na'amani (2005), the more the assumptions adhere to the real situation, the smaller the degree of error encountered. With the design used for the flow splitting devices, errors may have originated from diverse sources, affecting the estimation of total laundry water discharge. For example, the partial pressure might occur in some cases at the outlets, which would make the assumption about the similar atmospheric pressure at both ends invalid. The existence of air-bubble intrusion through the pump might also conflict the assumption about the uniform velocity across flow section. In addition, the difference in orifice size and the inconsistence of the pump pressure from the washing machine might result in the difference in head loss at the outlets. All these assumptions are likely to affect the stability of the split ratio. The difference in washing machines used for calibrating and sampling might also affect, to some extent, an accuracy of the results contained.

Form the calibration data (Appendix G), the coefficient variation was calculated to evaluate the reliability of each flow split devices in maintaining a stable split ratio. The coefficient variation is equal to the division of standard deviation by the mean split ratio, which were obtained from the calibration data. The table 4.1 compares the performance reliability of 10 flow split devices that were constructed for sample collection purpose. The results show that the coefficient of variation varied from device to device due to the factors such as difference in cross section areas, surface roughness and fitting of parts between devices. However, all devices have coefficient variation less than 10%. Therefore, the flow splitting devices could be considered accurate.

Table 4. 2: Performance reliability of flow splitting devices analysed from calibration data

Device	Calibration Test	Splitting ratio	Mean ratio %	Standard Deviation (SD)	Coefficient of variation (= SD/Mean*100%)
1	1	0.069	6.8%	0.00033965	0.50%
	2	0.069			
	3	0.068			
2	1	0.069	7.0%	0.0003863	0.55%
	2	0.070			
	3	0.070			
3	1	0.071	7.2%	0.00097556	1.36%
	2	0.073			
	3	0.072			
4	1	0.071	7.1%	0.00175973	2.48%
	2	0.069			
	3	0.072			
5	1	0.064	6.4%	0.00033052	0.52%
	2	0.063			
	3	0.064			
6	1	0.066	6.4%	0.00444504	6.97%
	2	0.066			
	3	0.059			
7	1	0.051	5.2%	0.00035615	0.69%
	2	0.052			
	3	0.051			
8	1	0.069	6.8%	0.00075136	1.10%
	2	0.069			
	3	0.068			
9	1	0.068	6.9%	0.00079949	1.16%
	2	0.069			
	3	0.069			
10	1	0.071	7.2%	0.00082176	1.14%
	2	0.073			
	3	0.073			

Despite of possibility of the errors mentioned above, the flow split unit was considered a useful tool to provide the representative sample for water quantity and quality measurements. Since the amount of generated laundry water could vary from house to house, and even between washes within an individual house, the study aimed to provide the potential range of laundry water quantity that can be available for reuse. Moreover, these flow splitting units was designed in simple way and was cheap, costing of about $22 per sample collection kit (Appendix H). This made the construction of multiple units for simultaneous collection of samples in various households economically feasible.

4.6 Measurement of Water Quality

4.6.1 Types of Analysis

Due to economical constraints associated with project funding, a certain physical, chemical and biological quality parameters were selected for laundry water analysis. These analyses included pH, total suspended solids (TSS); electrical conductivity (EC); 5 day-biochemical oxygen demand (BOD_5); concentration of selected cations (Na, Ca, Mg and K); nutrients (total phosphorus, total nitrogen); and faecal coliforms. Total nitrogen in water samples included organic nitrogen and ammonia nitrogen referred to as “Kjeldahl nitrogen”, nitrate and nitrite. As literature review shows that heavy metals were not commonly found in laundry water, the analysis on heavy metal was not covered in this study. In order to evaluate the potential health hazard associated with laundry water reuse, faecal coliform analysis was used to identify the major source of human diseases causing pathogens in laundry water.

4.6.2 Description of Quality Measurements

Thirty laundry water samples collected from 15 households were used for physical, chemical and microbiological analyses.

pH and EC of the sampled laundry water was measured with pH and EC electrodes and meters manufactured by TPS Pty Ltd, Brisbane. Both pH and EC meters were calibrated according to the manufacturer's instructions for the measurement of sample temperature and standard buffer solutions.

Total suspended solids (TSS) of laundry water samples were measured by filtering a well-mixed sample through a weighed glass fibre filter (1.5 μm particle retention) and drying the residual retained on the filter to a constant weight at 103-105^{o}C. The difference in weight of the filter after drying represented the TSS. The protocols for the analysis of TSS are described in Standard Method for the Examination of Water and Wastewater- Method 2540D (APHA 1998).

The BOD of laundry water samples were determined using a 5-day BOD test described in Standard Method for Examination of Water and Wastewater - Method 5210B (APHA 1998). The water samples were collected in sterilised bottles to avoid the interference from contaminants. The samples were also cooled to near freezing temperature during storage to minimise reduction of BOD, but were warmed to approximately 20^{o}C before the analysis. The water samples were diluted at different concentrations with standard solutions into airtight bottles of 300mL, which were then incubated at 20^{o}C for 5 days. It was known from literature that BOD_5 of laundry water usually ranges from 10 to 520 mg/L (Christova-Boal et al. 1995). Therefore, three dilution ratios of 2 mg, 6 mg and 20 mg sample per 300-mL bottle were used. The depletion of oxygen in the dilutions after 5 days was measured using the membrane electrode DO meter and then it was multiplied by the known dilution ratio to get the BOD_5 value of the undiluted laundry water.

The concentration of Na, Ca, K and Mg in laundry water were measured using Flame Atomic Adsorption Spectrometry with direct Air-Acetylene Flame Method. When the water sample was burnt and atomised in the flame, it absorbed a certain amount of light corresponding to the atomised element in the flame (APHA 1998). Because each metal has its own characteristic absorption wavelength, the source lamp composed of that element was used to generate the light beam through the flame into a monochromator and onto a detector. Since the concentration of the element in the sample is proportional to the amount of light absorbed, the detector would identify the concentration of the element by measuring the amount of energy at the characteristic wavelength absorbed in the flame. The testing procedures for these elements are outlined in the Standard Method for Examination of Water and Wastewater - Method 3111B (APHA 1998).

The total phosphorus in laundry water was quantitated using QuickChem Method 10-115-01-1-E (Prokopy 1992 cited by Widderick 2001). This method used flow injection colorimetry to analyse the concentration of orthophosphate ions (PO_4^{3-}). Phosphorus in water is usually in the forms of polyphosphates, organic phosphorus and orthophosphate (APHA 1998, Miller 2004). Therefore, polyphosphate and organic phosphorus were converted into orthophosphate by sulphuric acid digestion and persulphate digestion respectively before the analysis (Widderick 2001). The light absorbance corresponding to 880 nm wavelength by orthophosphate mixture under the lamp source is proportional to the concentration of orthophosphate in the sample.

Total Kjeldahl Nitrogen (TKN) was analysed using Block Digestion and Flow Injection Analysis explained in the Standard Method for Examination of Water and Wastewater - Method 4500-N_{org} D (APHA 1998). The principle is similar to the determination of total phosphorus, except that a sample is digested in a block digestion with sulphuric acid and copper sulphate before the light absorption corresponding to a wavelength of 660 nm was measured with a UV-VIS spectrophotometers (Widderick 2001). Nitrate and Nitrite, on the other hands, were quantitated using Ion Chromatography according to description in the Standard Method for Examination of Water and Wastewater - Method 4110B (APHA 1998). A water sample was injected into a steam of carbonate-bicarbonate eluent and passed through a series of ion exchangers. The concentration of the anion was determined on the basis of the difference in conductive strength between acid of the anion and carbonic acid at a certain retention time corresponding to the anion of interest.

Laundry water samples were analysed for faecal coliform according to the protocols described in the Standard Method for Examination of Water and Wastewater - Method 9221E (APHA 1998). The EC medium was required to produce presumptive fermentation. Random presumptive colonies were selected from each fermentation tubes or bottles and were transferred to EC broth. Tubes were incubated at $44.5 \pm 0.2^{o}C$ for approximately 24 hours. Faecal coliforms were present if growth was visible in the tube.

In order to avoid the biological contamination, the samples were collected in sterile bottles and stored in dark room below 4^{o}C until the analysis.

The full procedures for these tests were complied in Appendix I.

4.6.3 Effects of Storage on Laundry Water Quality

All wastes, either solids or liquids undergo biodegradation over time. According to Pepper et al. (1996), the degradation rate is the function of microbial numbers, available nutrients, environmental conditions and pollutant compositions. The degradation of laundry water occurs naturally, but might produce unwanted and harmful by-products if the water was stored before reuse. Therefore, the investigation on the change in quality of stored laundry water over short period was studied, as it would allow laundry water to be reused more effectively. For example, the householders may store laundry water during the rainy day, and use it in a next couple of days for watering their lawn or garden when no precipitation occurs.

Five of the 30 collected samples were subject to time storage analysis to include one sample from each family type. Subsamples of these laundry water samples were stored and analysed after two and six days. They were stored in sealed sterile bottles at normal ambient temperature of approximately 20^{o}C. The airtight condition was used to ensure that chemical or biological changes in the laundry samples were exclusive to the influences of the microbes and nutrients contained in the sample. After desirable time of storage, these samples were analysed for cations, nutrients and faecal coliforms for other water samples as described before.

4.7 Statistical Analysis

A factorial analysis of variance (ANOVA) was performed to determine the extent to which laundry water quality was influenced by the type of detergents. The quality parameters of laundry water examined in this analysis were pH, total P, total N, Na, SAR and TDS. This analysis was done because elevated values of these parameters in the irrigation water are known to affect soil properties and plant growth severely (Myers et al. 1999). ANOVA analysis was based on two factors: detergent types (liquid or powder) and phosphorus content-labelling (P or NP).. The level of significance considered for all analysis was 95% ($\alpha = 0.05$). Therefore, when a factor was significant ($p < 0.05$) corresponding to a certain quality parameter, it implied that this quality parameter was influenced by the factor (Zar 1999). The ANOVA analysis also examined the interaction between detergent types and P-content labelling in order to determine whether the effect of one factor depended on the level of another factor.

When the P-labelling information for a detergent was unavailable, the data for those laundry water samples were excluded from the analysis. Similarly laundry water samples arising from the use of fabric softeners or obtained using a partial load for washing were excluded from the analysis to avoid any complicating effects arising from these factors that could not be covered by the analysis. Thus, the selected quality parameters analysed for the laundry water samples were all obtained with a full load without any significant effect on the water consumption rate of the washing machines.

Paired t-tests were used to examine if there was any significant changes in the chemical characteristics of laundry water during storage. These tests were used to compare the chemical and microbiological characteristics of the samples without storage (Day 1 of sample collection) and after 2 days (Day 3 after sample collection) and 6 days of storage (Day 7 after sample collection). The mean of differences in concentrations of total N, total P and other chemicals in laundry water between all possible pairs of storage time (such as day 1 and day 3; day 1 and day 7; and day 3 and day 7) were compared. The null hypothesis tested was that there was no change in the concentration of the selected quality parameter over the storage period. With significance level set at 95%, the null hypothesis was rejected if $p \leq 0.05$.

Chapter 5

RESULTS AND DISCUSSION

5.1 Results

5.1.1 Quantity of laundry water

In order to determine the quantity of laundry water produced by households in Toowoomba, various types of information were collected from each household via survey. Full results of the survey on the washing habits, washing machine types and laundry detergents are given in Appendix J and K. Table 5.1 summarises the average quantities (over two washes) of laundry water available for reuse from different family types and three replicate households representing those family types. The average amount of laundry water available for reuse per day was estimated on the basis of total laundry water generated per week. The latter amount was estimated from the sample volume measured over two washes and the washing frequency.

Table 5. 8: Survey results for laundry water consumption

Family Type	Site Number	Washing machine Type	Washing frequency (washes/week)	Average laundry water generated per full load (L)	Average laundry water generated per day (L/d)
2A	1	Front	5	155.7	111.2
	2	Front	3	49.0	21.0
	3	Front	4	58.9	33.7
2A+1C	4	Top	5	117.3	83.8
	5	Top	9	115.8	148.9
	6	Front	7	97.5	97.5
2A+2C	7	Top	6	159.5	136.7
	8	Top	7	121.1	121.1
	9	Top	8	187.0	213.7
1A+C	10	Top	3	337.9	144.8
	11	Top	5	118.2	84.4
	12	Top	6	150.3	128.8
2A+B	13	Front	6	124.8	107.0
	14	Front	13	66.6	123.6
	15	Front	10	64.3	91.8

Generally, the amount of water used in a laundry washing machine is slightly greater than the amount of laundry water drained from it because of possible leakage and absorption by clothes. However, this loss is usually negligible compared with the amount of discharge and hence, it can be neglected. Therefore, the inflow to the washing machine was assumed to be equal to its outflow. Results in table 5.1 show that the daily quantity of laundry water use in surveyed houses varied largely from 21 L/day to 213.7 L/day, with mean $\overline{X} = 190.9$ and standard deviation σ = 46.6 L/day. The results also indicate that the average daily water consumption in a washing machine per house is relatively normally distributed (Figure 5.1). Since the group of collected samples is a representation of a whole Toowoomba population, the daily amount of laundry water use in a Toowoomba household is also normally distributed (Figure 5.2).

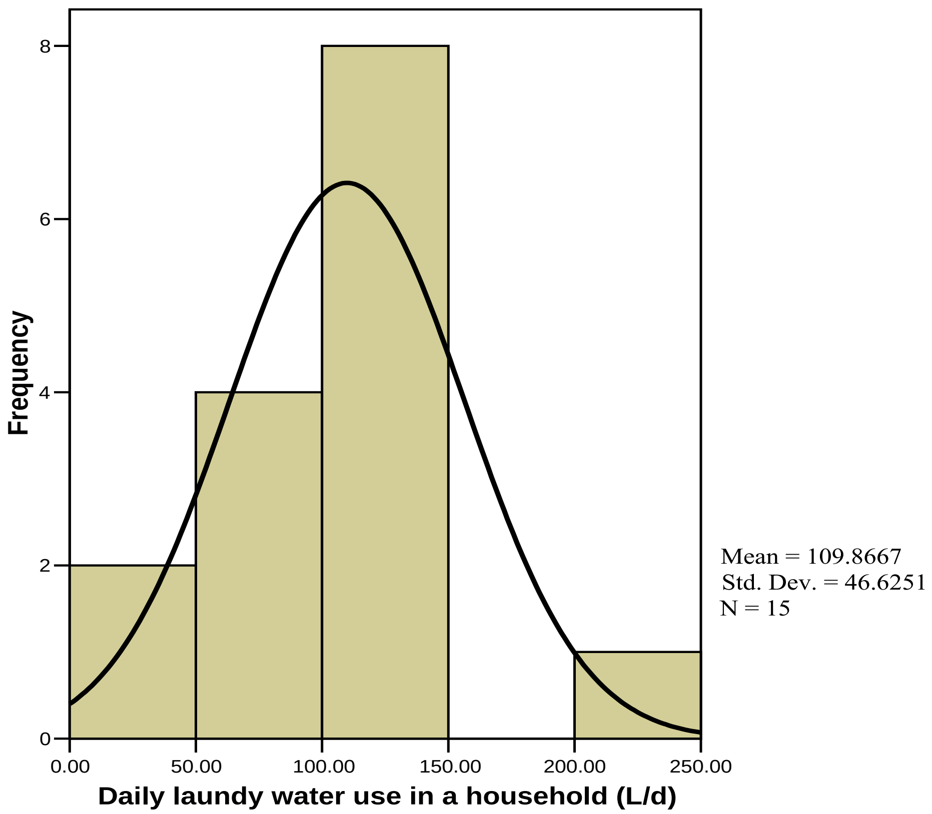

Figure 5. 4: Frequency distribution of daily laundry water use in sample households

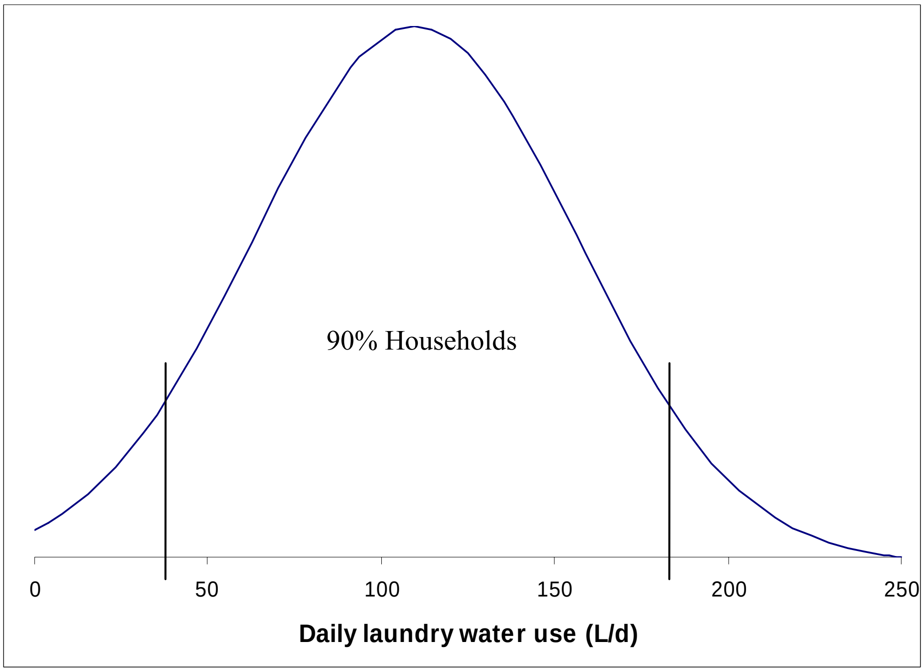

Figure 5. 5: Normal distribution of daily laundry water use for Toowoomba residents. Area of the normal curve outside the vertical lines represent ±5% of the population and the corresponding values of daily laundry water use

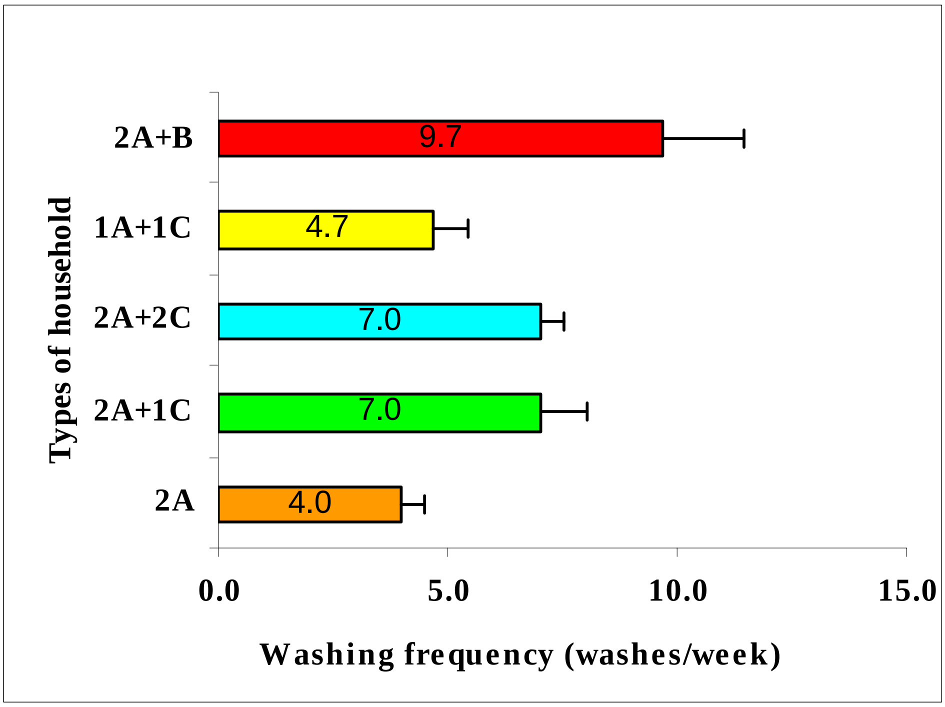

Figure 5. 6: Comparison of washing frequency for different family types in Toowoomba. Mean values are shown with one positive standard error (+ SE).

Figure 5.3 compares the washing frequency for various family types. It can be seen from this figure that washing frequency is dependent on age and number of occupants. It is also clear that the larger the size of the family, the more often washing is likely to occur. However, the families with babies appeared to have the higher washing rate per week of approximately ten washes, compared with those families with equivalent or more number of children. Such families also have a highest variability (largest standard error) in washing frequency.

5.1.2 Laundry Water Quality

The quality analyses of laundry water parameters aimed to identify the contaminants in laundry water, which could affect human health and the environment adversely if this wastewater is used for irrigation. A summary of the laundry water quality parameters found in this project is presented in the Table 5.2. The full results of quality analyses are compiled in Appendix L and M.

Overall, the results show high variability in laundry water quality as it is affected by many factors such as the quality of water source, water use efficiency of washing appliances, family size, age, washing habits and type of detergents used. Despite this variation, the results show remarkable similarity in the range of values for various chemical and microbiological parameters in laundry water in this project and other previous studies.

Faecal coliforms were detected in some samples at varying concentrations (Table 5.3). Interestingly, 73.3% of all measured values were at the limit of detection (<1 cfu/100 mL), 20% were below 100 and only 6% were higher than 1000. Levels of faecal coliforms in laundry water obtained from a family with baby or young child were higher than the other families. However, not all samples from families with baby or children were detected with high level of faecal coliform. In addition, only samples collected from the same site experienced similar levels of faecal contamination.

Table 5. 9: Typical values of laundry water quality parameters and corresponding recommended limits for irrigation use

Quality Parameters	Laundry water	Literature Values for laundry water			Untreated greywater	Secondary treated wastewater	Potable supply	Recom. limits for irrigation purposes*
	Project values	(1)	(2)	(3)	(4)	(5)	(4)	(6)
pH	7.3-10.3	-	9.3-10	6.3-9.5	6.6-8.7	6.9-9.6	6.5-8.5	6.5-8.5
TSS (mg/L)	18-290	280	88-250	26-400	45-330	-	-	-
BOD5 (mg/L)	18-440	380	48-290	10-520	90-290	7-37	-	<40
EC 25^{o}C (µS/cm)	496-2161	-	190-1400	83-880	325-1140	46-1500	-	950-1900
Sodium Na (mg/L)	45.6-501	-	49-480	12-480	29-230	50-250	180	<230 (a)
Phosphorus, total as P (mg/L)	0.2-93.3	57	0.062-42	0.062-42	0.6-27.3	2-18	-	<12 (b)
Nitrate & Nitrite as N (mg/L)	0.21-2.57	-	<0.1-1.9	<0.1-0.44	<0.1	-	50	-
Total Kjeldahl Nitrogen (mg/L)	3.2-28.2	21	1-40	1-40	2.1-31.5	2-50	-	25-125 (c)
Calcium (mg/L)	0.9-16.2	-	3.9-12	2.3-12	-	11-55	-	-
Magnesium (mg/L)	2.3-15.1	-	1.1-2.9	0.7-5.3	0.01-0.075	5-50	0.1	-
Potassium (mg/L)	2.6-10.2	-	1.1-17	1.1-23	-	-	-	-
Faecal Coliforms (cfu/100ml)	0-19000	-	110-1090	10^4-10^6	6-8x10^6	-	0	<1000 (d)

(1) Siegrist, Witt & Boyle (1976) cited by Sharman (1993)
(2) Christova-Boal et al. (1995a)
(3) Christova-Boal et al. (1995b)
(4) Radcliffe (2004)
(5) Myers et al. (1999)
(6) ANZECC (2000) & Myers et al. (1999)

** Low potential hazard to trees, soil and groundwater*
(a) *Related to SAR*
(b) *Agricultural irrigation water short term trigger value for nitrogen (up to 20 years), Site specific assessment is required.*
(c) *Agricultural irrigation water short term trigger value for phosphorus (up to 20 years)*
(d) *For food crop and non-food crop and where edible products and humans are not in direct contact with irrigation water (See table 3.4 for other uses)*

Table 5. 10: Observations of faecal coliform levels in different family types

Faecal Coliforms (cfu/100 mL)	2A family	2A+C family	2A+2C family	1A+C family	2A+B family	No of Observations	Percent %
No detection	5	4	5	5	3	22	73.3%
1-10	1	0	1	1	1	4	13.3%
11-100	0	2*	0	0	0	2	6.7%
101-1000	0	0	0	0	0	0	0.0%
1001-10000	0	0	0	0	1**	1	3.3%
> 10000	0	0	0	0	1**	1	3.3%
Total No of samples:	6	6	6	6	6	30	100%

** Samples were from the same household B1 (2A+C family) with 6 years old child*
*** Samples were from the same household E1 (2A+B family)*

5.1.3 Effects of Detergents on Laundry Water Quality

The two factor ANOVA analysis was used to determine the effects of detergents used on laundry water quality (α = 0.05). Full details of the data used for this analysis are given in Appendix N. Table 5.4 summarises the significance of the effects of various factors resulting from ANOVA analysis. Table 5.5, on the other hand, compared the mean values of laundry water parameters for different detergents regarding to their types and P-content labelling.

Table 5. 11: P values from factorial analysis of variance for main laundry water chemical parameters with different detergents used

Factors	Probability P-values					
	pH	TDS	N	P	Na	SAR
Detergent type (liquid or powder)	0.0001	0.4556	0.9597	0.7562	0.0443	0.0637
P content labelling (P or NP)	0.0182	0.0002	0.0003	0.0030	0.0001	0.0239
Detergent Type * P-content labelling	0.9348	0.5617	0.2283	0.7774	0.0270	0.2797

Table 5. 12: Mean values of laundry water chemical parameters for different types of detergents used

Choice of detergents	Mean values per full wash					
	pH	TDS (g)	N (g)	P (g)	Na (g)	SAR
Powder, P	9.9	86.4	0.14	3.86	26.5	14.3
Liquid, P	8.5	74.8	0.16	4.58	14.1	7.4
Mean P	9.4	82.5	0.14	4.10	22.3	12.0
Powder, NP	9.2	41.0	0.09	0.05	5.7	6.3
Liquid, NP	7.8	39.5	0.07	0.08	6.4	4.3
Mean NP	8.5	40.3	0.08	0.07	6.1	5.3

The results show that laundry water pH was significantly lower (p = 0.0001) for liquid detergent than with the powder detergent, regardless of its P-content. In addition, the use of P-free detergents (labelled as NP) also considerably reduced pH level in laundry wastewater by 0.7 units in pH scale (p = 0.0182) for both powder and liquid detergents. The mean pH of laundry water for NP-liquid detergent was only 7.8, compared with 9.9 pH value for P-powder detergent.

Phosphorus content in detergents was significantly different between those having P and NP labels (p = 0.0001). Indeed, laundry water associated with P labelled detergents had much higher P content (mean value = 4.1 g per wash) than laundry water associated with NP-labelled detergents (mean value = 0.07 g per wash). Hence, NP label truly indicated that there was very little contribution of P from these detergents to laundry water. The manufacturers of these detergent labels possibly do not use P compounds during manufacturing of these detergents. The analysis also showed that the detergent type had no significant influence on P content in laundry effluent.

Total dissolved salt, N and SAR of laundry water were significantly influenced by the P content of detergents ($p < 0.05$), but not by the type of detergents. Average values for these parameters in Table 5.5 shows that P containing detergents contributed to significantly higher amounts of RDS, N and SAR.

Sodium content detected in laundry water were significantly influenced by detergents type and P-labelling and also there was a strong interaction between detergent type and its labelling ($p < 0.05$). Mean values of Na in laundry water were in the order Powder P > Liquid P > Liquid NP ≈ Powder NP.

5.1.3 Effect of Storage on Laundry Water Quality

Table 5.6 gives a summary of the quality of laundry water samples after storage for 2 and 6 days (at day 3 and day 7 respectively) in comparison with their quality without storage (day 1). The null hypothesis was no change in their concentrations over the short period of storage used. Paired t-tests showed little significant difference in concentrations for several chemicals in laundry water samples during storage (Table 5.7). Of the significant differences found, the evidence against the null hypothesis was only strong for the differences between levels of Na during day 1 and 3 and for K during day 3 and 7 ($P < 0.05$). No significant differences in N, P, Ca and Mg were found for any of the storage periods used. Lack of consistent effects of storage on the studied chemicals illustrates possible inconsistency during subsampling or error from random sources. Overall, on the basis of chemical parameters used for the analysis, there was no strong evidence to suggest that concentration of the selected chemicals varied greatly due to storage and thus the null hypothesis used for the analysis is accepted.

Table 5. 13: Effects of storage time on quality of laundry water

Sample number	Storage time after collected (days)	Testing Date*	Family type	Total N	Total P	Faecal coliform	Ca	Mg	Na	K
				mg/L	mg/L	CFU/ 100mL	mg/L	mg/L	mg/L	mg/L
A1 sample1	0	Day 1	2A	19	35.9	<1	12.5	11.4	232	5.7
	2	Day 3	2A	11.4	35.8	<1	11.9	11.4	215	6.3
	6	Day 7	2A	10.5	35.3	<1	1.5	2.4	250	5.8
B1 sample1	0	Day 1	2A+1C	5.9	17.5	<1	13.7	13.5	213	5.2
	2	Day 3	2A+1C	6.2	17.9	<1	13.5	13.3	206	6.9
	6	Day 7	2A+1C	5.3	16.5	<1	2	3.6	225	6.7
C1 sample1	0	Day 1	2A+2C	15.7	21.6	3	0.9	2.3	101	3.9
	2	Day 3	2A+2C	7.9	24.6	<1	0.9	1.6	101	3.2
	6	Day 7	2A+2C	9.1	24.9	<1	0.6	1.1	81.4	2.3
D1 sample1	0	Day 1	1A+C	5.1	4.73	<1	10.6	8.9	88.9	3.6
	2	Day 3	1A+C	5.3	4.73	<1	11.9	11.5	70.3	6.5
	6	Day 7	1A+C	5.1	5.7	<1	11.4	10.3	71	5.7
E1 sample1	0	Day 1	2A+B	11.4	10.4	19000	5.6	7.5	75.8	3.5
	2	Day 3	2A+B	13	9.6	84000	7.7	9.6	68.9	8.4
	6	Day 7	2A+B	11	9.68	280000	7.2	8.7	73.9	7.8

In contrast to the chemical properties, the faecal coliform concentrations in laundry water, to some extent, were affected by the storage time (Table 5.6). Indeed, the results for sample E1-1 show that the faecal level of this sample significantly increased from 19000 cfu/100 mL in day 1 to 84000 in day 3 and then to 280000 in day 7 after storing at ambient temperature. However, for those samples from which no or very few faecal coliforms were detected in the initial test, there was little sign of faecal coliform growth during storage period.

Table 5. 14: Significant difference resulting from the paired T-tests with Ho: no change in chemical concentrations and Ha: chemical concentrations decrease over time (one-side hypothesis tests).

Parameters	Comparison	Null Hypothesis	Critical $t_{0.05}$ with 4 df	t	P
Total N	day1 - day 3	Mean difference = 0	2.132	1.283	0.134
	day1 - day 7		2.132	1.793	0.074
	day 3 - day 7		2.132	1.065	0.173
Total P	day1 - day 2	Mean difference = 0	2.132	-0.764	0.756
	day1 - day 7		2.132	-0.485	0.673
	day 3 - day 7		2.132	0.276	0.398
Na	day1 - day 3	Mean difference = 0	2.132	2.849	0.023
	day1 - day 7		2.132	0.247	0.409
	day 3 - day 7		2.132	-0.877	0.785
Ca	day1 - day 3	Mean difference = 0	2.132	-1.025	0.818
	day1 - day 7		2.132	1.388	0.119
	day 3 - day 7		2.132	1.797	0.073
Mg	day1 - day 3	Mean difference = 0	2.132	-1.145	0.842
	Day1 - day 7		2.132	1.414	0.115
	day 3 - day 7		2.132	2.044	0.055
K	day1 - day 3	Mean difference = 0	2.132	-1.955	0.939
	day1 - day 7		2.132	-1.295	0.868
	day 3 - day 7		2.132	4.899	0.004

5.2 Discussion

5.2.1 Quantity of Laundry Water Use

From Figure 5.1, it can be seen that number of washings per week in individual households varied significantly by the age and number of occupants. It is clear that more people in the house, more frequent are the washing. In addition, houses with young children and babies also tend to change clothes more often and thus, wash their clothes more often than families with equivalent number of adults. These social issues affecting quantity of laundry water is not investigated further in this project. However, wide variation in washing frequency observed for families consisting of babies in this project is a related social trend where some families with babies may be using disposable nappies that reduces washing frequency and causes more variability in laundry water production.

There also other factors that affect the volume of laundry water available from individual households for reuse, such as types, brand model and age of the washing machines. As most front loading washing machines are designed to use water more efficiently than the top loading washing machine (Ferguson et al. 2003), the outflow from the front loading machine is expected to be lower. The brand model and age of washing machine also plays a part in water consumption. For example, the front loading washing machine at site 1 consumed more water (155.7 L/load) than other front loading washing machines, and even more water than some of the top loading machines (Table 5.1).

Regardless of the household characteristics and the types of washing machine in use, the probability distribution of laundry water use indicates that 95% of households in Toowoomba are likely to use more than 40 L/day for washing their clothes (Figure 5.2). These results also show that an average household in Toowoomba can generate approximately 110 L/day. With the average water consumption of 240 KL/year, laundry water reuse will save 6 to 16.5% of total water consumption based on the rate of 40–110 L per day. As detailed in the literature review, 240 L/day is the average amount of water used by a typical Toowoomba household for watering garden and lawn. This means the reuse of those amounts of laundry water can save nearly half of fresh water required for irrigating residential lawns and gardens in Toowoomba.

The amount of laundry water available for reuse in an average Toowoomba household compares well with a typical urban Australian house. In fact, Marshall (1997) found that an average urban Australian house used 820 L for indoor and outdoor activities (480 L and 340 L, respectively). In addition, he also estimated that an average of 110 L was used for laundry washing, equal to 13.4% of the daily water consumption, that is within the range of estimates (6-16.5%) made from the project data.

5.2.2 Laundry Water Quality

Analysis of laundry water quality obtained in this project indicated that quality parameters vary considerably depending on many factors, such as water consumption rate of the washing machines, type of detergents and fabric softener used, family structure including numbers and age of the occupants, and individual lifestyle. The results are quite consistent with a wide range of values reported in previous studies (Sharman 1993, Christova Boal et al. 1995).

Some laundry water samples in this project exhibited higher values of P, Ca and Mg than the maximum limits mentioned in previous studies (Sharman 1993, Christova Boal et al. 1995). The elevated P levels observed in these laundry water samples might be due to the combined effects selected households using detergents with high P content and low water consumption washing machines such as front loading machines. High Mg and Ca levels could be associated with the characteristics of Toowoomba water supply sources. Indeed, about 15% of current fresh water supply in Toowoomba originates from bore water, i.e. also referred to as ground water (TCC 2005a). When groundwater seeps through the rocks, it picks up high levels of bicarbonate salts of Ca and Mg ($Ca(HCO_3)_2$ and $Mg(HCO_3)_2$) causing hardness in groundwater (David and Cornewell 1998). Therefore, water used from such sources is likely to contribute to high Ca and Mg concentration in laundry water samples.

A comparison of laundry water quality obtained in this project with the water quality recommended for irrigation in Australian and New Zealand guidelines (ANZECC 2000) showed that chemical parameters, such as pH, sodium and phosphorus reached unacceptably high levels at which the irrigation with laundry water could pose a potential hazard to trees, soils and groundwater. Other parameters such as BOD, TSS in some cases also exceeded the recommended limits mentioned in the irrigation guidelines. Therefore, direct laundry water reuse for garden irrigation needs to be approached with some care and that specific irrigation practices or treatment methods might be required to overcome problems associated with the elevated levels of these quality parameters. However, the levels of total dissolved salt estimated from EC values and total nitrogens in laundry water were found to be quite reasonable with the quality requirement for irrigation. This indicates that laundry water may not cause severe salinity or nitrogen pollution related problems if it is used for garden irrigation.

Results from this study indicated that faecal coliform in majority of laundry samples (73.3%) below the detection range and about 93.3% of measured samples showed low faecal coliform numbers of less than 100 cfu/100 mL. Assuming that the studied group adequately represents the Toowoomba population, these results imply that more than 93% of Toowoomba households could safely reuse laundry water to irrigate non-consumable crop, such as lawns and ornamental gardens as faecal coliforms < 1000 cfu/100 mL is considered as a safe limit. This study also found that there were a significant number of faecal coliforms observed in one family with a baby (eg. 19000 cfu/100 mL). However, the presence of babies is not always definitive indicator of the level of faecal coliforms in laundry water as there were other similar families in this study showing little or no faecal coliforms in laundry water. From laundry water reuse perspective it may be useful to restrict reuse of laundry water whenever households choose to wash nappies that is a potential contributor of coliforms via human faeces.

5.2.3 Detergents

The project findings also indicated some quality parameters (the levels of pH, Na, P, N, TDS and SAR) to be clearly related to the composition of the laundry detergents. The laundry water associated with powder detergents was subject to higher levels of pH and

Na than those associated with liquid detergents. This is because the content of alkaline substances and Na compounds in solid particles are higher than in a solution per unit volume. The nutrients and salt concentrations in laundry water were also related to the phosphorus content in the laundry detergents. It was found that P-free detergents with NP label not only have low P content, but also lower Na, N and total dissolved salts than the detergents labelled with P. Therefore, nutrients levels are strongly related to the levels of other dissolved salts in detergents. In addition, P content labelling scheme could be used as an indicator of elevated levels of nutrients and other salts in laundry water. Since SAR value is directly related to Na content in laundry water (Equation 3.1), the detergent type and its P content is likely to influence SAR of laundry water.

Overall, the P-labelled powder detergents increased pH, TDS, Na and SAR of laundry water to unreasonably high levels that would potentially reduce the reuse potential of laundry water effluent (Table 5.5). On the other hand, P-free liquid detergents were very effective in reducing the concentration of harmful chemicals in laundry water to a level that remained well below the limits specified in the water quality guidelines for irrigation. Thus, this type of effluent would be considered chemically safe for reuse and is expected to cause minimum environmental damage. the increase in levels of chemical parameters in laundry water is associated with detergents in order NP-liquid, NP-powder, P-liquid and P-powder detergents. It was found that the use of NP-liquid detergents significantly lowered the P, Na and pH levels, which were major constraints for the laundry water reuse scheme due to their detrimental effects on soils and plants at high levels. From table 5.2, mean pH value in laundry water associated with NP-liquid detergents is 7.8 and in optimum range for irrigation. The nutrient and Na pollutions caused by this detergent type in laundry water were also low with average values of 0.07 g N, 0.08 g P and 6.4 g Na applied per full wash. If more than 40 L of water used in laundry washing machine per wash, the concentrations levels of N, P and Na in laundry water would less than 1.75 mg/L, 2 mg/L and 160 mg/L respectively. Hence, the quality of laundry water is well under the limits of the irrigation guideline. The combination of detergent types (powder or liquid) and P-content labelling can be considered as a good reference for consumers to select detergents that will minimise chemical pollution in laundry water and maximise its reuse. However, it needs to be aware that the chemical compounds in different detergents will vary depending on types and formulae that the producers have used to produce those detergents.

5.2.4 Storage Time

Although this project did not aim to quantify the odour level, the first effect of storage of laundry water can be physically recognised with an unpleasant (smelly) odour due to the development of anaerobic conditions. Indeed, organic matters in laundry water were degraded quickly by aerobic organisms, depleting the dissolved oxygen in this water (David and Cornwell 1998). Since there was no oxygen replacement from the outside atmosphere due to storage in airtight containers, anaerobic organisms became dominant in this stored laundry water, causing unpleasant smell.

This project found that there was little significant change in the concentration of nutrients and other cations in laundry water samples after a short storage period (i.e. less than 1 week). The relatively small number of samples tested and the selection of storage period may have influenced these results. It is also possible that the nutrients and cations in laundry water samples are not as easily degradable as organic matter; hence not significantly affecting the biochemical processes during the brief storage period used.

With regard to microbiological quality of stored laundry water, there was a significant growth of faecal coliform during storage at ambient temperature for those samples, which had high faecal coliform before storage. For other samples with little or no faecal coliforms (< 3 cfu/ 100mL), faecal coliform could not be detected after the short storage period (< 6 days). The disappearance of faecal coliforms in laundry water samples implies that other microbes might have suppressed the growth of faecal coliforms. The greater the population of organisms in the environment, the more advantages they might have while competing for energy and nutrients (Miller 2004). Thus, lack of growth of faecal coliforms in laundry water during storage when it has a small initial population does not exclude the possibility that there may be other pathogenic organisms that might have grown and suppressed the growth of faecal coliforms. Without further detailed analysis of microbiological quality of laundry water, it is prudent to avoid storage option for untreated laundry water to minimise the risks of possible disease outbreak.

Chapter 6
MICROBIOLOGICAL RISK ASSESSMENT

6.1 Concept of Quantitative Microbiological Risk Assessment

As mentioned in the earlier sections, both direct and indirect risks of human infection arise from the presence of microbial pathogens in laundry water used for lawn and garden irrigation. The higher the risks, the more numbers of people are likely to be infected and more severe are the outbreak of diseases. However, the risks of infectious diseases depend on the type of pathogens, microbial levels in laundry water, immunity of an individual and the degree of human contact with this wastewater during and after irrigation. According to Pepper et al. (1996), risk is the key factor in all decision making. In this study, the human health safety is the most important criterion for people as well as water regulatory authorities to accept the laundry water reuse scheme. Therefore, the risk assessment focused on various aspects of human health.

In order to judge the safety associated with laundry water reuse for garden irrigation, the quantitative microbial risk assessment was employed. Quantitative microbiological risk assessment (QMRA) is defined as "the application of principles of risk assessment to estimate of consequences from a planned or actual exposure to infectious microorganisms" (Hass et al. 1999, p 9). This QMRA estimates the risks of human infection from the use of laundry water for garden irrigation and express it in terms of probability. This numerical value (i.e. probability) provides a clear picture to all people on how safe the laundry water is if it is applied in urban household gardens.

The microbiological risk assessment for laundry water consists of four basic steps (Pepper et al. 1996):

- Identifying a type of pathogenic microorganism that has a high risk to cause adverse diseases in humans;

- Determining the concentration of pathogen in the environment and the dose that a typical person is likely to intake;
- Quantifying the adverse effects arising from exposure to a hazard and finally
- Estimating the potential impact of the hazard based on the degree of infection caused by the pathogen and the amount of exposure.

6.2 Procedure Used for Microbiological Risk Assessment

6.2.1 Risk Assessment Model

There are two common dose-response models, such as Beta-Poisson and Exponential Model, which have been developed to perform the quantitative microbiological risk assessment for many enteric organisms (Haas et al. 1999). The Beta-Poisson Model was adopted in this study since this model is the most suitable for *E. coli* (Regli et al. 1991). As mentioned in previous sections, *E. coli* belongs to the faecal coliform group.

For the Beta-Poisson model, the probability of infection from a single exposure can be stated as:

$$P = 1 - \left(1 + \frac{N}{\beta}\right)^{-\alpha}, \qquad (6.1)$$

where P = the probability of infection from a single exposure,

N = the number of pathogenic organisms ingested per exposure (cfu) and

α and β = constants corresponding to enteric waterborne pathogen of interest.

Annual risk of infection can be estimated as

$$P_A = 1 - (1 - P)^{365}, \qquad (6.2)$$

where P_A is the annual risk (365 days) of contracting one or more infections.

The lifetime risk of infection is estimated as:

$$P_L = 1 - (1 - P)^{25550} \text{ ,} \qquad (6.3)$$

where P_L is the lifetime risk (assuming a lifetime of 70 years = 25500 days) of contracting one or more infections.

Finally, the risk of mortality over a lifetime = $P_L \times I \times M$, (6.4)

where *I* is the percentage of infection that result in clinical illness and

M is the percentage of clinical cases that results in mortality.

6.2.2 Key Assumptions used for Quantitative Risk Assessment

Water CASA (1998) found that the background levels of faecal coliform in soil is naturally low (< 10 cfu/100 mL). Therefore, the health risks of infection caused by faecal coliforms can be attributed to levels of faecal coliforms in laundry water rather than those in natural soils.

The risk assessment was modelled based on some key assumptions:

- All faecal coliforms detected were *E. coli* and all of pathogenic strains;
- Laundry water was applied to lawn and garden at the soil surface;
- Irrigated soils at the surface reached saturation equivalent to the maximum water holding capacity of soil.

These assumptions constitute the worst case scenario in which the concentration of *E. coli* in soil surface is at maximum level.

6.2.3 Estimation of Faecal Coliform Level in Soils Irrigated with Laundry Water

The procedure used to estimate the faecal coliform level in soil was as follows.

- Bulk Density (BD) of an average Toowoomba soil was taken as 1.19 g/cm^3 (A. Sivongxay, 2005, personal communication).
- Particle density (PD) was assumed to be 2.65 g/cm^3 (Singer and Munns 2002).

- Soil porosity = $1-\frac{\text{BD}}{\text{PD}}$ = 0.55 cm^3/cm^3 or 55%.
- Saturated volumetric soil moisture content (VMC_{sat}) = porosity = 0.55 (cm^3/cm^3).
- Saturated gravimetric moisture content (GMC_{sat}) = $\frac{\text{VMC}_{\text{sat}}}{\text{BD}}\times\rho_{water}$ = 0.463 g/g,

  where ρ_{water} = density of laundry water ≈ 1 g/cm^3.
- Concentration of *E. coli* in soil (cfu/g) = $\text{GMC}_{\text{sat}}\times C_{water} = 0.463\times C_{water}$,

  where C_{water} was the number of faecal coliforms detected in 1 g or 1 mL of laundry water.

Since all faecal coliforms were assumed to be *E. coli*, the concentration of *E. coli* in irrigated soil could be estimated as follows:

$$C_{soil}=\frac{0.463\times C_{laundry}}{100}. \qquad (6.5)$$

C_{soil} = concentration of *E. coli* in irrigated soil (cfu/g)

$C_{laundry}$ = concentration of *E. coli* (i.e. faecal coliforms) detected in laundry water (cfu/100 mL)

For *E.* coli, the model parameters α and β in Beta Poisson Model were 0.1705 and 1.61×10^6, respectively (Regli et al. 1991). The amount of organism intake through soil ingestion per day (N) was assumed to be approximately 200mg/day and 100mg/day for a child less than 6 year old and a child over 6 years old who may be present near the irrigated soils (Haas et al. 1999). Haas et al. (1999) also found the average clinical illness and mortality ratios for *E. Coli* to be 28% and 0.57%, respectively for the people of these age groups. These parameters were applied into equations (6.1-6.4) to estimate the lifetime probability of infection and mortality for children.

6.3 Results and Discussion

Table 6. 2:Lifetime probability of infection and death for children due to the reuse of laundry water for garden irrigation.

Faecal coliform concentration in laundry water (cfu/100 mL)	Lifetime risk of infection for a child < 6 yrs old	Lifetime risk of infection for a child >6 yrs old	Lifetime risk of mortality for a child < 6 yrs old	Lifetime risk of mortality for a child > 6 yrs old
10	0.0025%	0.0013%	0.000004%	0.000002%
100	0.0250%	0.0125%	0.000040%	0.000020%
5,00	0.1250%	0.0625%	0.000199%	0.000100%
1,000	0.2498%	0.1250%	0.000399%	0.000199%
5,000	1.2425%	0.6232%	0.001983%	0.000995%
10,000	2.4696%	1.2425%	0.003942%	0.001983%
19,000	4.6401%	2.3476%	0.007406%	0.003747%
20,000	4.8782%	2.4696%	0.007786%	0.003942%
40,000	9.5184%	4.8782%	0.015191%	0.007786%
50,000	11.7529%	6.0601%	0.018758%	0.009672%
100,000	22.1243%	11.7529%	0.035310%	0.018758%

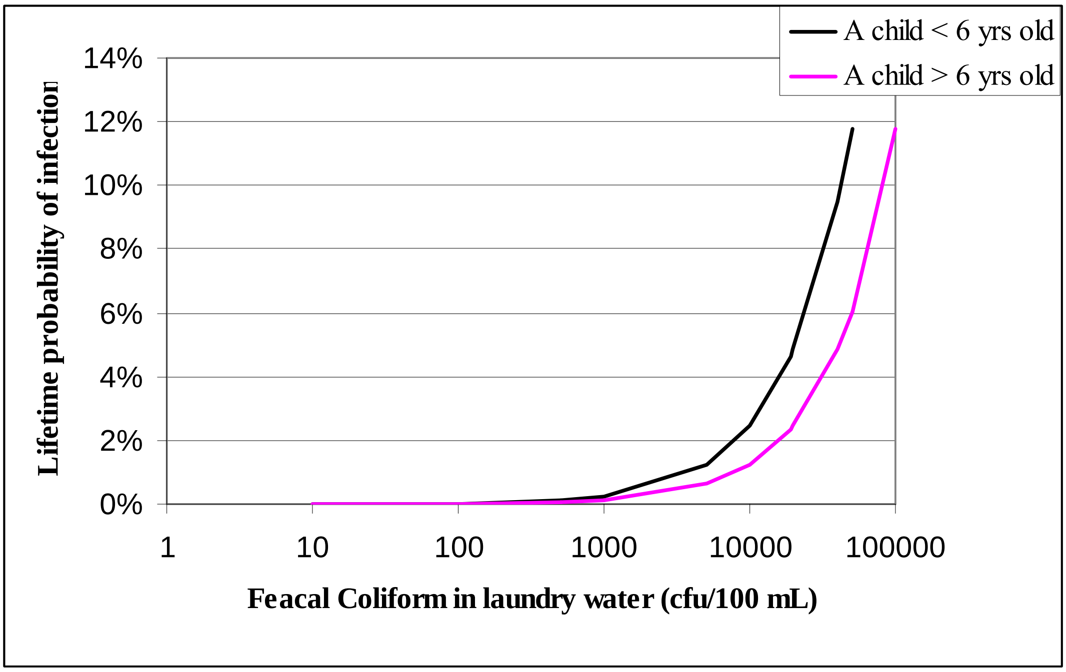

Figure 6. 2: Lifetime probability of disease infection and mortality for children due to the reuse of laundry water for garden irrigation.

It was found that a young child (less than 6 year old) is exposed to greater risk of disease infection and mortality than an older child (over 6 years old) if they played on the ground recently irrigated with laundry water. From Table 6.1 and Figure 6.1, it can be seen that the lifetime risk of infection for a child was very negligible, with a probability of 0.0250% if laundry water contained low levels of faecal coliforms (< 100 cfu/100 mL). In the previous chapter, it was shown that more than 93% of laundry water samples in this project had been found to have faecal coliform <100 cfu/100 mL. This implies that laundry water is reasonably safe to use for garden irrigation.

For laundry water detected with high level of faecal coliform (in a household with a baby), the lifetime risk of infection may become unacceptable (4.6 % for a child less than 6 years old and 2.3% for a child over 6 years old). The chance that this risk would lead to children mortality is still low, i.e. 0.007% over 70 years (human lifetime). However, for safety reason, the laundry water arising from nappy washing should not be reused for irrigation.

The actual health risks associated with the use of laundry water for garden irrigation used in this study would be considerably lower as the health risk assessment was based on the worst case scenario. In fact, faecal coliform concentrations in soil is naturally lower than in laundry water Apart from this, soil does not remain saturated for long period as it tends to attain field capacity or moisture is easily lost via evapotranspiration. Hence pathogen concentration in drier soil is expected to be much lower than that in wet soils. Indeed, many pathogens like virus, bacteria and other microorganisms become inactive or destroyed outside the water medium (Fegan et al. 1998). In addition, the UV from sunlight at certain wavelengths can also kill the microorganisms, which are present on the soil surface (Middlebrooks 1982). Considering these issues and also that the current recommendation for laundry water reuse is via subsurface irrigation systems, pathogens such as faecal coliforms on the soil surface are expected to be much lower than in laundry water.

Chapter 7

POTENTIAL IMPACTS ON TOOWOOMBA ENVIRONMENT FROM LAUNDRY WATER REUSE

7.1 Impacts of Laundry Water Irrigation on Soil

Even though laundry water may have higher pH (7.3 to 10.3) than potable water, the land application of laundry water is unlikely to result in excessive soil pH increases due to the nature of the soil. The major soil found around Toowoomba city is the red clay soil classified as Red Ferrosol, covering 90% of Toowoomba city area (Biggs et al. 2001). Ferrosol soil is slightly acidic with pH increasing from 6.3 to 6.6 along the depth of soil profile (Beckmann et al. 1974). In addition, most soils have a high pH buffering capacity which resists pH change. According Singer and Munns (2002), the added base (OH^-) would react with colloid surface to yield (H^+) and Al^{3+}, which will reverse soil pH to the original level. The pH buffering rate depends on clay content and humus, clay colloid reactivity, cation exchange capacity and pH-dependent charge in soil (Singer and Munns 2002).

However, the excessive additions of highly alkaline water (greater than 8.5) may induce soil pH change in short term, which in turn has detrimental effects on healthy tree growth (Myers et al. 1999, ANZECC 2000). Therefore, the pH level in laundry water may need to be corrected before use for garden irrigation by either using low pH detergents (e.g. NP-liquid powder) or applying gypsum over the soil. Van der Ryn (1987 cited by Sharman 1993) suggested if the pH in soil exceeds 7.5, gypsum could be applied at a rate of 1 kg/30 m^2/ month until pH falls below 7.0.

Many laundry water samples in this project were found to contain high concentration of sodium (Na). As mentioned in the previous section, the build-up of Na in soil may become toxic to certain plants. But the overriding effect of high Na is to cause the clay particles to disperse and eventually block soil pores. According to (Myers et al. 1999), when the particles disperse and move to deeper horizons in the soil, the damage is difficult to reverse. However, the deterioration of soil structure is not directly related to the Na concentration in water, but is attributed to relative concentration of Na compared with other cations Ca and Mg. This combination is represented by Sodium Adsorption Ratio (SAR) value (See Equation 3.1). A recent study of Emdad et al. (2004) indicates that the infiltration under the field conditions was inversely related to SAR of the applied water.

Application of laundry water with high total dissolve salts (TDS) to soils over extended periods of time could also lead to salinity problems. However, based on this study's finding, it appeared that an average dissolved salt content in laundry water was not too high to cause the salinity problem, following the irrigation guidelines (also see section 5.2.5). During drought period in Toowoomba, however, the salt added continuously through irrigation may become concentrated in soil as water is taken up by trees or is lost from soil via evaporation. The accumulation of salts in plant root zone may affect growth of some plants adversely if it reaches the salt tolerance limit of the plant. To control this problem, fresh water in excess of plant water use at certain time intervals may be needed to leach the accumulated salt down the root zone (Sharman 1993, Myers et al. 1999).

Low level of salts in irrigation water is sometimes perceived to have a beneficial effect for sodic soils. Singer and Munns (2002) explained that an increase in total dissolved solids (or equivalent EC) increases the ionic strength between soil particles, therefore reducing the dispersion of clay. Therefore, the SAR of laundry water must be considered in the relation to its EC. Figure 7.1 compares the EC-SAR of laundry water found in this study with the threshold values for soil structural stability. All laundry water samples were in the intermediate zone between stable and unstable conditions. This intermediate zone is not clearly defined as it depends on many factors such as clay content, types of clay, the salinity of the leaching water and clay particle reactivity to the cations in soil solution (Myers et al. 1999). On other words, the use of laundry water may be suitable for certain soils, but may result in an unstable soil structure (i.e. clay particle dispersion) for other soils. Since no further information on Toowoomba's soil characteristics available, it is difficult to confirm whether the use of laundry water for garden irrigation will cause any severe damage to this soil. More information on

Toowoomba soil characteristics is needed to determine the effects of laundry water on Toowoomba soils.

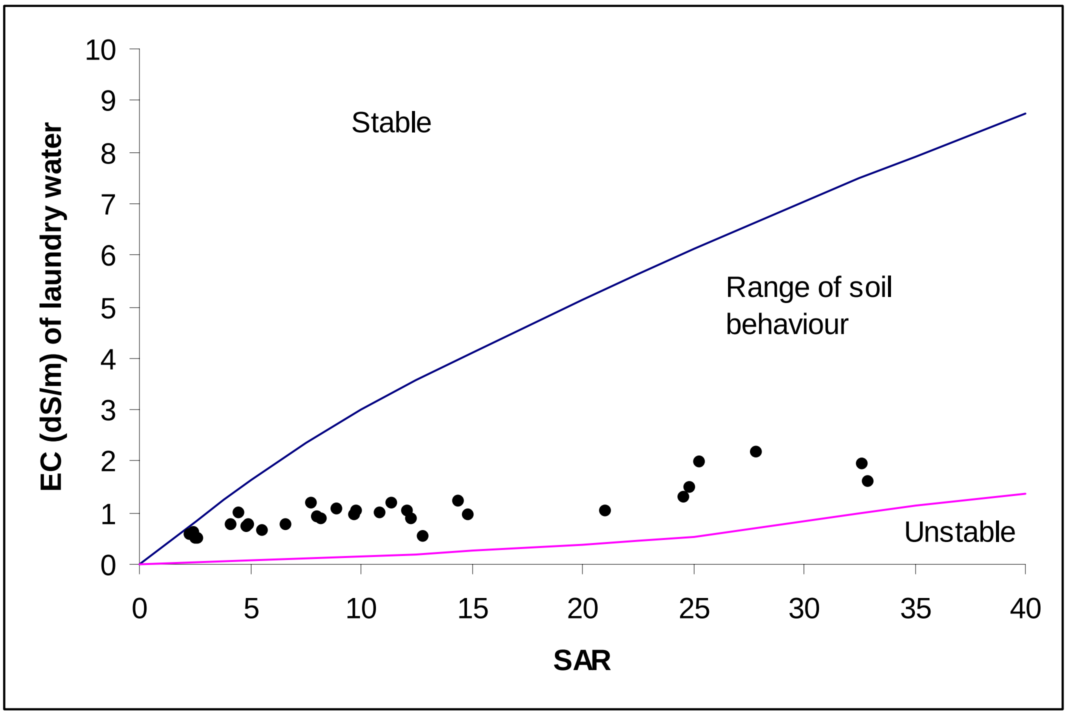

Figure 7. 2: Comparison of laundry water quality in this project with a permeability threshold values for soil types as a function of SAR and EC (adapted from Myers et al. 1999).

7.2 Impacts of Laundry Water on Water Surface and Groundwater

Nutrient surplus such as phosphorus (P) and nitrogen (N) are major causes of eutrophication and algal bloom if high amount of these nutrients are discharged into water bodies. As mentioned in previous section (Chapter 5), N concentration is not considered to be a major problem with laundry water reuse due to its low concentration in soils. Instead, laundry water is more likely to have a problem with elevated P content. According to Christova Boal et al. (1995), phosphorus from detergents do not pose a major problem when disposed to land since it is normally required as a nutrient for plants. However, soil may become phosphorus saturated if the application rate is higher than the plant's uptake rate. Hence there is a potential for leaching to groundwater or transport via runoff to a watercourse if laundry water is used for irrigation with high concentration of these nutrients.

The topography of Toowoomba area seems to favour the laundry water reuse scheme, as there are few water bodies such as lakes and creeks, but no rivers within Toowoomba city. Therefore, the eutrophication problem related to nutrient runoff is minimised, provided they are not discharged within close proximity to lakes and creeks. The study on bore water levels in Toowoomba areas (TCC 2005b) shows that Toowoomba does not have any problem with shallow groundwater. In fact, the water level in bores significantly decreased further during the drought period such as this year. Therefore, groundwater contamination by nutrient leaching is also negligible.

Chapter 8
CONCLUSION

Compared with other countries like Japan and USA, greywater reuse is a new emerging issue for Australia to improve its water saving strategy. However, this option has recently attracted attention from many government agencies and water authorities. Among other water saving options, greywater reuse in general and laundry water reuse for garden irrigation are highly supported by the public in many areas around Australia.

Overriding criterion to the acceptance of greywater reuse is the public health safety. Governments and water authorities are more aware of potential hazards associated with greywater reuse than the public, and are treating this issue with a great caution. The degrees of awareness are also different between governments and water authorities, reflected by the difference in their policies and regulatory guidelines.

The inconsistent and inadequate scientific information in the existing guidelines in are major constraints for the public to translate their supports into actions. Therefore, these issues must be addressed before the water reuse scheme can be introduced. Many state government and water authorities are funding and supporting many researches on greywater to obtain more scientific based information to develop a comprehensive nationwide guideline.

Cost of greywater treatment is also a significant factor affecting the degree of acceptance toward greywater reuse scheme. The treatment costs for greywater both at centralised plants and at household levels were too high compared with current price for fresh water. Unless the actual price of water is introduced, reuse of treated greywater is not economical feasible.

Direct reuse of laundry water for backyard irrigation (lawn and garden) is considered a feasible option to overcome economical constraints. This practice is reviewed by preceded studies to be beneficial in many aspects such as supplementing soils with essential plant nutrients, preventing septic tank and treatment systems from hydraulic shock and fresh water conservation. Low contamination level of laundry water and its water saving aspect are two crucial arguments that support the reuse of laundry water on domestic gardens without treatment.

The Toowoomba City Council aimed to develop a guideline for greywater reuse in the near future, therefore the Council also concerned about the possibility of the direct reuse of laundry for garden irrigation. The investigation on laundry water use in Toowoomba area was carried out to evaluate the possibility of its reuse for household garden irrigation. Data on laundry water quantity and quality were analysed from 15 households to be a representation for the whole Toowoomba population. Four types of families involved in the study were 2 adults, 2 adults + 1 child, 2 adults + 2 children, 2 adults + 1 baby, and a single parent family.

The flow splitting device was designed to assist the collection of laundry water sample from the washing machine. The design used the simple hydraulic principles (i.e. Bernoulli's and Continuity' Equations) to divide the discharge into two parts. The small proportion of discharge was collected for quantity and quality analyses. The unit cost for the device was cheap (i.e. $22 per sample collection kit) so that the construction of multiple devices was economically acceptable. In addition, a performance of each device was adequately acceptable (less than 10% variation in flow split ratio) for the purpose in this study.

This study found that for an average Toowoomba household, the volume of laundry water available for reuse is approximately 110 L/day. This quantity of laundry water was consistent with that for an average Australian household found in other previous studies. The quantity of laundry water generated in the individual house depends on the washing habit, age and number of the occupants. More than 95% of families in Toowoomba were found to use more than 40 L/d for laundry washing. If this amount of laundry water can be reused, at least 6% from fresh water consumption can be saved.

Regarding the quality of laundry water, the finding of this project indicated as follow:

- Probability of laundry water contaminated by faeces may be low for most families, except those associated with nappy washings. Approximately 73.3%

of the observed samples were below limit for detecting faecal coliforms (< 1 cfu/100 mL), 20% have faecal coliform concentration of less than 100 cfu/100 mL. That implies other pathogenic microorganisms may be minimal in laundry water.

- Laundry water may contain elevated concentrations of many chemicals and nutrients, such as pH, sodium (Na), total dissolved salts (TDS) and phosphorus (P) that unacceptably exceeded the recommended limits for irrigation water's quality.
- Non-phosphate (NP) liquid detergents contributed less chemical contaminants to laundry water than other types of detergents. Laundry water associated with NP-detergents had pH, EC, chemical and nutrient contents more suitable for irrigation purposes than those associated with P-detergents. The P-content labelling scheme for detergents (P or NP) was perhaps a trustable hint for customers to choose the more environmentally friendly detergents.

A short storage time (less than 1 week) may not have any substantial effect on the chemical contents in laundry water. However, faecal coliform levels in laundry water were observed to increase significantly during storage period. The storage also results in the anaerobic conditions, which release unpleasant smells. Therefore, storage of laundry water should be avoided.

The quantitative microbiological risk assessment showed that the risks of disease infection and mortality to humans caused by faecal coliforms were negligible for most families when laundry water (without treatment) was used to irrigate the backyard garden, except those using laundry water associated with nappy washing. This again implies that laundry water reuse for garden irrigation was possibly safe in families who did not wash the clothes contaminated by faeces.

The application of laundry water with high pH level on a garden soil does not affect the soil pH in long term because soils usually have a high capacity to resist pH change (buffering capacity). However, short term change in soil pH due to application of highly alkaline laundry water may damage plants growth.

The elevated sodium concentration in laundry water can lead to sodicity problem which cause damage to plants after along period of application. The soil structure may also be affected by the use of high Na content laundry water, such as soil particle dispersion, reduction in filtration rate and soil pore blockage. However, more information on Toowoomba soil properties is required in order to conclude whether or not laundry water severely impacts on the soil structure stability.

Laundry water in some cases may contain high level of nutrients such as phosphorus (P) and Nitrogen (N) compounds; therefore the application of this laundry water may build up content of these nutrients in soils. These nutrients possibly will leach through the root zones or runoff on the surface during rainfall events. However, the eutrophication and ground water contamination problems seemed not to be of great concern in Toowoomba due to geological features of Toowoomba area.

Chapter 9

FURTHER STUDY

9.1 Effect of Fabric Softener on Laundry Water Quality

Fabric softener is a mixture of chemical compounds which is usually used to reduce the stiffness in fabric structure caused by cleaning agents in detergents. Fabric softeners may contribute high amounts of chemicals, nutrients and even toxic matters to laundry water quality. The analysis on the chemical contents of different fabric softeners would provide better information for consumers to make their choice on the washing products which have low contamination levels. The better the laundry water quality, the wider range of application this wastewater can be reused for.

9.2 Effects of Electrical Conductivity and Sodium Absorption Ratio on Toowoomba Soil

It is desirable to undertake a further study on the changes in structure stability of an average Toowoomba soil corresponding to applications of different sodium and dissolved salt contents. This analysis would help to determine whether or not reuse of laundry water for garden irrigation without treatment will cause severe physical degradations in the soil structure in Toowoomba.

9. 3 Treatment Systems for Laundry Water

Laundry water in many cases has high contamination levels and may cause problems to soil, irrigation system and human health. Therefore, it is desirable to develop the simple and cheap treatment methods which are capable to reduce the physical, chemical and microbial contents in laundry water to the suitable levels before applying on soils. The treatments should be economically feasible for any individual households regarding to the capital and operation costs. It may be also more convenient if these treatments can operate automatically or semi-automatically with minimal human attendance required.

9.4 Physical Properties of Soil Affecting Infiltration, Retention and Drainage

Different soil types may have different infiltration, retention and drainage. When laundry water is disposed or used via irrigation, the laundry water absorption by soils will vary depending on the soil physical properties. Therefore, it is useful to determine the essential properties of surface materials in order to irrigate residential areas with laundry water. Soil texture, bulk density and water holding capacity of the soils and the variation of these properties with depth may need to study further, particular for soils in Toowoomba area, in order to provide a general picture of the capacity of the soils and landscape materials to allow infiltration, hold water and avoid water logging.

9.5 Chemical and Microbial Properties of Soil Affecting Leaching and Chemical Retention

Soil is considered to be a natural medium to filter salts, nutrients, toxic ions, microbes and pathogens. This capacity is dependent on chemical and microbial properties. As laundry water may contain a high concentration of sodium, phosphates, pH and EC, the chemical properties of soil including cation exchange capacity, buffering capacity and sodium adsorption ratio of soils could be useful in determining the capacity of soil to retain and or leach salts and nutrients. Soil organisms also play an important in degrading or neutralising chemicals and nutrients content in soils. The further study on chemical and microbial properties of soils in Toowoomba is desirable to determine how well Toowoomba soil can adapt the chemical contents of laundry water.

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Appendix A: Project Specification

University of Southern Queensland
FACULTY OF ENGINEERING AND SURVEYING

ENG4111/4112 Research Project
PROJECT SPECIFICATION

FOR: **Minh Nhat LE**
TOPIC: Reuse Potential of greywater (laundry source) for irrigation for Toowoomba Region
SUPERVISOR: Dr. Rabi Misra
SPONSORSHIP: Faculty of Engineering and Surveying, USQ and Toowoomba City Council

PROJECT AIM: The projects aims to define the quantity and quality of greywater from laundry source, evaluate the feasibility of direct reuse of untreated laundry water for garden irrigation in Toowoomba Region.

PROGRAMME: **Issue B, 5st July 2005**

1. Research the background information related to reuse of greywater in Australia including trends, policy regulations and the public health issues.
2. Design a device that can sample total discharge from the laundry machine by using volume reduction principle, and evaluate its applicability, accuracy, convenience and costs.
3. Identify major characteristics of untreated greywater related to impacts on soils and plants.
4. Research the effect of increasing storage time on the wastewater quality
5. Discuss the potential impacts of untreated greywater on soils (Toowoomba region).

As time permits

6. Research the inexpensive and simple methods to pre-treat greywater before applying to the soil.

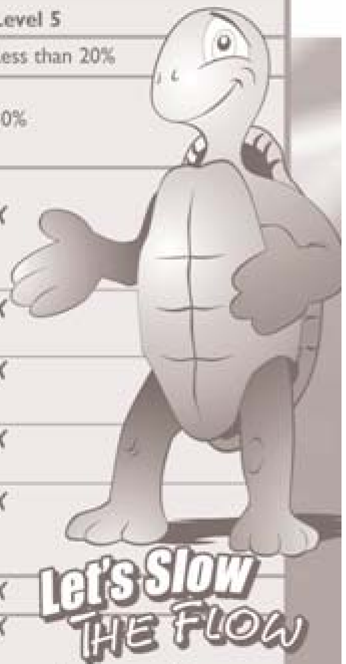
Appendix B: Toowoomba Water Restriction Policy

Toowoomba Water

water restrictions

TOOWOOMBA CITY COUNCIL

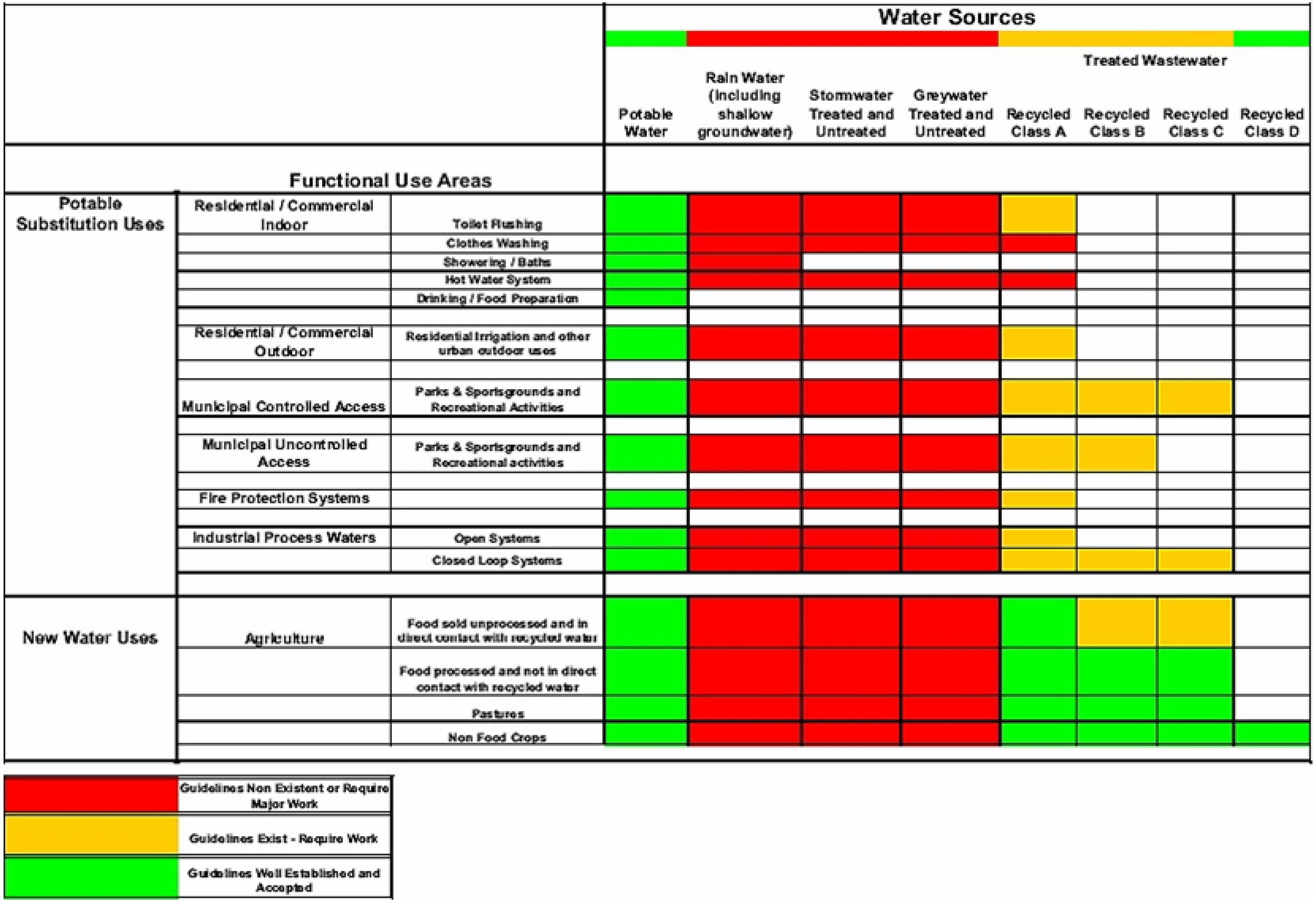
	Level 1	Level 2	Level 3	Level 4	Level 5
Dams useable storage	Greater than 55%	55% to 40%	40% to 30%	30% to 20%	Less than 20%
Dams useable storage Trigger point to lift Restrictions to next level		65%	50%	40%	30%
Gardens and lawns					
Hand-held hosing	✓	✓	Lawns not permitted. Gardens Odd and Even – refer below*	✗	✗
Watering systems not approved by Council	Odd and Even – refer below*	✗	✗	✗	✗
Council approved drip irrigation systems	Anytime Tuesday to Sunday	Odd and Even – refer below*	Wednesday and Saturday 7am to 9am and 5pm to 7pm	Wednesday – 7am to 9am	✗
New turf	Application for exemption to water restrictions	Application for exemption to water restrictions	Application for exemption to water restrictions	✗	✗
Carnival of flowers gardeners or residents with special circumstances	Odd and Even – refer below	Application for exemption to water restrictions	✗	✗	✗
Cleaning paved areas	✓	✗	✗	✗	✗
Motor vehicle washing	✓	✓	Wash - bucket filled directly from a tap Rinse - water from hose fitted with trigger nozzle	Wash - bucket filled directly from a tap Rinse - water from hose fitted with trigger nozzle	✗ except by commercial car wash that recycles water



***Odd or unnumbered properties** - Tuesday, Thursday and Saturday - 5am to 9am and 5pm to 9pm. **Even numbered properties** - Wednesday, Friday and Sunday - 5am to 9am and 5pm to 9pm.

For more detailed information on the Water Restrictions Policy refer to www.toowoomba.qld.gov.au and follow link to Toowoomba Water or telephone 4688 6704.

Appendix C: Availability of Current Guidelines on Water Reuse Schemes



Appendix D: Laundry Water - Data Collection Form

Toowoomba City Council Laundry Water Feasibility Study
Laundry Water Collection Data Form

Site number *: ____________________ Sampling kit code: ____________________

Family Type *(circle one)*: 2A 2A+C 2A+B 1A + C

Owner name: ____

Street address: ______________________________ Suburb: ______________

GPS Northing: ______________________ GPS Easting: ______________________

Washing machine & cleaning product information:

Machine brand: __________________________ Machine model: ______________

Front loader / Top loader *(circle one)* Capacity (kg): ______________

Brand of detergent: ________________________ Powder / Liquid *(circle one)*

Brand of fabric softener: ______________________________________

Average numbers of washes per week:______________________________

Laundry water sample information:

Washing Number *	Date and time of washing *	Estimated washing load (½, ¾, full etc)	Amount of detergent used (scoops)	Amount of fabric softener used (capfuls)

* *Site number, washing number, date & time to be marked clearly on water sample bottles*

The names of participants in this project will remain confidential. Participant's street address may be used to spatially locate water sampling points on maps to be produced as part of the project's reporting requirements. All other information may be aggregated and released as part of the project's reporting requirements.

I, __________________________ give my permission for project personnel to enter my house and collect laundry water that will be used as outlined above. I understand that my name will be kept confidential but other data may be used as outlined above.

Print Name: __________________ Signature: _______________ Date: ________

USQ NCEA Landloch TOOWOOMBA CITY COUNCIL

Appendix E: Laundry Water Survey Package (Installation)

Figure E1: Right view of the flow splitting device after installed

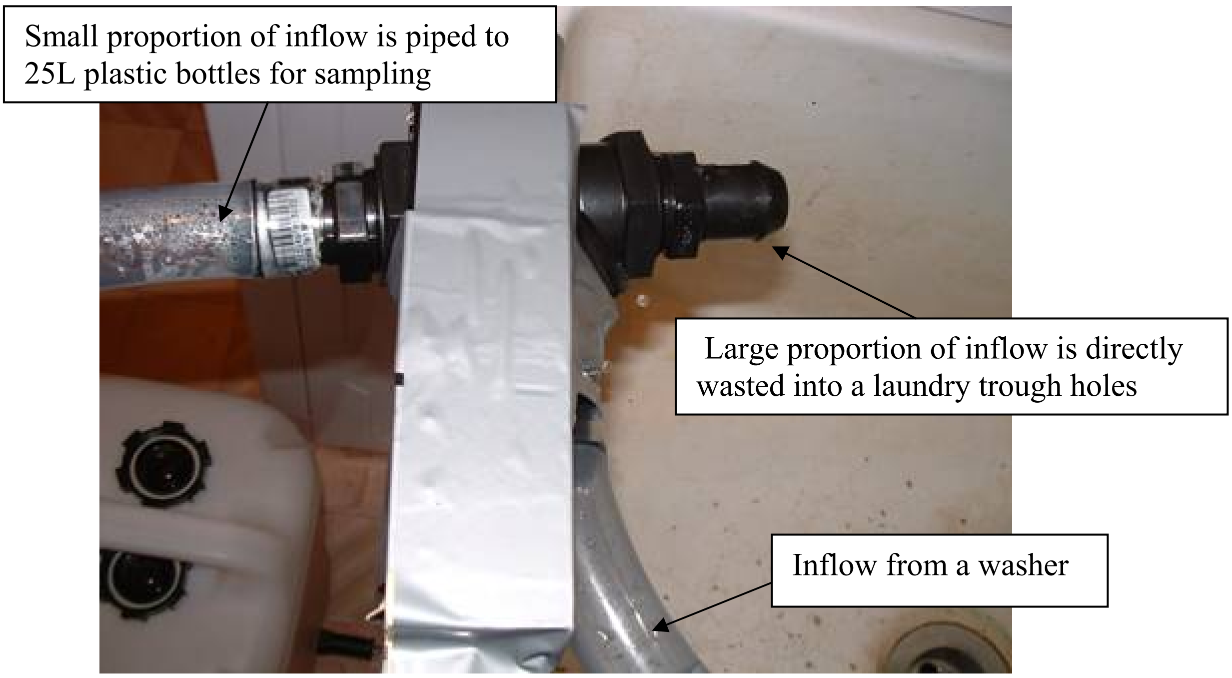


Figure E2: Top view of the flow splitting device after installed

Appendix F: Splitting Flow Device in Parts

Figure F1: Sampling end of the device

Figure F2: Wasting end of the device

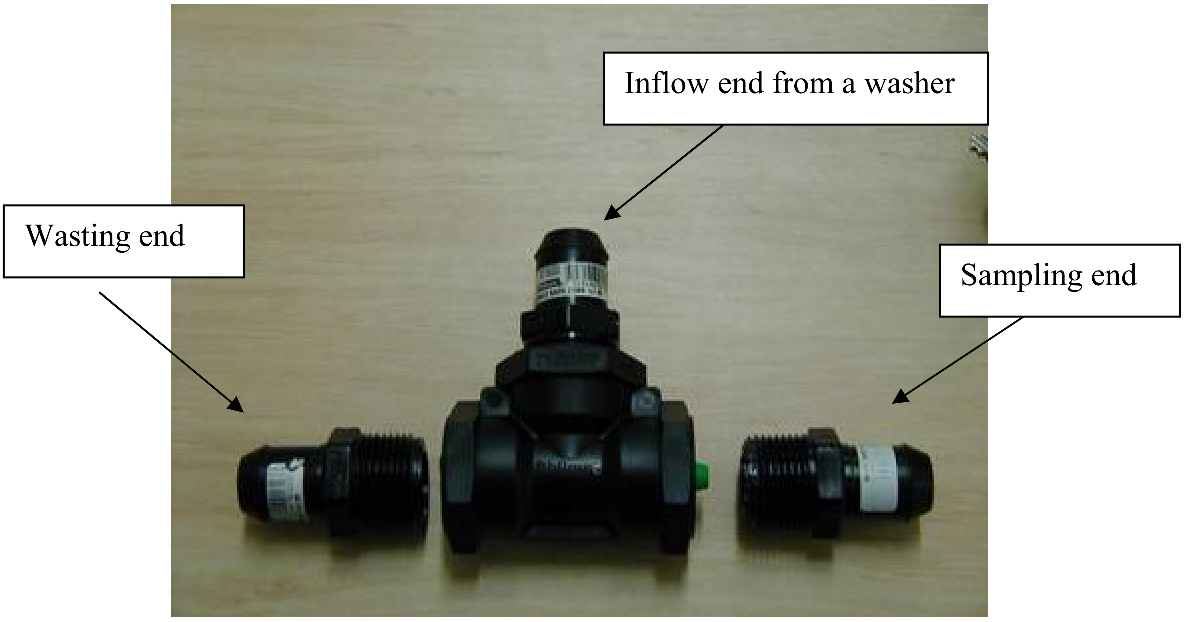


Figure F3: Positions of parts before assemblage

Appendix G: Calibrated Sample Ratio for Flow Splitting Units Used

DEVICE	Test	Sample +bottle	Sample Bottle	Net Sampling	Wasting +bottle	Wasting Bottle	Net Wasting	Sample Ratio	Average Ratio
		(kg)	(kg)	(kg)	(kg)	(kg)	(kg)		
1	1	1.875	0.260	1.615	22.935	1.033	21.902	0.069	6.8%
	2	2.063	0.264	1.799	25.444	1.035	24.409	0.069	
	3	2.020	0.265	1.755	25.061	1.034	24.027	0.068	
2	1	2.227	0.264	1.963	27.326	1.038	26.288	0.069	7.0%
	2	2.223	0.264	1.959	26.991	1.042	25.949	0.070	
	3	2.356	0.265	2.091	29.001	1.039	27.962	0.070	
3	1	2.252	0.265	1.987	27.123	1.038	26.085	0.071	7.2%
	2	2.666	0.264	2.402	31.669	1.039	30.630	0.073	
	3	2.445	0.264	2.181	29.160	1.035	28.125	0.072	
4	1	2.100	0.261	1.839	24.979	1.032	23.947	0.071	7.1%
	2	1.920	0.264	1.656	23.398	1.032	22.366	0.069	
	3	1.904	0.260	1.644	22.108	1.036	21.072	0.072	
5	1	1.990	0.262	1.728	26.357	1.030	25.327	0.064	6.4%
	2	1.963	0.263	1.700	26.186	1.034	25.152	0.063	
	3	2.076	0.263	1.813	27.600	1.038	26.562	0.064	
6	1	2.124	0.262	1.862	27.208	1.038	26.170	0.066	6.4%
	2	2.106	0.261	1.845	27.043	1.038	26.005	0.066	
	3	1.883	0.262	1.621	27.059	1.036	26.023	0.059	
7	1	1.485	0.262	1.223	23.672	1.036	22.636	0.051	5.2%
	2	1.505	0.263	1.242	23.701	1.033	22.668	0.052	
	3	1.625	0.262	1.363	26.176	1.039	25.137	0.051	
8	1	2.229	0.265	1.964	27.520	1.037	26.483	0.069	6.8%
	2	2.289	0.261	2.028	28.500	1.036	27.464	0.069	
	3	2.428	0.265	2.163	30.854	1.031	29.823	0.068	
9	1	2.178	0.261	1.917	27.363	1.037	26.326	0.068	6.9%
	2	2.189	0.266	1.923	26.950	1.035	25.915	0.069	
	3	2.175	0.265	1.910	26.653	1.037	25.616	0.069	
10	1	2.288	0.263	2.025	27.363	1.033	26.330	0.071	7.2%
	2	2.299	0.267	2.032	26.950	1.032	25.918	0.073	
	3	2.285	0.269	2.016	26.653	1.032	25.621	0.073	

By weight:
Net Sampling = Weight of (Sampling flow and bottle) – Weight of sample bottle
Net Wasting = Weight of (Wasting flow and bottle) – Weight of wasting bottle
Sample Ratio = Net sample/(Net sample + Net wasting)

Appendix H: Costs of the Sample Collection Package

Ten sample collection kits were been constructed so that ten samples can be simultaneously collected from households per week for quantitative and qualitative analysis.

Item	Description	Dimension	Units per Sampler	Price/unit*	Total units	Total cost/Item
1	Fitting (thread)	25 mm MTH	3	$0.87	30	$26.10
2	T-section	25 mm FTH	1	$2.64	10	$26.40
3	Conical Cap (sampling)	8mm X20mm	1	$1.00	10	$10.00
4	Storage Container	25 L (plastic)	1	$13.00	10	$130.00
5	Clear plastic tube	25 mm OD	1.0-1.5 m	$1.2/m	20m	$24.00
					Total Cost	**$216.50**
					Cost per sampling package	**$21.65**

Appendix I: Descriptions of Laboratory Testings for Laundry Samples

The following descriptions are detailed procedures of experimental analysis that I have taken water and wastewater laboratory, Faculty of Engineering and Surveying, University of Southern Queensland.

pH and EC Determination

Apparatus

1. *pH meter*: Model MC-80 manufactured by TPS Pty Ltd, capable of reading to the nearest 0.01
2. *EC meter:* Model MC-84 manufactured by TPS Pty Ltd, capable of reading to the nearest 1 µS/cm
3. *Glassware*

Procedure

1. *pH meter calibration:* calibrate the temperature electrode of pH meter against the temperature measured by the good quality mercury thermometer. Then calibrate the meter against the pH buffer solutions obtained from the manufacturer. All calibration standard procedures follow the manufacturer’s instructions.
2. *EC meter calibration:* Calibrate the temperature electrode against the temperature of the good quality mercury thermometer. Then calibrate the meter against the EC buffer solutions obtained from the manufacturer. All calibration standard procedures follow the manufacturer’s instructions.
3. Warm the chilled samples to room temperature of about 20^oC
4. Stir the samples in glass beaker thoroughly before taking the reading
5. pH meter will provide a direct reading of sample pH on the pH screen at 20^oC
6. EC meter will read and convert EC values of samples at 20^oC into those at 25^oC automatically and will display it on screen of EC the meter. Therefore, the results given by EC meter are sample EC at 25^oC

Total Dissolved Solids Dried at 103-105°C

Apparatus:

1. *Filtration apparatus,* with reservoir and coarse (40-60 um) fitted disk as filter support.
2. *Glass-fibre filter disks* Whiteman grade 934AH, Gelman type A/E, Millipore type AP40 (particle retention of 1.5 um in size).
3. *Suction pump,* with tubing to filtration apparatus, and an adequate capacity to produce a partial vacuum.
4. *Drying oven,* operating at 103 to 105 °C.
5. *Desiccator*
6. *Analytical balance* with capacity of weighing to 0.1 mg.
7. *Magnetic stirrer* with TFE stirring bar.
8. *Wide-bore* pipettes.

Procedure:

- Dry filter disks in an oven at 103-105°C until constant weight for 1 hour, cool and store in desiccator until used.
- Weigh filter disk immediately before use.
- Assemble filtering apparatus and carefully sit filter disk with wrinkled side up on filter support.
- Stir sample with a magnetic stirrer
- Pipette well-mixed sample of 100 mL volume onto the seated glass-fibre filter
- Begin suction until all water is visually removed from the filter
- Carefully remove the filter from the filtration apparatus and transfer it to aluminium drying dish.
- Dry filter disk at 103-105°C for approximately 1 hour to constant weight
- Cool the disk in desiccator and weigh to calculate the weight of residue remaining on the filter disks.
- Obtain average values with at least three duplicates per sample.

Calculation

$$\text{Total suspended solids mg/L} = \frac{(A - B) \times 1000}{\text{sample volume, (100 mL)}}$$

Where A = weight of filter and dried residue (mg)

B = weight of filter (mg)

Reference Documents

Standard Methods for Examination of Water and Wastewater 20th Edition Method 2540D.

5-Day BOD Test

Apparatus:

1. *Incubation bottles,* of 300mL capacity, having a ground-glass stoper and a flared mouth. Bottles are cleaned with a detergent, rinsed thoroughly and drained well before use.
2. *Air incubator,* with a thermostatistically controlled temperature of 20 ± 1^{o}C.
3. *Magnetic stirrer,* with TFE stirring bar.
4. *Membrane electrode DO meter,* Model 90-D. The meter was calibrated according to manufacturer's instruction
5. *Volumetric Pipettes,* with 1000-5000 µL capacity.
6. *Analytical balance* with capacity of weighing to 0.1 mg.
7. *Aluminium foil*

Reagents

1. *Phosphate buffer solution*: dissolve 8.5 g KH_2PO_4; 21.75 g K_2HPO_4; 33.4 g $Na_2HPO_4.H_2O$ and 1.7 g NH_4Cl in about 500 mL distilled water and dilute to 1 L.
2. *Magnesium sulphate solution:* dissolve 22.5 g $MgSO_4.7H_2O$ in distilled water and dilute to 1 L.
3. *Calcium chloride solution:* dissolve 27.5 g $CaCl_2$ in distilled water and dilute to 1 L solution.
4. *Ferric chloride solution:* dissolve 0.25 g $FeCl_3.6H_2O$ in distilled water and dilute to 1 L.
5. *Acid and alkali solutions:* 1N for neutralisation of caustic and acidic samples.
   Acid solution: slowly add 28 mL concentrated H_2SO_4 acid while stirring to distilled water and dilute to 1 L.
   Alkali solution: dissolve 40 g NaOH in distilled water and dilute to 1 L.
6. *Sodium sulphate solution:* dissolve 1.575 g Na_2SO_3 in 1L distilled water
7. *Nitrification inhibitor:* 2-chloro-6-(trichloro methyl) pyridine
8. *Glucose-glutamic acid solution:* dry reagent-grade glucose and reagent-grade glutamic-grade acid at 103^{o}C for 1 hour. Add 150 mg glucose and 150 mg glutamic acid to distilled water and dilute to 1 L.

All reagents are prepared in advance except sodium sulphate and glucose-glutamic acid solutions, which need to be prepared immediately before use. However, depending on characteristics of water or wastewater samples, only certain reagents are used for BOD_5 analysis.

Procedure

- Prepare dilution water by adding 1 mL each of phosphate buffer, $MgSO_4$, $CaCl_2$ and $FeCl_3$ solutions to each litre of distilled water. Each sample needs approximately 3 L of dilution water.
- Before use bring dilution water to temperature by storing in the incubator at $20^{o}C$.
- Saturate with DO by shaking in partially filled bottle or by aerating with organic free filtered air.
- Bring samples to about $20^{o}C$ before making dilutions.
- Using graduated cylinders or volumetric flasks to prepare solution.
- Dilute samples with dilution water in different concentrations so that residual DO of at least 1 mg/L and a DO uptake of at least 2 mg/l after 5 day incubation. For laundry water, use the following dilutions: 2 mL/300 mL bottle, 6 mL/ 300 mL bottle and 20 mL/ 300 mL bottle.
- Prepare dilutions directly in BOD bottles using a wide tip volumetric pipet to add the desired sample volume to individual 300 mL bottles. Fill bottles with enough dilution water so that insertion of stopper will displace all air, leaving no bubbles.
- Determine initial DO on the bottle of each dilution using membrane electrode DO meter while stirring. Time period between preparing dilution and measuring initial DO should not exceed 30 minutes.
- Replace any displaced contents with dilution water before capping.
- Stopper tightly, water seal with aluminium foil and incubate for 5 days at $20^{o}C$.
- Determine final DO on the bottle after 5 day incubation.
- Rinse DO electrode between determinations to prevent cross contamination of samples.

Calculations

For each test bottle having residual DO of at least 1 mg/L and a DO uptake of at least 2 mg/L, calculate BOD_5 as follows (dilution is not seeded):

$$\text{BOD5, mg/L} = \frac{D_{ini} - D_{fin}}{P}$$

where: D_1 = DO of diluted sample immediately after preparation, mg/L

D_2 = DO of diluted sample after 5 day incubation at 20^{o}C, mg/L

P = decimal volumetric fraction of sample used (dilution ratio)

Reference documents

Standard Methods for Examination of Water and Wastewater 20^{th} Edition Method 5210B.

Note: Since Cation, Phosphorus, Nitrogen and faecal coliform analysis are performed by commercial laboratory - Mount Kynoch water and wastewater laboratory in Toowoomba, the detailed procedure of the tests would not be described in this report.

Appendix J: Information from Surveyed Households

Site Code	Family Type	Sample Kit Code	Machine Brand	Machine Model	Capacity	Front loader /Top Loader
A1	2A	5	Kleenmaid	KFL800N	5	Top
	2A	5	Kleenmaid	KFL800N	5	Top
A2	2A	2	Whirlpool	AWM6100	6.5	Front
	2A	2	Whirlpool	AWM6100	6.5	Front
A3	2A	1	Whirlpool	AWM8121	7	Front
	2A	1	Whirlpool	AWM8121	7	Front
B1	2A+1C	9	Hoover	2300L	6.5	Top
	2A+1C	9	Hoover	2300L	6.5	Top
B2	2A+1C	2	Simpson	Esprit 550	5.5	Top
	2A+1C	2	Simpson	Esprit 550	5.5	Top
B3	2A+1C	1	LG	WD8013F	7	Front
	2A+1C	1	LG	WD8013F	7	Front
C1	2A+2C	9	Simpson	Genesis 505	5	Top
	2A+2C	9	Simpson	Genesis 505	5	Top
C2	2A+2C	9	Maytag	Atlantis	7.5	Top
	2A+2C	9	Maytag	Atlantis	7.5	Top
C3	2A+2C	5	Simpson	Esprit 600	6	Top
	2A+2C	5	Simpson	Esprit 600	6	Top
D1	1A+C	2	Hoover	Elite 1210	6	Top
	1A+C	2	Hoover	Elite 1210	6	Top
D2	1A+C	9	Fisher & Paykel	Smart Drive 500	5	Top
	1A+C	9	Fisher & Paykel		5	Top
D3	1A+C	2	Fisher & Paykel	Smart Dive 9	5.5	Top
	1A+C	2	Fisher & Paykel	Smart Dive 9	5.5	Top
E1	2A+B	5	Bendix	Duomatic WDB1074T	6	Front
	2A+B	5	Bendix	Duomatic WDB1074T	6	Front
E2	2A+B	3	Miele	Novotronic W828	5.5	Front
	2A+B	3	Miele	Novotronic W828	5.5	Front
E3	2A+B	8	Whirlpool	AWM8121	7	Front
	2A+B	8	Whirlpool	AWM8121	7	Front

Appendix J: Information from Survey Households (cont.)

Site Code	Family Type	Detergent Brand	Detergent Type	Fabric Softener	Wash Size	Detergent Amount	Fabric Softener
A1	2A	Dynamomatic Conc	Powder	-	Full	1 scoop	-
	2A	Dynamomatic Conc	Powder	-	Full	1 scoop	-
A2	2A	Greencare	Liquid	-	Full	1 cap	-
	2A	Greencare	Liquid	-	Full	1 cap	-
A3	2A	Omomatic	Powder	Moresoft	Full	1 scoop	1 cap
	2A	Omomatic	Powder	Moresoft	Full	1 scoop	1 cap
B1	2A+1C	Fab Concentrate	Powder	-	Full	1 scoop	-
	2A+1C	Fab Concentrate	Powder	-	Full	1 scoop	-
B2	2A+1C	Bushland	Powder	-	Full	1 scoop	-
	2A+1C	Bushland	Powder	-	Full	1 scoop	-
B3	2A+1C	Earth Choice	Liquid	-	Full	2 caps 60mls	-
	2A+1C	Earth Choice	Liquid	-	Full	2 caps 60mls	-
C1	2A+2C	Omo Sensitive	Powder	-	Full	1 scoop	-
	2A+2C	Omo Sensitive	Powder	-	Full	1 scoop	-
C2	2A+2C	Fresha Premium	Powder	-	Full	1 scoop	-
	2A+2C	Envirological	Powder	-	Full	1 scoop	-
C3	2A+2C	Dynamo	Liquid	-	Full	1 cap	-
	2A+2C	Dynamo	Liquid	-	Full	1 cap	-
D1	1A+C	Surf	Powder	-	Half	0.5	-
	1A+C	Surf	Powder	-	Half	0.5	-
D2	1A+C	Duo	Powder	-	Full	1	-
	1A+C	Duo	Powder	-	Full	1	-
D3	1A+C	Spree Conc	Powder	Cuddly	Full	1.5 scoops	1
	1A+C	Spree Conc	Powder	Cuddly	Full	1.5 scoops	1
E1	2A+B	Surf Concentrate	Liquid	-	Full	1	-
	2A+B	Surf Concentrate	Liquid	-	Full	1	-
E2	2A+B	Omomatic Concentrate	Powder	Huggies	1	0.75	2
	2A+B	Omomatic Concentrate	Powder	Huggies	0.5	0.5	1
E3	2A+B	Biozet	Powder	-	Full	0.33	-
	2A+B	Biozet	Powder	-	Full	0.33	-

Appendix K: Analysis of Laundry Water Quantity (Raw Data)

Site Code	Family Type	Sample Kit Code	Sample Ratio	Sample Volume	Total Volume	Washed Size	Type of Washing Machine	Full size total volume	Number of Washes per Week	Amount of water per week	Average Laundry water use per week	Average Laundry water use per day per house
			(%)	(L)	(L)		Front/Top			(L)	(L)	(L)
A1	2A	5	6.4	9.46	148.41	1.00	Front	148.41	5.00	742.03	778	111.2
A1	2A	5	6.4	10.39	162.97	1.00	Front	162.97	5.00	814.84		
A2	2A	2	7.0	1.64	23.53	0.50	Front	47.05	3.00	141.16	147	21.0
A2	2A	2	7.0	3.56	51.01	1.00	Front	51.01	3.00	153.03		
A3	2A	1	6.8	3.49	50.98	1.00	Front	50.98	4.00	203.92	236	33.7
A3	2A	1	6.8	4.58	66.88	1.00	Front	66.88	4.00	267.52		
B1	2A+1C	9	6.9	8.20	119.27	1.00	Top	119.27	5.00	596.34	586	83.8
B1	2A+1C	9	6.9	7.93	115.26	1.00	Top	115.26	5.00	576.32		
B2	2A+1C	2	7.0	8.45	121.16	1.00	Top	121.16	9.00	1090.47	1043	148.9
B2	2A+1C	2	7.0	7.71	110.53	1.00	Top	110.53	9.00	994.73		
B3	2A+1C	1	6.8	7.21	105.33	1.00	Front	105.33	7.00	737.29	683	97.5
B3	2A+1C	1	6.8	6.14	89.73	1.00	Front	89.73	7.00	628.10		
C1	2A+2C	9	6.9	11.84	172.11	1.00	Top	172.11	6.00	1032.67	957	136.7
C1	2A+2C	9	6.9	10.11	146.96	1.00	Top	146.96	6.00	881.76		
C2	2A+2C	9	6.9	8.48	123.35	1.00	Top	123.35	7.00	863.44	848	121.1
C2	2A+2C	9	6.9	8.18	118.87	1.00	Top	118.87	7.00	832.09		
C3	2A+2C	5	6.4	12.36	193.81	1.00	Top	193.81	8.00	1550.44	1496	213.7
C3	2A+2C	5	6.4	11.49	180.15	1.00	Top	180.15	8.00	1441.18		

Site Code	Family Type	Sample Kit Code	Sample Ratio	Sample Volume	Total Volume	Washed Size	Type of Washing Machine	Full size total volume	Number of Washes per Week	Amount of water per week	Average Laundry water use per week	Average Laundry water use per day per house
D1	1A+C	2	7.0	11.69	167.55	0.50	Top	335.10	3.00	1005.30	1014	144.8
D1	1A+C	2	7.0	11.88	170.37	0.50	Top	340.75	3.00	1022.25		
D2	1A+C	9	6.9	6.97	101.32	1.00	Top	101.32	5.00	506.61	591	84.4
D2	1A+C	9	6.9	9.29	135.08	1.00	Top	135.08	5.00	675.41		
D3	1A+C	2	7.0	10.75	154.13	1.00	Top	154.13	6.00	924.79	902	128.8
D3	1A+C	2	7.0	10.21	146.40	1.00	Top	146.40	6.00	878.43		
E1	2A+B	5	6.4	9.24	144.94	1.00	Front	144.94	6.00	869.66	749	107.0
E1	2A+B	5	6.4	6.67	104.61	1.00	Front	104.61	6.00	627.66		
E2	2A+B	3	7.2	4.80	66.82	1.00	Front	66.82	13.00	868.64	865	123.6
E2	2A+B	3	7.2	2.38	33.15	0.50	Front	66.30	13.00	861.94		
E3	2A+B	8	6.8	1.98	28.89	0.50	Front	57.77	10.00	577.72	643	91.8
E3	2A+B	8	6.8	2.422	35.37	0.50	Front	70.74	10.00	707.40		

Appendix L: Analysis of Laundry Water Quality (Raw Data)

Site Code	Family Type	Full size total volume	EC	pH	BOD5	TSS	Total N	Total P	Faecal Coliform	Ca	Mg	Na	K
		(L)	µS/cm		mg/L	mg/L	mg/L	mg/L	CFU/ 100mL	mg/L	mg/L	mg/L	mg/L
A1	2A	148.41	1166	9.65	202	88.7	19	35.9	<1	12.5	11.4	232	5.7
A1	2A	162.97	994	9.71	164	102.0	15.2	32.9	1	12.9	11.8	224	6.2
A2	2A	47.05	623	7.99	267	110.0	13.3	1.46	<1	12.9	9.5	48.9	5.1
A2	2A	51.01	583	8.02	258	105.3	13.3	3.19	<1	15.2	9.2	45.6	6.3
A3	2A	50.98	1994	9.41	433	154.0	30.7	93.3	<1	6.1	14.3	501	9.6
A3	2A	66.88	1217	9.26	364	96.7	25.2	46	<1	8.5	14.6	299	10.2
B1	2A+1C	119.27	1010	9.90	117	79.3	5.9	17.5	<1	13.7	13.5	213	5.2
B1	2A+1C	115.26	890	9.64	134	116.7	7.1	13.5	<1	15.4	14.2	187	8.1
B2	2A+1C	121.16	509	8.60	48	40.0	3.5	0.2	<1	16.2	15.1	60.9	5.2
B2	2A+1C	110.53	496	8.54	102	54.7	4.4	0.2	<1	16	13.9	57.5	4
B3	2A+1C	105.33	928	7.61	204	125.3	17	0.5	30	6.8	7.7	129	9.1
B3	2A+1C	89.73	1005	7.61	204	184.7	22.9	0.5	21	11.6	13.4	94.7	9.6
C1	2A+2C	172.11	537	10.15	224	88.0	15.7	21.6	3	0.9	2.3	101	3.9
C1	2A+2C	146.96	1044	10.32	410	115.6	6.9	58.8	<1	1.5	2.4	179	2.6
C2	2A+2C	123.35	952	9.61	78	98.7	4.3	10.8	<1	4.8	5.6	132	4.2
C2	2A+2C	118.87	1062	9.73	54	80.7	3.9	1.12	<1	7.4	8.5	150	3.7
C3	2A+2C	193.81	632	8.81	127	51.6	6.5	21.5	<1	2.9	4.5	65.5	6.5
C3	2A+2C	180.15	868	9.63	179	37.3	6.8	61.4	<1	2.1	4	132	5.7

Site Code	Family Type	Full size total volume	EC	pH	BOD5	TSS	Total N	Total P	Faecal Coliform	Ca	Mg	Na	K
		(L)	µS/cm		mg/L	mg/L	mg/L	mg/L	CFU/ 100mL	mg/L	mg/L	mg/L	mg/L
D1	1A+C	335.10	727	8.86	62	33.3	5.1	4.73	<1	10.6	8.9	88.9	3.6
D1	1A+C	340.75	777	9.21	51	25.7	4.2	6.92	<1	8.2	7.4	68	3.7
D2	1A+C	101.32	1476	10.07	150	26.7	6	24.3	<1	1.8	4.4	272	5.5
D2	1A+C	135.08	939	9.85	64	18.3	4.2	12.8	<1	3.1	4	168	2.7
D3	1A+C	154.13	2162	9.89	118	64.9	9.1	22.2	2	4	10.4	465	6.1
D3	1A+C	146.40	1941	10.11	114	48.0	6.8	20.3	<1	2.7	6	421	6.2
E1	2A+B	144.94	743	7.32	440	108.4	11.4	10.4	19000	5.6	7.5	75.8	3.5
E1	2A+B	104.61	771	8.15	437	107.6	16.8	15	7100	2.9	5.6	83.9	6.1
E2	2A+B	66.82	1607	9.81	384	187.6	18.4	62.2	<1	1.7	3.3	319	7.2
E2	2A+B	66.30	1279	9.90	193	99.3	9.6	44.4	<1	1.7	3.5	244	2.8
E3	2A+B	57.77	1166	9.90	227	290.3	28.9	1.26	3	6.3	7.5	122	3.2
E3	2A+B	70.74	1023	9.75	300	279.1	16.3	1.07	<1	4.8	4.9	158	4.2

Appendix M: Qualitative Analysis of Laundry Water (Processed Data)

Site Code	Family Type	Total N per full wash	Total P per full wash	Ca per full wash	Mg per full wash	Na per full wash	K per full wash	Ca per full wash	Mg per full wash	Na per full wash	K per full wash	SAR	EC	TDS
		mg	g	g	g	g	g	mmol/L	mmol/L	mmol/L	mmol/L		dS/m	mg/L
A1	2A	0.148	5.328	1.86	1.69	34.43	0.85	0.6	0.9	10.1	0.1	11.4	1.17	746
A1	2A	0.163	5.362	2.10	1.92	36.50	1.01	0.6	1.0	9.7	0.2	10.8	0.99	636
A2	2A	0.047	0.069	0.30	0.22	1.15	0.12	0.6	0.8	2.1	0.1	2.5	0.62	399
A2	2A	0.051	0.163	0.78	0.47	2.33	0.32	0.8	0.8	2.0	0.2	2.3	0.58	373
A3	2A	0.051	4.757	0.31	0.73	25.54	0.49	0.3	1.2	21.8	0.2	25.3	1.99	1276
A3	2A	0.067	3.076	0.57	0.98	20.00	0.68	0.4	1.2	13.0	0.3	14.4	1.22	779
B1	2A+1C	0.119	2.087	1.63	1.61	25.40	0.62	0.7	1.1	9.3	0.1	9.8	1.01	646
B1	2A+1C	0.115	1.556	1.78	1.64	21.55	0.93	0.8	1.2	8.1	0.2	8.3	0.89	570
B2	2A+1C	0.121	0.024	1.96	1.83	7.38	0.63	0.8	1.2	2.6	0.1	2.6	0.51	326
B2	2A+1C	0.111	0.022	1.77	1.54	6.36	0.44	0.8	1.1	2.5	0.1	2.5	0.50	317
B3	2A+1C	0.105	0.053	0.72	0.81	13.59	0.96	0.3	0.6	5.6	0.2	8.0	0.93	594
B3	2A+1C	0.090	0.045	1.04	1.20	8.50	0.86	0.6	1.1	4.1	0.2	4.5	1.01	643
C1	2A+2C	0.172	3.718	0.15	0.40	17.38	0.67	0.0	0.2	4.4	0.1	12.8	0.54	344
C1	2A+2C	0.147	8.641	0.22	0.35	26.31	0.38	0.1	0.2	7.8	0.1	21.1	1.04	668
C2	2A+2C	0.123	1.332	0.59	0.69	16.28	0.52	0.2	0.5	5.7	0.1	9.7	0.95	609
C2	2A+2C	0.119	0.133	0.88	1.01	17.83	0.44	0.4	0.7	6.5	0.1	8.9	1.06	680
C3	2A+2C	0.194	4.167	0.56	0.87	12.69	1.26	0.1	0.4	2.8	0.2	5.6	0.63	404
C3	2A+2C	0.180	11.061	0.38	0.72	23.78	1.03	0.1	0.3	5.7	0.1	12.3	0.87	556

Site Code	Family Type	Total N per full wash	Total P per full wash	Ca per full wash	Mg per full wash	Na per full wash	K per full wash	Ca per full wash	Mg per full wash	Na per full wash	K per full wash	SAR	EC	TDS
		mg	g	g	g	g	g	mmol/L	mmol/L	mmol/L	mmol/L		dS/m	mg/L
D1	1A+C	0.335	1.585	1.78	1.49	14.90	0.60	0.5	0.7	3.9	0.1	4.9	0.73	465
D1	1A+C	0.341	2.358	1.40	1.26	11.59	0.63	0.4	0.6	3.0	0.1	4.1	0.78	497
D2	1A+C	0.101	2.462	0.18	0.45	27.56	0.56	0.1	0.4	11.8	0.1	24.9	1.48	945
D2	1A+C	0.135	1.729	0.42	0.54	22.69	0.36	0.2	0.3	7.3	0.1	14.9	0.94	601
D3	1A+C	0.154	3.422	0.62	1.60	71.67	0.94	0.2	0.9	20.2	0.2	27.9	2.16	1384
D3	1A+C	0.146	2.972	0.40	0.88	61.64	0.91	0.1	0.5	18.3	0.2	32.7	1.94	1242
E1	2A+B	0.145	1.507	0.81	1.09	10.99	0.51	0.3	0.6	3.3	0.1	4.9	0.74	476
E1	2A+B	0.105	1.569	0.30	0.59	8.78	0.64	0.1	0.5	3.6	0.2	6.6	0.77	493
E2	2A+B	0.067	4.156	0.11	0.22	21.31	0.48	0.1	0.3	13.9	0.2	32.9	1.61	1028
E2	2A+B	0.066	2.944	0.06	0.12	8.09	0.09	0.1	0.3	10.6	0.1	24.6	1.28	819
E3	2A+B	0.058	0.073	0.18	0.22	3.52	0.09	0.3	0.6	5.3	0.1	7.8	1.17	746
E3	2A+B	0.071	0.076	0.17	0.17	5.59	0.15	0.2	0.4	6.9	0.1	12.1	1.02	655

$$\text{SAR of water} = \frac{[Na]}{\sqrt{[Ca]+[Mg]}}$$

Total mass (eg. N, P, Ca, Mg etc.) = Concentration (mg/L) × Total volume of laundry water per wash (L)

$$TDS\ (mg/L) = 640 \times EC\ (dS/m)$$

Appendix N: Adopted samples for factorial ANOVA analysis

*Derived from detergent names based on the study of (Patterson 1999), shown in table

Detergents	P-content labelling*	Sample Code	pH	TDS(g) per full wash	N(g) per full wash	P(g) per full wash	Na(g) per full wash	SAR
Powder	P	A11	9.65	110.75	0.148	5.33	34.43	11.4
Powder	P	A12	9.71	103.67	0.163	5.36	36.50	10.8
Powder	P	B11	9.90	77.09	0.119	2.09	25.40	9.8
Powder	P	B12	9.64	65.65	0.115	1.56	21.55	8.3
Powder	P	C11	10.15	59.15	0.172	3.72	17.38	12.8
Powder	P	C12	10.32	98.19	0.147	8.64	26.31	21.1
Powder	P	D21	10.07	95.71	0.101	2.46	27.56	24.9
Powder	P	D22	9.85	81.18	0.135	1.73	22.69	14.9
Powder	NP	E31	9.90	43.11	0.058	0.07	3.52	7.8
Powder	NP	E32	9.75	46.31	0.071	0.08	5.59	12.1
Powder	NP	B21	8.60	39.47	0.121	0.02	7.38	2.6
Powder	NP	B22	8.54	35.09	0.111	0.02	6.36	2.5
Liquid	P	C31	8.81	78.39	0.194	4.17	12.69	5.6
Liquid	P	C32	9.63	100.08	0.180	11.06	23.78	12.3
Liquid	P	E11	7.32	68.92	0.145	1.51	10.99	4.9
Liquid	P	E12	8.15	51.62	0.105	1.57	8.78	6.6
Liquid	NP	A21	7.99	18.76	0.047	0.07	1.15	2.5
Liquid	NP	A22	8.02	19.03	0.051	0.16	2.33	2.3
Liquid	NP	B31	7.61	62.56	0.105	0.05	13.59	8.0
Liquid	NP	B32	7.61	57.71	0.090	0.04	8.50	4.5

3.1, with P = Phosphorus detergents and NP = Non-phosphorus detergents.

Sample Code: eg. A11 = Site A1 sample 1

Omitted samples: A31, A32, C21, C22, D11, D12, D31, D32, E21 & E22