Laundry Grey Water Potential Impact on Toowoomba Soils - Final Report

Prepared by
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Executive Summary

Continued population growth is putting increased pressure on Toowoomba's water supply systems. More recently, drought conditions have brought household water use efficiency issues into sharp focus. The Queensland State Government is currently reviewing grey water use under the On Site Sewerage Code of Queensland with a "Draft for Comment" already circulated. The comments period has closed, and the document is currently with the Queensland Government for finalisation. Toowoomba City Council is actively investigating the potential impacts of this legislative change on the demand for water from the city's storages and on the environmental and health issues that may result from its use.

Grey water is the common term for effluent arising from laundry, bath and shower, and kitchen. The quality of grey water can vary considerably depending on its origin within the house.

Many people are currently using grey water from their laundries (unlawfully so, as the legislation to make this legal does not come into force until March 2006) to irrigate lawns and gardens. This practice is becoming more popular due to current water restrictions imposed by Council. While seeming to be a harmless activity, long-term use of this water on Toowoomba's soils will result in soil structural degradation, increased soil pH and poor plant growth of those plants adapted to acidic conditions.

This suitability study focused on grey water produced by laundries. Laundry grey water contains nutrients such as nitrogen (N) and phosphorus (P). It also contains soluble salts, of which, sodium can have adverse impacts on soil structure. Laundry grey water may also contain bacteria that are harmful to human health.

To assess properties of laundry grey water in Toowoomba, samples of laundry water were collected from 15 households in Toowoomba and analysed by the Toowoomba City Council's Laboratory Services for nutrients, salts and faecal coliforms. The volume of water produced by washing machines was also measured, and information collected on the washing machines and detergents used.

The water sampled had low salinity levels (if used for irrigation purposes) but very high concentrations of sodium. Phosphorus levels varied with the brand of detergent. Nitrogen concentrations were very low.

No faecal coliforms (below the limit of reporting from the laboratory) were recorded for the majority of samples. Only one household produced samples with faecal coliform values that would cause concern. This household contained a baby.

The volumes of water used for washing by various households depended on the type of washing machine used. Front loading washing machines used approximately half the water used by top loading machines. The use of front loading machines increased total N and Total Suspended Solid (TSS) concentrations. Front loading machines did not significantly increase the salinity of the water or change the proportion of sodium, calcium, magnesium or potassium cations in the water.

A sample from each household type was stored for seven days and the change in nutrients and salts recorded on the second and seventh day of storage. The concentrations of nutrients or salts did not change during storage, but the levels of faecal coliform did increase fifteen-fold in the sample that had a high initial faecal coliform count.

Undisturbed core samples of five soils from Toowoomba were collected and leached with two solutions prepared to represent laundry grey water of “average” and “poor” quality. The soils were subsequently leached with deionised water to simulate the application of rain water following prolonged irrigation with laundry grey water. The flow rate through the soil samples was recorded during leaching with the saline solutions and with the deionised water. All five soils, when leached with the solution higher in sodium[1] (SAR = 23.1), had lower flow rates than when they were leached with the solution lower in sodium (SAR = 9.2).

The five soils were also leached with saline solutions and disturbed to simulate what would happen if soils that had been leached with laundry water were disturbed eg a garden bed being dug over or a grassed area subjected to vehicle traffic. All soils leached with high sodicity (SAR = 23.1) and lower salinity[2] water (EC = 1.5 dS/m) rapidly dispersed. Soil leached with the lower sodicity water (SAR = 9.2) showed minor soil dispersion or no dispersion at all.

Clay dispersion in soils is typically associated with very low permeability when wet, restricted drainage, and hard-setting and cloddy structure when dry.

The Water Futures Toowoomba Fact Sheet dated 14 December 2005 notes that “*It is expected that when the revised code is finalised, the requirements for use of greywater in sewered areas will be very similar to those now applying to unsewered areas.*” Some of the likely requirements noted by the Fact Sheet include:

- *Spraying or hosing will not be allowed – the greywater will need to be released underground or under mulched garden beds*
- *Set back distances (between the disposal area and the property boundary or buildings) will apply*

It is possible that the revised code will allow bucketing of greywater from showers, baths and laundries, but this is yet to be confirmed.

An irrigation system (other than the use of a bucket or hose) will need to consist of a link to the sewer system in case the irrigation system is unusable, a sump, a pump, a filter, subsurface irrigation pipe and a controller. A system of this nature is quite costly for the area of lawn or garden required to dispose of the water and nutrient. The Plumbing and Drainage and Other Legislation Amendment Act 2005 regards the use of a hose from the washing machine to the irrigated area as unsuitable as there

[1] The potential for an irrigation water to affect soil sodium levels is calculated as its Sodium Adsorption Ratio (SAR) which considers the concentration of sodium relative to that of Calcium and Magnesium.
[2] Salinity of soil solutions and of water is commonly measured as its Electrical Conductivity (EC)

is no automatic diversion of the laundry water to the sewer system if blockages in the irrigation system occur.

Use of laundry grey water for irrigation is likely to be unattractive to most householders, given the potential impacts of the water on the soil, on plant growth, and the cost and complexity of the irrigation system required. Opportunistic use via simpler delivery systems may be more widely acceptable and practicable, but the potential for damage to soils and plants will remain.

1.0 Introduction

Many local governments across Australia are seriously considering use of grey water (generated from laundries and bathrooms) as an option for irrigating household lawns and gardens, thereby reducing residents' demand for potable water.

This study was carried out to assess the potential for use of grey water from laundries in Toowoomba to irrigate gardens and lawns. Its broad aims were to assess the properties of grey water, and to identify the issues associated with short- and long-term irrigation of soil in Toowoomba using such water.

1.1 Typical quantities of water used in different parts of the house

Within Toowoomba, 63% of all water supplied to the town is used in residential dwellings (Toowoomba City Council, 2005). Laundry water accounts for one-fifth of the total indoor water use for a typical residential house in Queensland (ABS, 2000). Data from Toowoomba City Council (Toowoomba City Council, 2005) on water use in different areas of the house (Figure 1) shows a similar pattern. Figure 1 also shows that 24 % of the potable water supplied to residents is used for watering lawns and gardens.

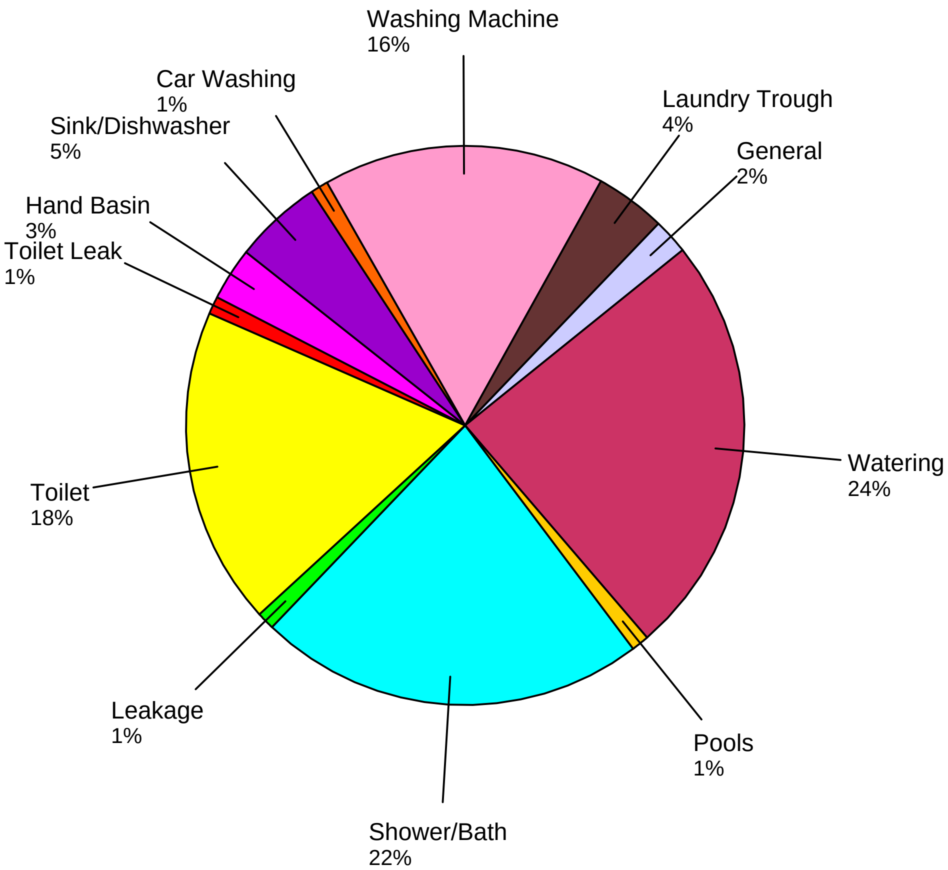

Figure 1: *Breakdown of total water used by a typical residential property in Toowoomba (adapted from Toowoomba City Council, 2005).*

Table 1 shows typical volumes of water used in different areas of the home. The actual amount of water that is used can vary greatly. Much can be done to reduce the amount of water that is used for a given activity within a home.

There are two main types of washing machines available in Australia – front loaders and top loaders. Front loaders, in general, use less water per wash than top loaders, though some of the newer top loading machines do have comparable water use data. The type of washing machine has a large impact on the quantity of water used in the laundry.

Table 1: *Typical water uses from various appliances or activities around the home (Brisbane City Council, n.d.)*

Water Use	Average flow rate	Average total water used
Shower with normal shower rose (8 mins)	15 l/min	120 l/shower
Shower with water-saver rose (8 mins)	8.5 l/min	68 l/shower
Single-flush toilet	12 l/flush	120 l/day
Dual-flush toilet	6 or 3 l/flush	40 l/day
Washing machine (twin tub)	40 l/wash	40 l/day
Washing machine (top loader)	170 l/wash	170 l/day
Washing machine (front loader)	80 l/wash	80 l/day
Dishwasher	20 - 50 l/load	20 - 50 l/day
Cooking, cleaning and drinking	10 l/min	150 l/day
Brushing teeth (water running)	5 l/brush	40 l/day
Bath	10 - 20 l/min	50 - 150 l/bath
Sprinkler/hand-held hose	10 - 20 l/min	2000 l/day
Hosing path/driveways	20 l/min	200 l/10 minutes
Washing the car (with hose running)	10 - 20 l/min	100 - 300 l/car
Filling a swimming pool		Up to 55,000 l

1.2 Typical constituents of laundry water

The quality of domestic laundry water varies between households, due to the washing machine used, the brand and amount of detergent used and the cleanliness of the clothes that are being washed. Laundry grey water is typically alkaline and has elevated salinity levels, high sodium concentrations and high suspended solid concentrations. It usually has high levels of phosphorus, though phosphate-free detergents are available. Laundry grey water may contain excessive faecal coliforms. Christova-Boal *et al*. (1995) list water quality data collected from laundries during a grey water study in Melbourne. This information is given in Table 2 for comparison with the data collected from Toowoomba in this study.

Table 2: *Laundry water quality data from laundries in Melbourne*

Parameter	Unit	Values
pH	-	6.3 - 9.5
Electrical Conductivity, *EC*	μS/cm	83 - 880
Total suspended solids, *TSS*	mg/L	26 - 400
Total nitrogen, *TN*	mg/L	1 - 40
Total phosphorus, *TP*	mg/L	0.062 - 42
Biochemical Oxygen Demand (5 day), BOD_5	mg/L	10 - 520
Calcium, *Ca*	mg/L	2.3 - 12
Magnesium, *Mg*	mg/L	0.7 - 5.3
Sodium, *Na*	mg/L	12 - 480
Sodium Adsorption Ratio, *SAR*[3]	-	1.33 - 13.03
Faecal coliform, *FC*	cfu/100mL	10^4 - 10^6

1.3 Potential impacts of grey water use on soil properties

The chemical properties of any water used for irrigation will change the chemical properties of the soil to which it is applied. Laundry grey water contains considerable amounts of salt, nutrients and suspended solids. Sodium is the dominant cation found in laundry grey water, though other cations (calcium, magnesium and potassium) do exist in smaller concentrations. Nutrients such as nitrogen and phosphorus are present in varying concentrations depending on the type of detergent used and the cleanliness of the clothes being washed. Suspended solids come from lint, hair and skin removed from clothes during the washing process.

Much of the discussion concerning the suitability of using grey water in sewered areas has focused heavily on the health implications of using it, and rightly so, as the risk to human health is of paramount concern to any community. There is, however, potential for environmental impacts - on soil structure and chemistry - that must also be considered when determining the suitability of laundry grey water as a replacement for less saline, less sodic water sources.

[3] Calculated on the basis of concentrations of Ca, Mg, and Na. SAR is an indicator of the potential for accumulation of exchangeable sodium in a soil.

2.0 Methodology – laundry water quantity and quality

This study of the quantity and quality of laundry grey water is based on laundry water samples collected from households of varying family composition (type) representing the population of Toowoomba and adjoining areas.

2.1 Selection of households

Toowoomba is divided by the Australian Bureau of Statistics (ABS) into five areas, Toowoomba – Central, Toowoomba – North-East, Toowoomba – North-West, Toowoomba – South-East and Toowoomba – West (Figure 2). The area known as Greater Toowoomba encompasses these and adjoining areas that are linked to Toowoomba either socially or economically, including areas within the shires of Rosalie, Crows Nest, Cambooya and Jondaryan (Figure 3). Due to the similarities in community characteristics of both areas, the results from this project are expected to apply to both areas equally and have provided some flexibility with the selection of households for this study.

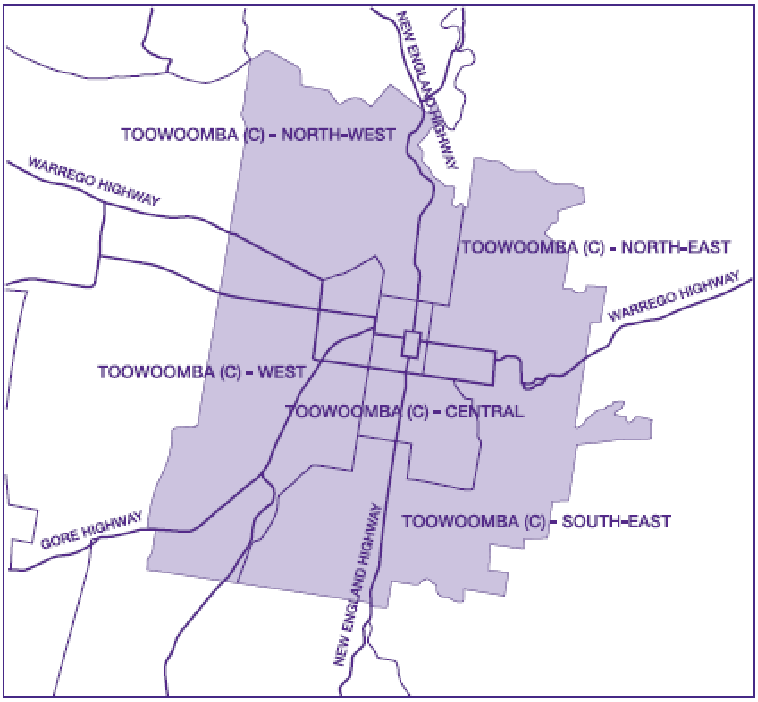

Figure 2: *Australian Bureau of Statistics' demarcation of Toowoomba's city boundary (from Toowoomba City Council, 2004).*

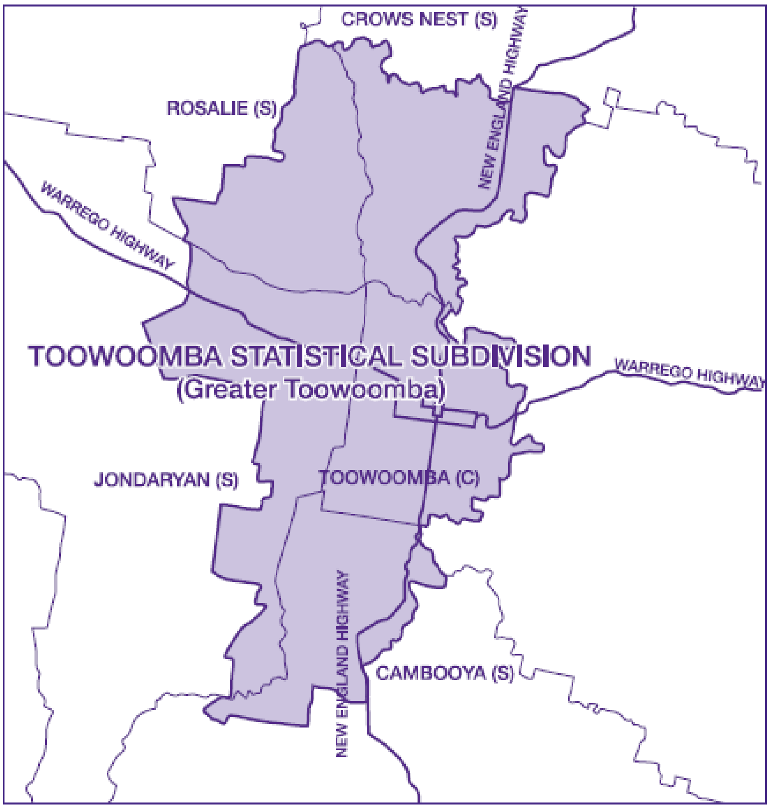

Figure 3: *Australian Bureau of Statistics' demarcation of the area of Greater Toowoomba (from Toowoomba City Council, 2004).*

2.2 Family types of Toowoomba and Greater Toowoomba

Couples with children and couples without children are the most common family types in Toowoomba (Table 3). Couples with children account for 42.4% of the total families in Toowoomba while couples without children account for 37.6% of the total families (ABS, 2001). The other major group is single parents. The variation in family types across Toowoomba is minor.

Table 3: *Family types within Toowoomba based on Statistical Local Areas*

Statistical Local Area	% in each Family Type			
	Couples with Children	Couples without Children	Single Parent	Other
Central	38.4	38.6	20.0	3.0
North-East	42.5	39.8	15.6	2.1
North-West	44.1	33.6	20.5	1.9
South-East	46.8	38.9	12.2	2.0
West	40.4	36.9	19.9	2.8
Average	***42.4***	***37.6***	***17.6***	***2.4***

A comparison of the family types in Toowoomba with those in Greater Toowoomba (Figure 4) shows some minor differences between the two areas, but the trend for various family types remains largely similar. Couples with children and couples without children remain the most common family type.

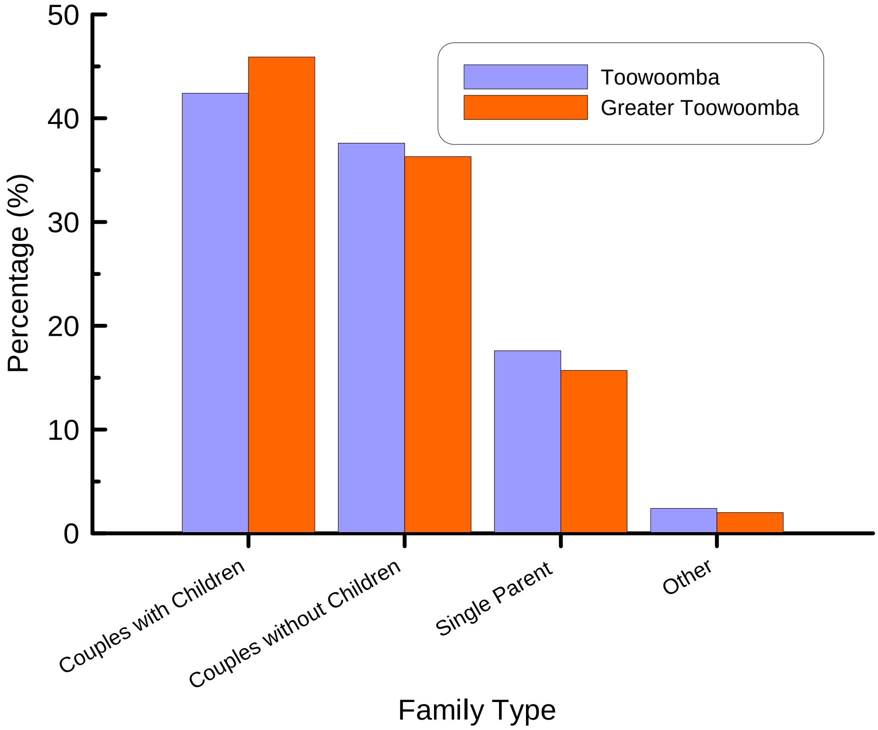

Figure 4: *Comparison of family types in Toowoomba and Greater Toowoomba*

2.3 Family types to be used as representative households

Data from the Australian Bureau of Statistics do not indicate the age or the number of children for any family type that include children. For this study, it was assumed that the quantity and quality of laundry water was independent of the number or age of children in a given family type - with the exception of a family that included babies (under the age of two years). However, the quantity and quality of laundry water was expected to be influenced by dirtiness of the clothing that was washed, the washing machine used and the nature of detergent and fabric softener used during washing. The washing of heavily soiled clothes was expected to increase the level of contaminants in the laundry water. For families with children, laundry water quality was expected to be different for couples with babies than couples with older children. It was also anticipated that washing nappies would increase faecal coliform counts in laundry water effluent. Families with babies were therefore included as one of the family types to account for this possibility. This study also included families of different sizes within a given family type as it was likely that families with two children wash more frequently than families with only one child.

Laundry grey water from fifteen households in Toowoomba was sampled on two occasions. Five different family types were sampled (Table 4). The codes used in this study for each family type are listed in brackets. Given the homogenous distribution of family types across Toowoomba, the location of these households was not a significant issue and households were chosen at random as shown in Figure 5.

Adults were defined in this study as people over the age of 18, children within the ages of 2-18 years and babies as children less than 2 years old. Households with many adult members such as share houses and houses with a single occupant were not included in the study. Over 97% of the households in Toowoomba fall within the five family types selected for this study.

Table 4: *Family types included in the laundry grey water feasibility study*

Family Type	Number of Representative Households
Couples without children (2A)	3
Couples with 1 child (2A+1C)	3
Couples with 2 children (2A+2C)	3
Couples with baby (2A + B)	3
Single parent with children (1A+C)	3
TOTAL	***15***

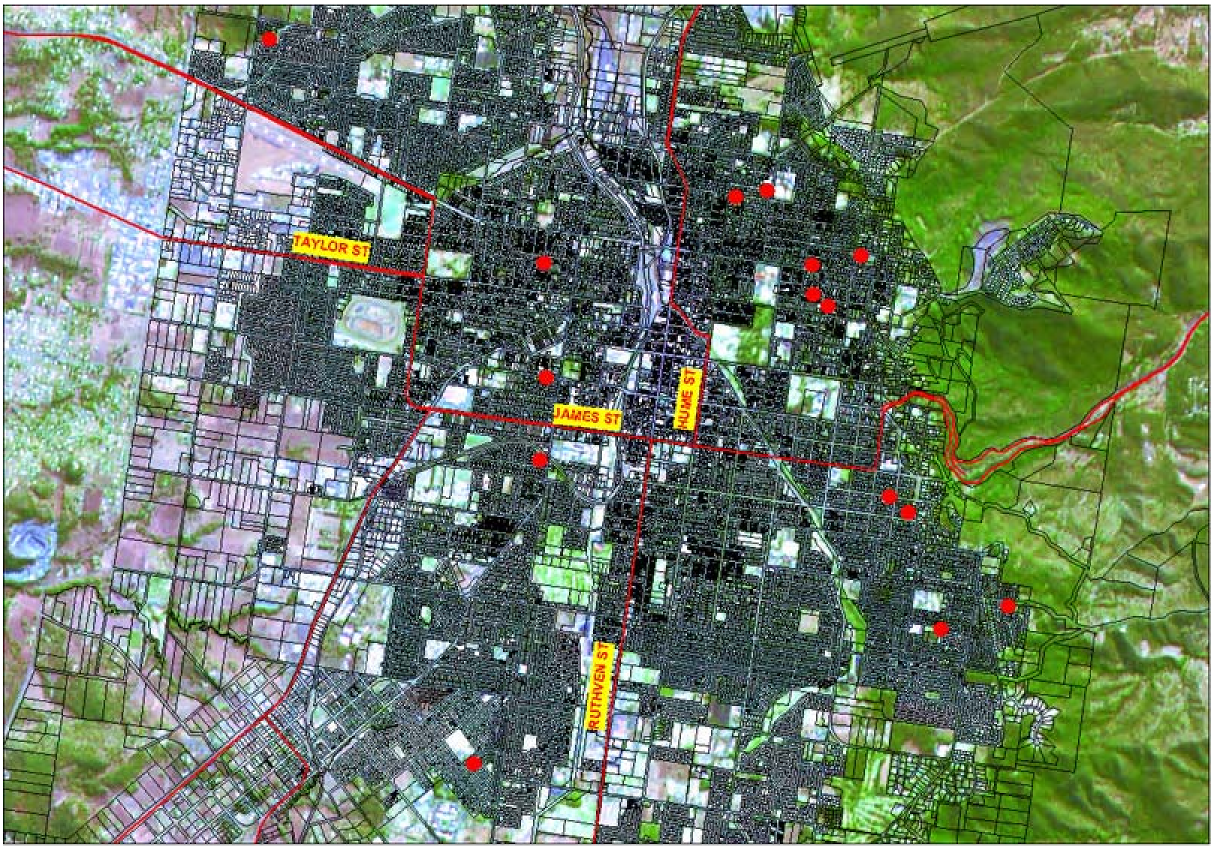

Figure 5: *Laundry water sampling sites marked with a red circle. Two grey water samples were taken from each household on the same day.*

2.4 Sampling laundry water

The principles and methods of laundry water sample collection used in this study are described below. The method of collection of laundry water samples was identical for all fifteen participating families used in this study.

2.4.1 Principles of flow splitting

A typical washing machine can use as much as 160 L of water in a single wash. The installation of a device to collect the entire volume of water from a wash could be cumbersome as some laundries may not be able to accommodate the large drums required. A sub-sampling technique was developed using a flow-splitting device (Figure 6). The flow-splitter takes a sub-sample of both the wash and the rinse water, ensuring that the sampled water quality was indicative of the water that would be applied to lawns or gardens.

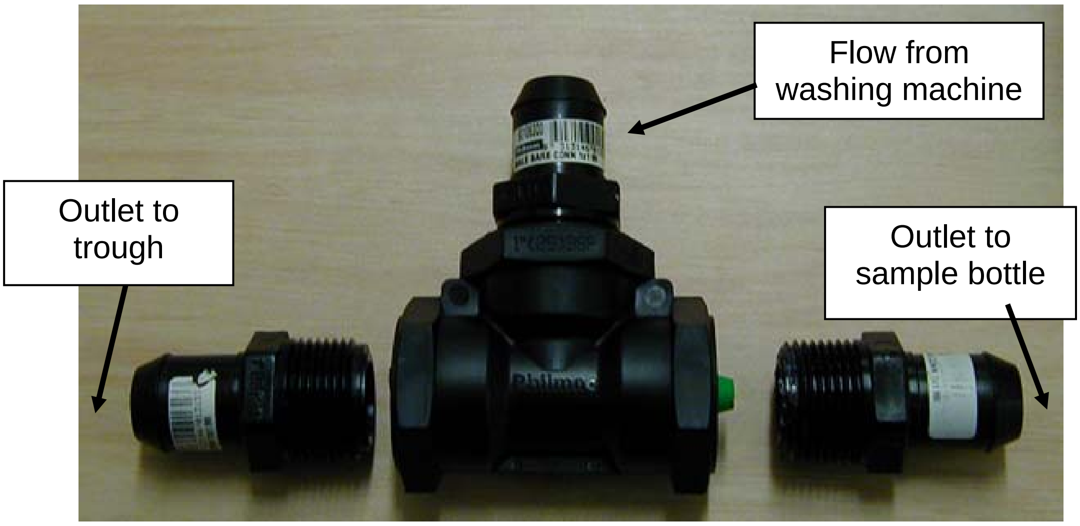

Figure 6: *The flow-splitting device has an orifice in each outlet. One is approximately 7% of the area of the other. Water is sampled through the small orifice. Water from the large orifice is directed into the laundry trough and is not sampled.*

Flow-splitting uses the principle of the continuity of water flow. The amount of water that enters the device is equal to the amount that exits the device through the two orifices. The discharge from each orifice is proportional to the diameters of the orifices (Equation 1). Q_1 and Q_2 are the flow rates (L/min) from the orifices and d_1 and d_2 are the diameters (mm) of the orifices. This equation assumes that the pressure remains the same at both orifices during the flow and that any pressure losses through the orifices are uniform when the device is mounted and used horizontally.

$$\frac{Q_1}{Q_2} = \frac{d_1^2}{d_2^2} \qquad (1)$$

The flow-splitting devices used had orifices nominally 4.6 mm and 17.6 mm in diameter (Figure 7). This resulted in the flow through the small orifice being approximately 6.8% of the flow through the large orifice (Equation 2).

$$\frac{Q_1}{Q_2} = 6.8\% \qquad (2)$$

Figure 7: *Orifices of different sizes enable the flow to be split at a known ratio.*

2.4.2 Calibration of flow-splitting device

Despite the assumptions made regarding the sub-sampling of flow using flow-splitting devices, small differences in dimensions of device components and unequal pressure losses through the orifices introduce errors. To overcome these errors, each of the flow-splitting devices used in this study was calibrated. A top loading washing machine was filled with a known volume of water. The water was drained out using the washing machine pump and collected from both outlets of each flow-splitting device. Three calibrations were done for each device. Table 5 shows the theoretical percentage sampled by the flow-splitting device and the average actual percentage sampled during the three calibrations of the devices.

Table 5: *Theoretical and average actual flow sampled from the flow-splitting devices used in this study.*

Flow-Splitting Device ID[4]	Theoretical % of Total Flow Sampled	Actual % of Total Flow Sampled
1	7.2%	6.8%
2	7.3%	7.0%
3	7.6%	7.2%
5	7.1%	6.4%
8	7.4%	6.8%
9	7.3%	6.9%

[4] Flow splitting devices 4, 6 and 7 were not used to collect laundry water samples and hence do not appear in this table.

2.4.3 Installation of flow splitting device

The devices were installed on the outlet hoses of washing machines in the laundries of fifteen houses across Toowoomba. Two samples were collected from each household on the same day[5]. The flow-splitting device was positioned on the laundry trough next to the washing machine (Figure 8). It was mounted horizontally using a spirit level. After considering the various laundry configurations found in households, taping the device to the trough using waterproof tape was deemed the most flexible and practical solution.

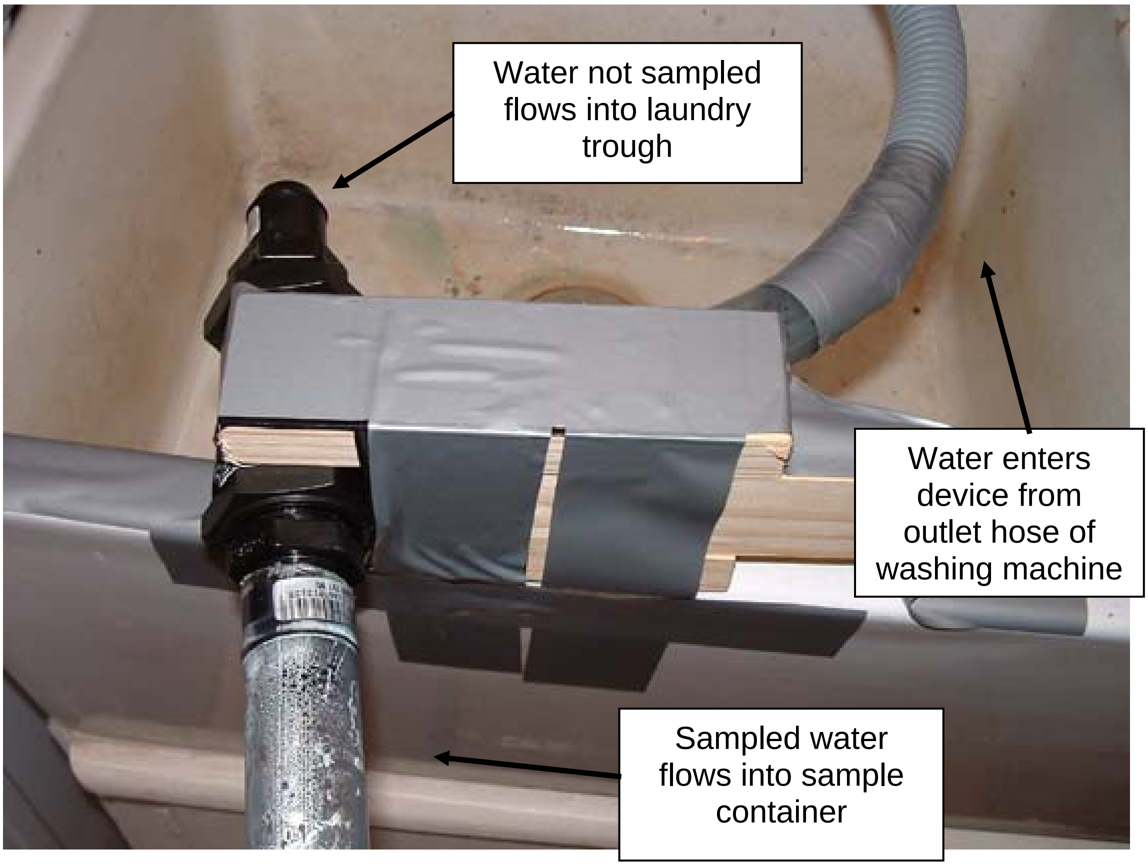

Figure 8: *Flow-splitting device installed on edge of laundry trough.*

2.5 Chemical and microbiological properties of laundry grey water

The following information was recorded or measured for each of the water samples tested:

- Washing machine size;
- Amount and type of detergent;
- Amount of fabric softener;
- Volume of water used per wash and frequency of washing;

[5] Laundry water was collected from one household on consecutive weekends because it was not possible to collect two samples on the same day.

- Electrical conductivity (EC);
- pH;
- Biochemical Oxygen Demand (BOD_5);
- Total suspended solids (TSS);
- Total nitrogen;
- Total phosphorus;
- Faecal coliforms; and
- Calcium, Magnesium, Sodium & Potassium.

Water with high pH will increase the pH of the soil to which it is applied. Nutrient deficiencies have been reported in alkaline soils and this can constrain plant growth.

Laundry detergents contain salts. Elevated salinity levels can cause salt build up in the surface layers of the soil and can affect growth. Salts that are dominated by sodium can cause structural degradation in clay soils and affect plant growth.

Solid particles, such as lint, hair, and skin are suspended in laundry water. High concentrations of suspended solids can cause blockages and increase organic matter growth in irrigation pipes and storage tanks.

High levels of phosphorus have been linked to elevated levels of algal growth in waterways (ANZECC, 2000). This can include blue green algae that can be harmful to human health. This organic matter could also cause blockages of filters, irrigation pipes and storage tanks. High levels of phosphorus are also recognised as being harmful to Australian native plants as these plants have evolved with the capability of extracting phosphorus from Australian soils that are inherently low in available phosphorus.

2.6 Water use survey

In addition to the households sampled, a separate survey was distributed among additional households to collect information on the household water use and washing patterns. These data were used to compare the water use data collected from the 15 households participating in the laundry water quality study.

The water use survey included the following data:

- Size of washing machine;
- Type of washing machine;
- Typical washing machine loading;
- Frequency of washing;
- Type and amount of detergent used; and
- Amount of fabric softener used.

3.0 Grey water impacts on soils – methodology

3.1 Soil types of the Toowoomba Plateau and surrounding areas

Five major soil associations exist within Toowoomba City's boundary. A soil association is an area that contains soils with similar chemical and physical properties. The name of the association denotes the dominant soil types found in that area. The five soil associations (the code used for these soils in this report is shown in brackets) are:

- Charlton-Beauaraba (CB);
- Charlton-Craigmore (CC);
- Toowoomba-Gabbinbar (TG);
- Ruthven-Middle Ridge (RM); and
- Drayton-Kynoch (DK).

Thompson and Beckmann (1959) surveyed the Toowoomba area and their soil descriptions are given in Table 6. Soils in Toowoomba are basaltic and variable in depth. The soils on the Toowoomba Plateau are red clays or clay loams. The soils on the uplands adjoining the Toowoomba Plateau to the west are grey or black clays, heavier in texture than those found on the plateau. The pH of the black soils is alkaline to neutral and the red soils are acidic to neutral. The red soils (TG, RM and DK) are generally deeper with soil depths reaching in excess of 2.0 m in areas. The black soils (CB and CC) are generally shallower, though they can still reach depths of 1.2 m.

Toowoomba's red soils contain high amounts of iron that help to maintain their highly permeable structure. The black soils are not as well drained as the red soils. All the soils are naturally low in salinity as measured by electrical conductivity (EC) and have low exchangeable sodium percentages[6] (ESP) (Table 7). Clay soils with low ESP and low EC are generally stable when wet. Clay soils with high ESP (>6%) and low EC tend to be unstable when wet, though the degree of instability can differ for different soils at similar ESP and EC values.

[6] Exchangeable sodium (m.eq./100 g) as a percentage of soil Cation Exchange Capacity (CEC) (m.eq./100g)

Table 6: *Description of soil associations as given in Thompson & Beckmann (1959)*

Soil Association	Location	Colour	Texture	Drainage	pH	Soil Depth (m)
CB	Uplands	Grey/Black	Heavy clay	Slow after initial wetting	Neutral - alkaline	0.1-0.8
CC		Brown/Black			Alkaline	0.3-1.2
TG	Toowoomba Plateau	Dark Red	Clay	Free draining	Acid	>2.0
RM		Red	Clay loam		Acid	>2.0
DK		Red	Clay		Acid - neutral	0.4-1.1

Table 7: *Chemical properties of soil surface layers (0-30cm).*

Soil Association	EC dS/m	ESP %	Total P mg/kg
CB	0.05	0.7	763
CC	0.07	1.0	624
TG	0.01	1.2	1728
RM	0.02	0.8	881
DK	0.08	0.6	729

3.2 Soil sampling locations

Undisturbed cores (0.1 m in diameter) of the five soils were collected. Cores were taken to a depth of 0.5 m where possible. The sampling site for TG only allowed cores to be taken to 0.2 m depth due to tree roots in the surface layer. Figure 9 is an example of an undisturbed core. Figure 10 shows the location of sampling sites relative to the different soil associations.

Figure 9: *Example of a 0.1 m diameter undisturbed core taken to a depth of 0.5 m.*

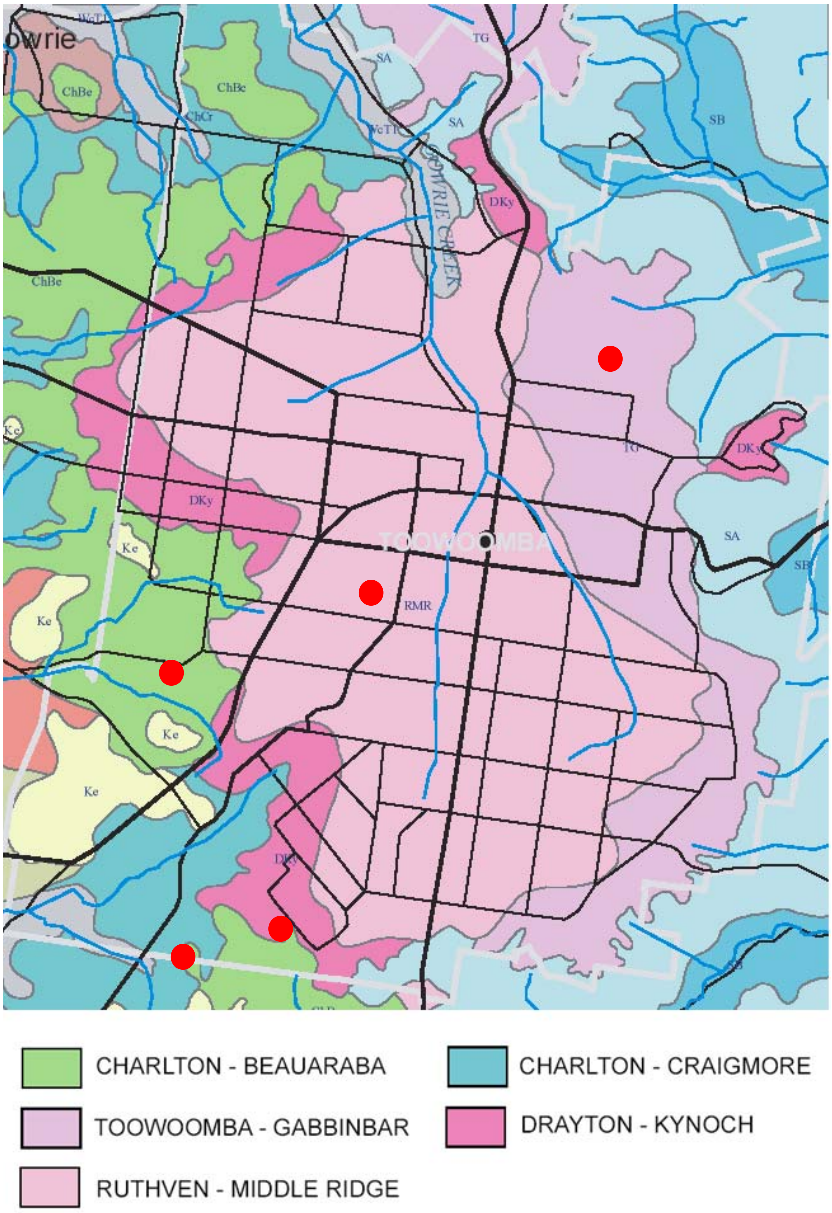

Figure 10: *Location of soil sampling points (shown by red dots) relative to the soil associations*

Table 8: *Location of soil sampling sites*

Soil Association	Location of Sampling Site
Charlton-Beauaraba	Greenwattle St road reserve (southern end)
Charlton-Craigmore	Harrow St road reserve
Toowoomba-Gabbinbar	Toowoomba City Council's Stuart St reservoir
Ruthven-Middle Ridge	Toowoomba City Council's Hennessy St reservoir
Drayton-Kynoch	USQ Agriculture Plot on Baker St

Soil cores were taken from undeveloped sites within each of the five soil associations. Developed land was not used as it could contain fill from external sources, or may be an area of cut, with the current surface soil layers actually being subsoil material. The samples were taken from Toowoomba City Council owned property, road reserves and from University of Southern Queensland property. Table 8 lists the location of the soil sampling sites.

3.3 Leaching trial procedure

The surface 0.1 m of the undisturbed core was placed inside a PVC tube (Figure 11). To ensure that water did not bypass the soil, the interface between the PVC tube and the soil was sealed using bentonite. Three replicates of each of the five soil types were prepared.

The TG cores collected were very dry and crumbly and contained a large amount of roots in the surface layer. The cores for this soil type were prepared by removing the surface 0.1 m of the core, packing it into the leaching columns and compacting it until the depth of the compacted core was 0.1 m. The roots were removed so they did not create preferential flow paths through the soil. All other cores were packed without being disturbed.

Figure 11: *Typical undisturbed core configuration for the leaching trials*

A constant depth of leaching solution (0.1 m) was maintained on each core during the trial. The flow rate of the leachate rate was recorded until fifteen soil pore volumes passed through the soil, at which time it was assumed that the cations initially in the soil had reached equilibrium with those in the leaching solution.

Approximately seven pore volumes are normally expected to be required for cation equilibrium to occur (pers comm. Dr S. Raine, USQ). Fifteen pore volumes were leached to ensure equilibrium occurred while also giving time for measurement of the leaching rate and EC and pH of the leachate. The EC and pH of the leachate were measured periodically. Selected leachate samples were also analysed for cations (calcium, magnesium, sodium and potassium), total N and total P.

After fifteen soil pore volumes were leached through the soil, they were left to drain until no free water remained on the soil surface. Deionised water (water with no cations) was then applied to the leached soil cores and the flow rate through the core measured.

The process outlined above was performed for two leaching solutions. These solutions differed in their EC, pH, composition of cations and amount of N and P. The two solutions were chosen to represent an "average" and a "poor" laundry grey water quality. The selection of these solutions was based on the laundry grey water qualities measured in this project. The two solutions will be referred to as the 1.0 dS/m ("average" quality) and 2.0 dS/m ("poor" quality) solutions in this report. Chemical properties of the two leaching solutions are given in Table 9. It is noted that these solutions are not strictly grey water, as they did not pass through a washing machine. The two solutions are, however, similar in their chemical properties to the grey water samples taken in this study.

Table 9: *Measured water quality parameters for the leaching solutions applied to undisturbed cores.*

Leaching Solution	pH	EC	Ca	Mg	Na	K	SAR	Total N	Total P
	-	dS/m	mg/l	mg/l	mg/l	mg/l	%	mg/l	mg/l
1.0 dS/m	10.4	1.0	18	13	210	4	9.2	0.5	22
2.0 dS/m	11.1	2.0	20	12	530	6	23.1	6.9	8.9

Sodium adsorption ratio (SAR) is a measure of the sodicity (amount of sodium cations compared to other cations) of a solution, and its potential to cause damage to irrigated soil. It is calculated on the basis of concentrations of Ca, Mg, and Na, as:

$$Na/[0.5(Ca+Mg)]^{0.5}$$

where all concentrations are expressed in m.eq./L.

Positively charged cations in soils are attracted to and can be adsorbed by negatively charged clay particles and organic matter. Through a process called cation exchange, the cations adsorbed onto negatively charged surfaces are exchanged with cations in the soil solution until an equilibrium is reached between the two. The types and amounts of cations adsorbed on the soil clay particles are important, as they strongly influence soil structure and stability. Sodium is generally associated with poor stability and structure, as the large, monovalent (single charge) cations push clay particles apart, causing the clay to break apart or disperse. In contrast, divalent cations such as calcium keep clay particles clumped together and maintain soil stability.

The effects of exchangeable cations on clay dispersion can be strongly modified by soil salinity. When the EC of the soil is high, the concentrated soil solution reduces or prevents the dispersion process, so that a saline sodic soil may be stable, whereas a non-saline sodic soil can be quite unstable and impermeable when wet. They have poor structure and are cloddy and hard-set when dry.

3.4 Stability tests on disturbed soils

Disturbed samples of each of the five soils were leached with three leaching solutions. They were air dried before an Emerson dispersion test was performed. The Emerson dispersion test indicates a soil's structural stability when wet. It involves taking a small sample of the soil and dropping it in deionised water and observing whether or not clay dispersion occurs.

4.0 RESULTS - Water quality and quantity

4.1 Laundry water use survey

A total of 33 households responded to the laundry water use survey. Washing machines surveyed ranged in capacity from 5.0 – 7.5 kg, with 5.0 kg machines being the most popular. Approximately three quarters of the households surveyed had top loading machines and one quarter had front loading machines (Figure 12). No one surveyed used another system such as a twin tub.

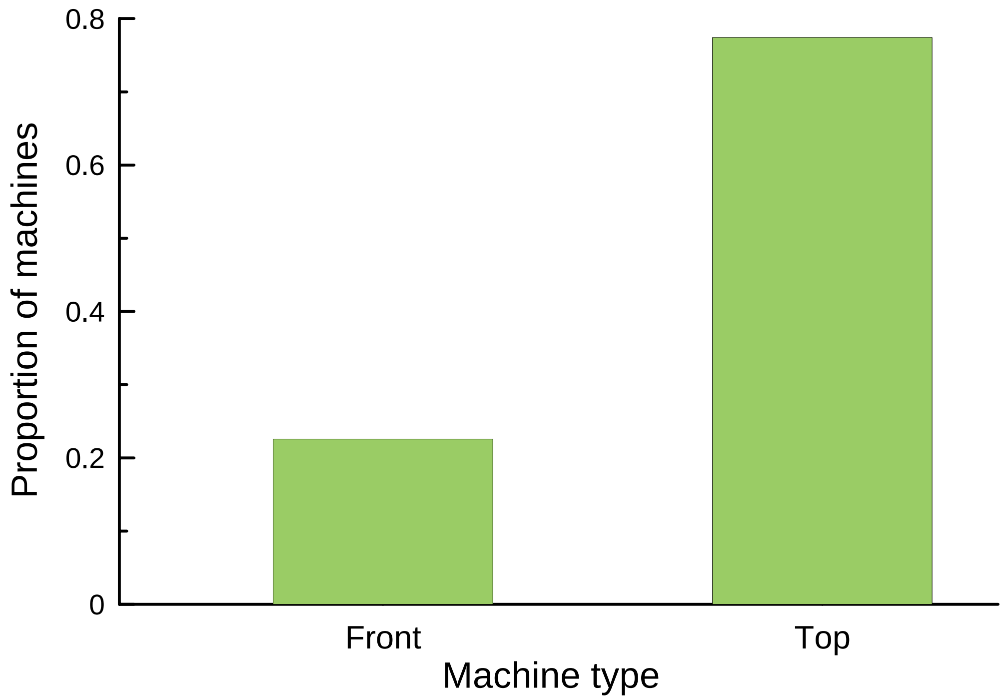

Figure 12: *Types of washing machines used Toowoomba households. Top loading washing machines were more common than front loading washing machines in this survey.*

Most households use powder rather than liquid detergents and most households did not use fabric softeners (Figures 13 and 14). 80% of surveyed households washed with full loads, 16% with three-quarter full loads and 4% with half full loads.

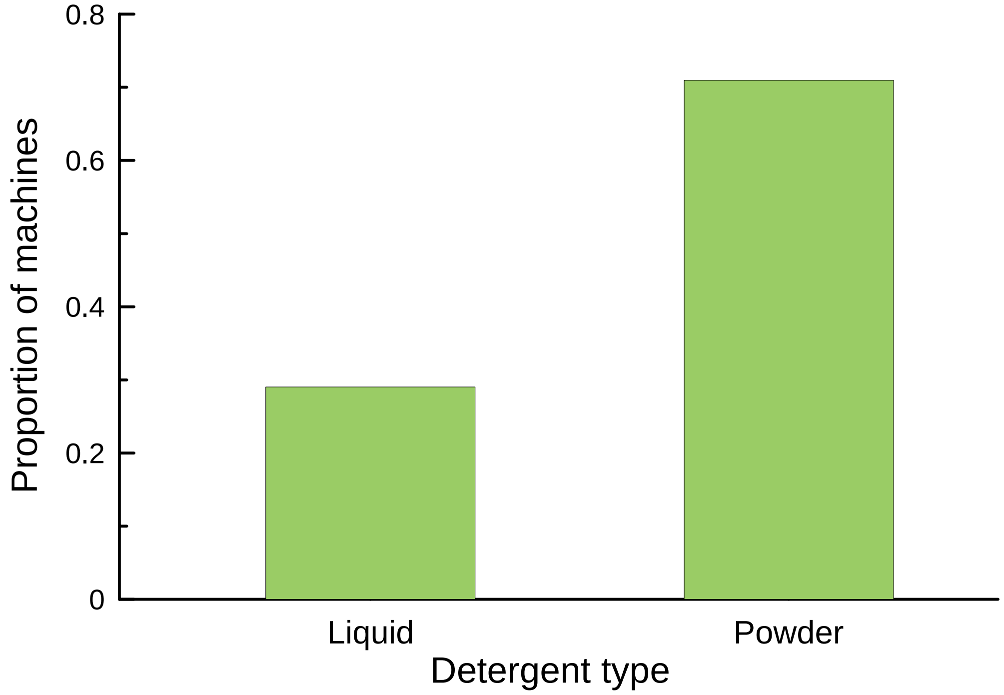

Figure 13: *The type of detergents used in washing machines by Toowoomba residents. More houses use powder detergents than liquid detergents.*

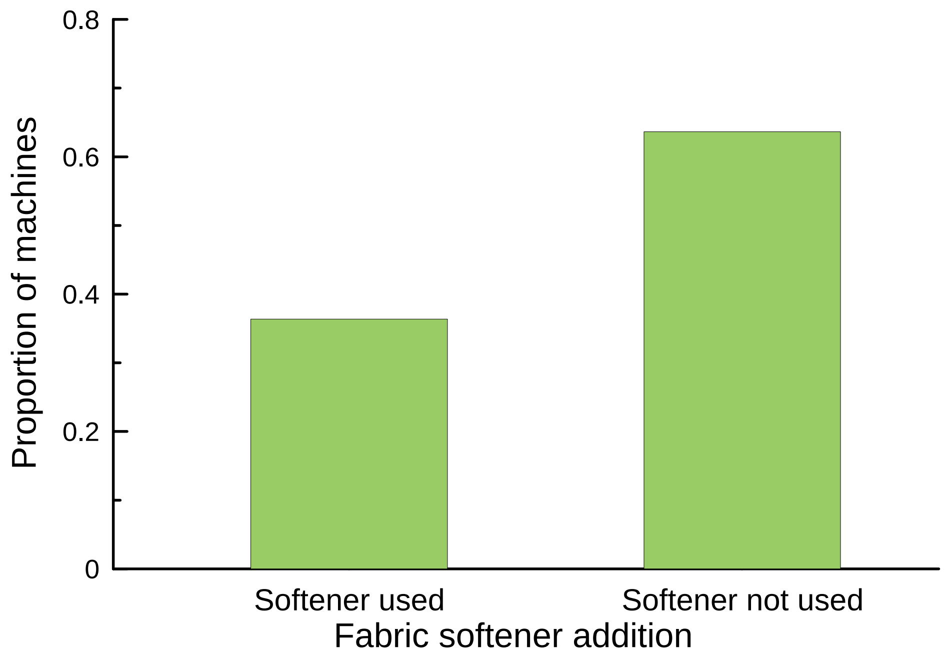

Figure 14: *Fabric softener usage in Toowoomba households; 64% of households do not use fabric softener.*

The number of washes per week for the 31 households that replied to an email questionnaire ranged from one to twelve. That information was combined with data from the 15 laundries which provided samples, and is shown Figure 15. The washing frequency did not depend on the washing machine type. The data indicate that an average household in Toowoomba washes five times a week.

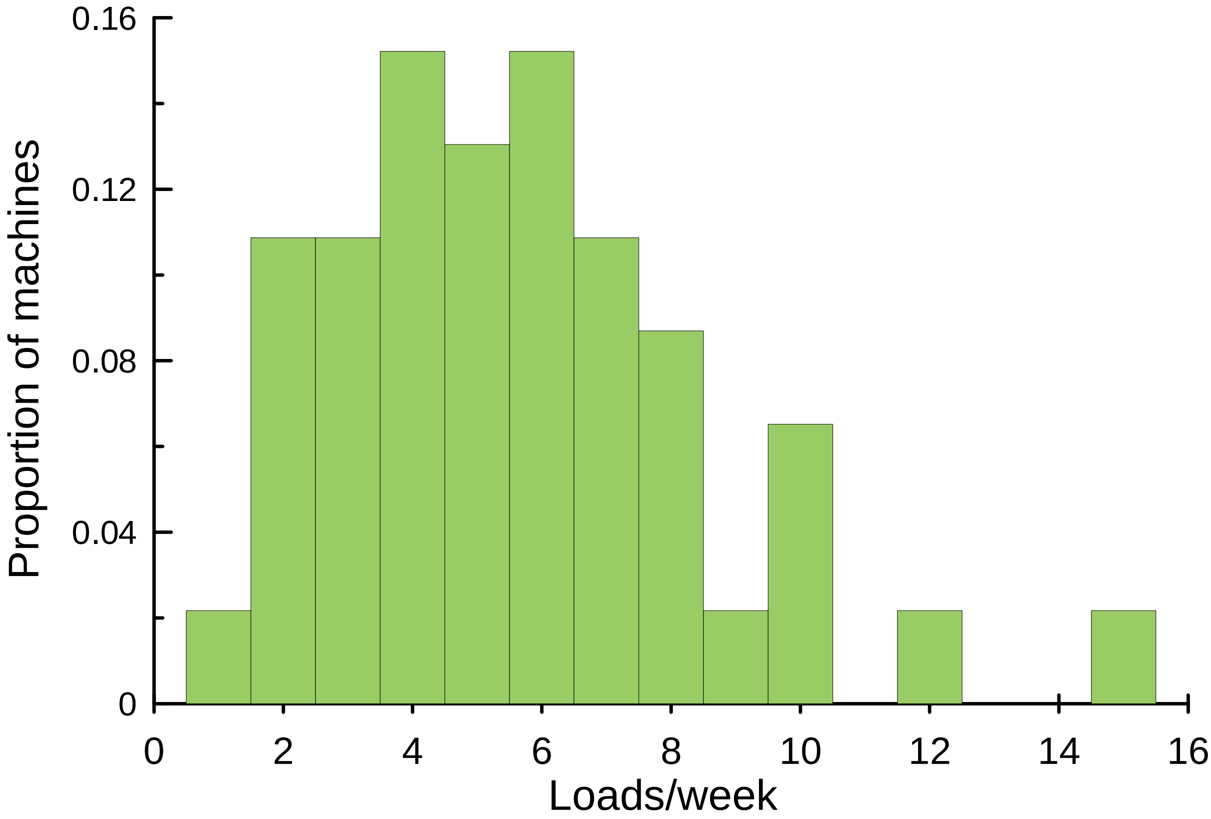

Figure 15: *Number of loads of washing done by Toowoomba residents per week – combined data from email survey and from laundries that provided samples for analysis.*

4.2 Laundry grey water characteristics

The quality of laundry water tested varied from household to household. The household type was not a significant factor in determining the water quality. The major determinant of quality of laundry grey water is the detergent used. Although the chemical characteristics of washing machine detergents are well known (Lanfax Laboratories, 1999), not all detergent added to the wash will end up in the grey water as a proportion of the nutrients and salts are expected to be retained by the wet clothes.

Table 10 shows the laundry grey water data collected from the 15 households across Toowoomba. The water is a composite sample of all the water put through the washing machine. This includes all water used for soaking, the first wash and the rinse cycle. Statistical analysis of the data was performed using a t-test.

***Table 10:** Laundry grey water data collected from 15 households. Each household supplied two samples from different washes.*

Sample	Family Type	Machine Type	Machine Size	Total Volume	Water Use	Washes	Total water use
			kg	L/wash	L/kg	washes/week	L/week
1	2A	Front	5	148	29.7	5	742
2	2A	Front	5	163	32.6	5	815
3	2A	Front	6.5	24	3.6	3	71
4	2A	Front	6.5	51	7.8	3	153
5	2A	Front	7	51	7.3	4	204
6	2A	Front	7	67	9.6	4	268
7	2A+1C	Top	6.5	119	18.3	5	596
8	2A+1C	Top	6.5	115	17.7	5	576
9	2A+1C	Top	5.5	121	22.0	9	1090
10	2A+1C	Top	5.5	111	20.1	9	995
11	2A+1C	Front	7	105	15.0	8	843
12	2A+1C	Front	7	90	12.8	8	718
13	2A+2C	Top	5	172	34.4	6	1033
14	2A+2C	Top	5	147	29.4	6	882
15	2A+2C	Top	7.5	123	16.4	7	863
16	2A+2C	Top	7.5	119	15.8	7	832
17	2A+2C	Top	6	194	32.3	8	1552
18	2A+2C	Top	6	180	30.0	8	1440
19	1A+C	Top	6	168	27.9	3	503
20	1A+C	Top	6	170	28.4	3	511
21	1A+C	Top	5	101	20.3	5	507
22	1A+C	Top	5	135	27.0	5	675
23	1A+C	Top	5.5	154	28.0	6	925
24	1A+C	Top	5.5	146	26.6	6	878
25	2A+B	Front	6	145	24.2	6	870
26	2A+B	Front	6	105	17.4	6	628
27	2A+B	Front	5.5	67	12.1	15	1002
28	2A+B	Front	5.5	33	6.0	15	497
29	2A+B	Front	7	29	4.1	10	289
30	2A+B	Front	7	35	5.1	10	354

Table 10: *Laundry grey water data cont'd*

Sample	Family Type	EC	pH	TSS	Total N	Total P	Faecal Coliform
		µS/cm	-	mg/L	mg/L	mg/L	cfu/ 100mL
1	2A	1166	9.7	88.7	19.0	35.9	<1
2	2A	994	9.7	102.0	15.2	32.9	1
3	2A	623	8.0	110.0	13.3	1.5	<1
4	2A	583	8.0	105.3	13.3	3.2	<1
5	2A	1994	9.4	154.0	30.7	93.3	<1
6	2A	1217	9.3	96.7	25.2	46.0	<1
7	2A+1C	1010	9.9	79.3	5.9	17.5	<1
8	2A+1C	890	9.6	116.7	7.1	13.5	<1
9	2A+1C	509	8.6	40.0	3.5	0.2	<1
10	2A+1C	496	8.5	54.7	4.4	0.2	<1
11	2A+1C	928	7.6	125.3	17.0	0.5	30
12	2A+1C	1005	7.6	184.7	22.9	0.5	21
13	2A+2C	537	10.2	88.0	15.7	21.6	3
14	2A+2C	1044	10.3	115.6	6.9	58.8	<1
15	2A+2C	952	9.6	98.7	4.3	10.8	<1
16	2A+2C	1062	9.7	80.7	3.9	1.1	<1
17	2A+2C	632	8.8	51.6	6.5	21.5	<1
18	2A+2C	868	9.6	37.3	6.8	61.4	<1
19	1A+C	727	8.9	33.3	5.1	4.7	<1
20	1A+C	777	9.2	25.7	4.2	6.9	<1
21	1A+C	1476	10.1	26.7	6.0	24.3	<1
22	1A+C	939	9.9	18.3	4.2	12.8	<1
23	1A+C	2162	9.9	64.9	9.1	22.2	2
24	1A+C	1941	10.1	48.0	6.8	20.3	<1
25	2A+B	743	7.3	108.4	11.4	10.4	19,000
26	2A+B	771	8.2	107.6	16.8	15.0	7,100
27	2A+B	1607	9.8	187.6	18.4	62.2	<1
28	2A+B	1279	9.9	99.3	9.6	44.4	<1
29	2A+B	1166	9.9	290.3	28.9	1.3	3
30	2A+B	1023	9.8	279.1	16.3	1.1	<1

Table 10: *Laundry grey water data cont'd*

Sample	Family Type	Ca	Mg	Na	K	SAR	Total Ca	Total Mg	Total Na	Total K
		mg/L	mg/L	mg/L	mg/L		g	g	g	g
1	2A	12.5	11.4	232.0	5.7	11.4	1.9	1.7	34.4	0.8
2	2A	12.9	11.8	224.0	6.2	10.8	2.1	1.9	36.5	1.0
3	2A	12.9	9.5	48.9	5.1	2.5	0.3	0.2	1.2	0.1
4	2A	15.2	9.2	45.6	6.3	2.3	0.8	0.5	2.3	0.3
5	2A	6.1	14.3	501.0	9.6	25.3	0.3	0.7	25.5	0.5
6	2A	8.5	14.6	299.0	10.2	14.4	0.6	1.0	20.0	0.7
7	2A+1C	13.7	13.5	213.0	5.2	9.8	1.6	1.6	25.4	0.6
8	2A+1C	15.4	14.2	187.0	8.1	8.3	1.8	1.6	21.6	0.9
9	2A+1C	16.2	15.1	60.9	5.2	2.6	2.0	1.8	7.4	0.6
10	2A+1C	16.0	13.9	57.5	4.0	2.5	1.8	1.5	6.4	0.4
11	2A+1C	6.8	7.7	129.0	9.1	8.0	0.7	0.8	13.6	1.0
12	2A+1C	11.6	13.4	94.7	9.6	4.5	1.0	1.2	8.5	0.9
13	2A+2C	0.9	2.3	101.0	3.9	12.9	0.2	0.4	17.4	0.7
14	2A+2C	1.5	2.4	179.0	2.6	21.1	0.2	0.4	26.3	0.4
15	2A+2C	4.8	5.6	132.0	4.2	9.7	0.6	0.7	16.3	0.5
16	2A+2C	7.4	8.5	150.0	3.7	8.9	0.9	1.0	17.8	0.4
17	2A+2C	2.9	4.5	65.5	6.5	5.6	0.6	0.9	12.7	1.3
18	2A+2C	2.1	4.0	132.0	5.7	12.3	0.4	0.7	23.8	1.0
19	1A+C	10.6	8.9	88.9	3.6	4.9	1.8	1.5	14.9	0.6
20	1A+C	8.2	7.4	68.0	3.7	4.1	1.4	1.3	11.6	0.6
21	1A+C	1.8	4.4	272.0	5.5	24.9	0.2	0.4	27.6	0.6
22	1A+C	3.1	4.0	168.0	2.7	14.9	0.4	0.5	22.7	0.4
23	1A+C	4.0	10.4	465.0	6.1	27.9	0.6	1.6	71.7	0.9
24	1A+C	2.7	6.0	421.0	6.2	32.7	0.4	0.9	61.6	0.9
25	2A+B	5.6	7.5	75.8	3.5	4.9	0.8	1.1	11.0	0.5
26	2A+B	2.9	5.6	83.9	6.1	6.6	0.3	0.6	8.8	0.6
27	2A+B	1.7	3.3	319.0	7.2	32.9	0.1	0.2	21.3	0.5
28	2A+B	1.7	3.5	244.0	2.8	24.6	0.1	0.1	8.1	0.1
29	2A+B	6.3	7.5	122.0	3.2	7.8	0.2	0.2	3.5	0.1
30	2A+B	4.8	4.9	158.0	4.2	12.1	0.2	0.2	5.6	0.1

4.3 Quantity of laundry grey water generated by households

The amount of laundry grey water generated by a particular family is largely dependent on the type of machine used. Table 11 outlines the average volume of laundry grey water produced by the different family types. Couples without children used less water in the laundry than other families, though all households sampled in this family type used front loading washing machines. Figure 16 and Table 12 show the volume of grey water produced by different family types and machine types.

Table 11: *Laundry water use of various family types in Toowoomba.*

Family Type	Code	Average volume of wash	Average total water use
		L	L/week
Couples without children	2A	84	375
Couples with 1 child	2A+1C	110	803
Couples with 2 children	2A+2C	156	1100
Couples with baby	2A+B	146	607
Single parent with children	1A+C	69	667
Average		*113*	*654*

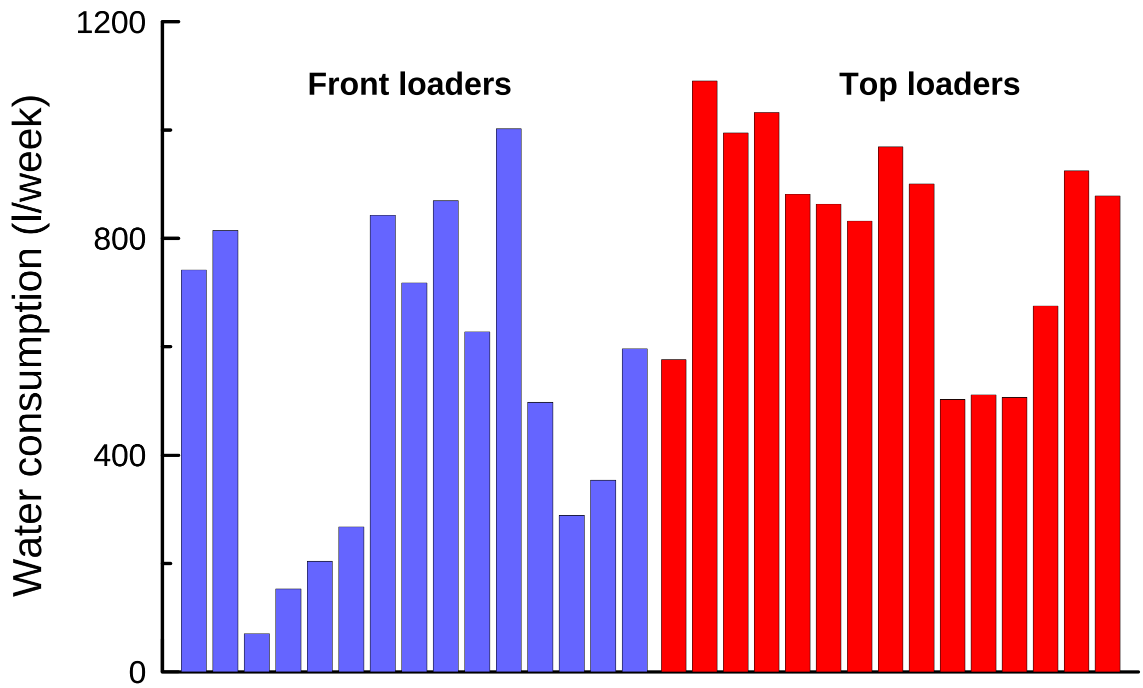

Figure 16: *Water consumption (L/week) for houses tested. The households in blue use front loading washing machines. The households in red use top loading washing machines.*

Table 12: *Average volume of water used in different washing machines types*

Machine Type	Average volume of wash	Average total water use
	L	L/week
Front Loading	79	532
Top Loading	142	866

4.4 Quality of laundry grey water

The water quality measured varied, due mainly to machine type and the different detergents used. Table 13 lists the range of water quality data measured.

Table 13: *Range of water quality data measured from 30 wash samples*

Characteristic	Unit	Measured Value		
		Minimum	*Average*	*Maximum*
EC	μS/cm	496	1037	2162
pH	-	7.32	9.23	10.32
BOD5	mg/L	48	227	787
TSS	mg/L	18.3	100.6	290.3
Total N	mg/L	3.5	11.9	30.7
Total P	mg/L	0.2	21.5	93.3
Faecal Coliform	cfu/ 100mL	<1	<1[7]	19000
SAR	(%)	2.3	12.4	32.9
Calcium	mg/L	0.9	7.36	16.2
Magnesium	mg/L	2.3	8.31	15.1
Sodium	mg/L	45.6	177.9	501.0
Potassium	mg/L	2.6	5.5	10.2

4.4.1 EC, pH, total N, total P, TSS and faecal coliforms

The salinity of the water (as measured by EC) is generally rated as very low or low, with few samples in the medium range. Table 14 gives water salinity ratings for water that would be used for irrigation (DNR, 1997).

Table 14: *Water salinity ratings and plant suitability*

EC μS/cm	Water salinity rating	Plant suitability
<650	Very low	Sensitive crops
650 – 1300	Low	Moderately sensitive crops
1300 – 2900	Medium	Moderately tolerant crops
2900 – 5200	High	Tolerant crops
5200 – 8100	Very high	Very tolerant crops
>8100	Extreme	Generally too saline

[7] Median value instead of average

Water with a very low or low salinity rating will not affect the growth of any common lawn grass and most common tree species (DNR, 2004). Leaching of salt from the soil profile by rainfall is likely to maintain suitable soil salinity values.

The laundry grey water is alkaline and addition of this water to soil will increase the soil's pH. Many plants grown in the local area are adapted to acidic conditions and plants may be stunted if excessive amounts of this high pH water are applied.

The total N found in the water is very low and within the ANZECC (2000) irrigation guidelines of 20-125 mg/L. This guideline aims at protecting ground and surface drinking water supplies. Total P, however, exceeds the ANZECC (2000) guidelines. P in excess of 0.05mg/L can cause clogging of irrigation pipes (assuming other conditions needed for algal growth are adequate). In areas where surface runoff can enter streams and rivers, high P levels can cause algal blooms and contaminate surface drinking water supplies.

Suspended solids are organic or inorganic particles that are entrained in water. When the flow velocity drops, these particles will settle out. If the suspended sediment is organic and if conditions are suitable, it may stimulate microbial activity, increasing nitrogen levels in the water. It may also assist the growth of faecal bacteria. A selection of samples were left at room temperature for seven days and retested for total N, total P and cations two and seven days after sampling. This is discussed further below. While no suspended solids guidelines exist that are relevant to this application of water, their reduction will reduce the risk of organic matter growth and irrigation line blockages. This could be done using simple filtration techniques.

Initially, it was thought that laundry grey water would be high in faecal coliforms because of the nappies and underwear in the laundry basket. Only one household, however, recorded faecal coliforms that would cause concern. Table 15 outlines the trigger values suggested by ANZECC (2000) for irrigation waters.

Table 15: *Levels of faecal coliforms suitable for different uses (ANZECC, 2000).*

Intended Use	**Level of faecal coliforms (cfu/100mL)**
Raw human food crops in direct contact with irrigation water (e.g. via sprays, irrigation of salad vegetables)	<10
Raw human food crops not in direct contact with irrigation water (edible product separated from contact with water, e.g. by peel, use of trickle irrigation); or crops sold to consumers cooked or processed	<1000
Pasture and fodder for dairy animals (without withholding period)	<100
Pasture and fodder for dairy animals (with a withholding period of 5 days)	<1000
Pasture and fodder (for grazing animals except pigs and dairy animals, i.e. cattle, sheep and goats)	<1000
Silviculture (trees), turf, cotton etc (restricted public access)	<10,000

Values less than 1,000 cfu/100mL are considered satisfactory for irrigation of pasture species. Water with as much as 10,000 cfu/100mL can be used to irrigate turf and trees if public access is restricted (subsurface irrigation). It is noted at this point also, that the storage of water from the household with high faecal coliforms counts greatly increased these counts. The number of colony forming units from all other households, however, did not increase when the water was stored for seven days. The low faecal coliform levels generally found in the grey water could be due to:

- Composition of laundry detergents;
- Residual chlorine in Toowoomba's town water; and
- Temperature of wash water.

Detergents contain ingredients that disinfect clothes as part of the cleaning process, reducing the ability for faecal coliforms to grow.

Toowoomba's town water contains residual chlorine for the express purpose of killing bacteria and supplying water to houses that is safe to drink. This is the same water that is used in the laundries.

The temperature of wash water (if warm water is used) will also affect the growth of faecal bacteria. Water temperatures greater than 40°C will reduce the growth of faecal coliforms (Mills, J 2005, pers. comm., 3 August). The high faecal coliform value was recorded in a household with a baby. The only other faecal coliform value greater than 10 cfu/100mL was recorded in a house with a young child.

4.4.2 Calcium, magnesium, sodium and potassium

The cations that are of interest are calcium, magnesium, sodium and potassium. Of these four, sodium and calcium are of particular interest as they have a significant bearing on whether the application of this water has the potential to cause soil structural problems.

Soils that are relatively low in EC but high in sodium compared to the other cations tend to be unstable in water. Hard surfaces can form, making it difficult for plants to germinate or grow. Infiltration rates are reduced and water-logging may occur as a result. The sodium adsorption ratio (SAR) is the ratio of sodium cations to calcium and magnesium cations. Irrigation waters with SAR values >6.0 are cause for concern. Approximately two-thirds of all the laundry water samples tested had SAR values >6.0, and the long-term application of such water to a single location without some addition of Calcium (e.g., as gypsum) could be expected to cause significant soil structural damage.

4.5 Effect of machine type of laundry grey water quality

Front loading washing machines used less water than top loading machines (Table 16). The concentrations of suspended solids and total N are increased in front loading machines due to the reduced volume of water they use. This trend, however, does not continue in the cations (Ca, Mg, Na and K) and total P, as the brand of detergent used will most likely determine the quantities of these components.

Table 16: *Average laundry grey water quality for different machine types*

Characteristic	Unit	Machine Type		Significance Level
		Front Loader (n = 14)	*Top Loader (n = 16)*	
Total volume	L	79.5	142.3	0.05
Water use	L/kg	13.4	24.7	0.10
EC	μs/cm	1079	1001	ns
PH	-	8.9	9.6	ns
BOD5	mg/L	291	171	ns
TSS	mg/L	145.6	61.2	0.10
FC	cfu/100mL	<1	<1	ns
Total N	mg/L	18.4	6.3	0.10
Total P	mg/L	24.9	18.6	ns
Ca	mg/L	7.8	7.0	ns
Na	mg/L	184.0	172.6	ns
Mg	mg/L	8.9	7.8	ns
K	mg/L	6.3	4.8	ns
SAR	-	12.0	12.7	ns
Total Ca	g	0.66	0.92	ns
Total Na	g	14.31	24.06	ns
Total Mg	g	0.74	1.05	ns
Total K	g	0.52	0.68	ns

The actual mass of salts, P and N applied to the soil is dependent on the volume of water used and the number of washes a household does in a week. Table 17 outlines the mass of salts, N and P added to soils if the grey water was used.

Table 17: *Average weekly water use and mass of nutrients and salts in laundry grey water*

Characteristic	Unit	Machine Type	
		Front Loader (n = 14)	*Top Loader (n = 16)*
Water	L/week	532	866
TSS	g/week	77.1	53.0
Total N	g/week	9.8	5.5
Total P	g/week	13.2	16.1
Ca	g/week	4.1	6.1
Na	g/week	97.9	149.5
Mg	g/week	4.7	6.8
K	g/week	3.4	4.2

4.6 Effects of storage on laundry grey water properties

One sample from each family type was stored and tested two days and seven days after sampling. Figures 17 - 23 show the results of these tests. All constituents except for the faecal coliforms remained the same or decreased over time. Only one sample, from the household with a baby showed faecal coliform levels that would be of concern. The number of faecal coliforms increased almost fifteen-fold over seven days (Figure 19). This suggests that water without faecal coliforms could be stored for up to seven days without concern. The actual time that it could be stored could be greater than seven days. If the laundry water does contain faecal coliforms, there is a risk to human health and this water should not be stored. As it is impossible to tell water that does contain faecal coliforms from water that does not without testing it, it seems most practical that the water be used immediately rather than stored.

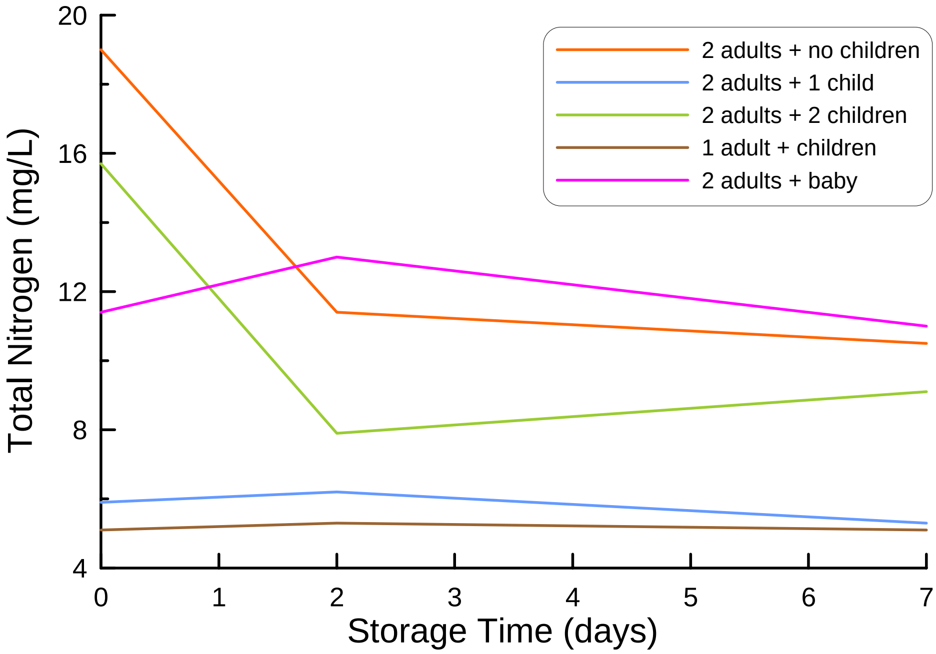

Figure 17: *Change in total N when samples were stored for seven days*

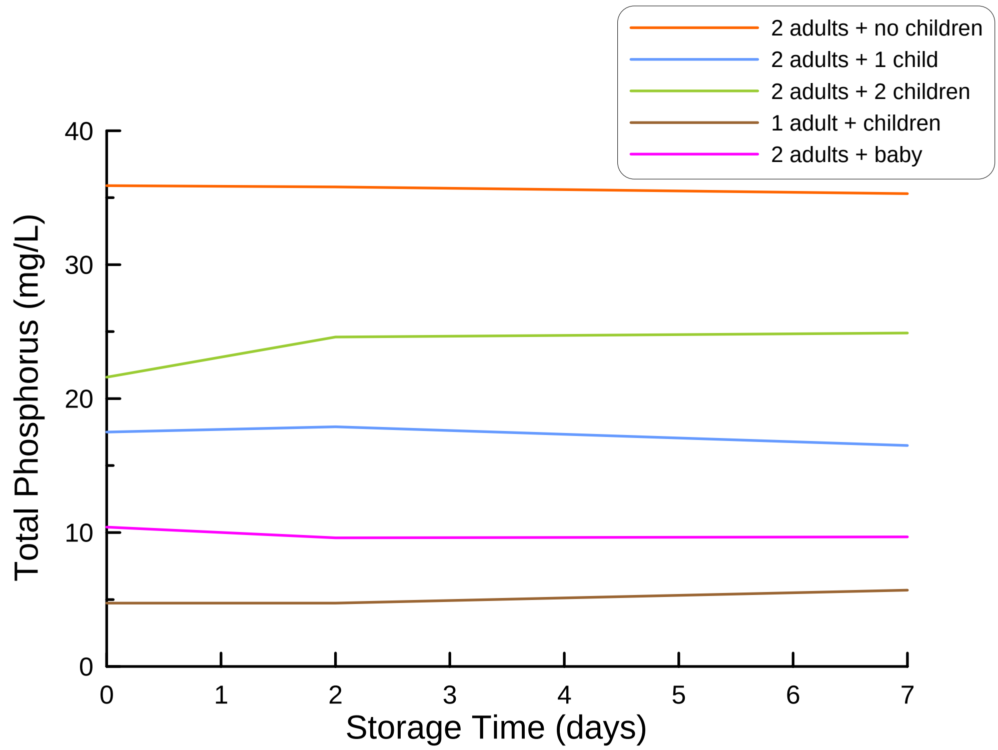

Figure 18: *Change in total P when samples were stored for seven days*

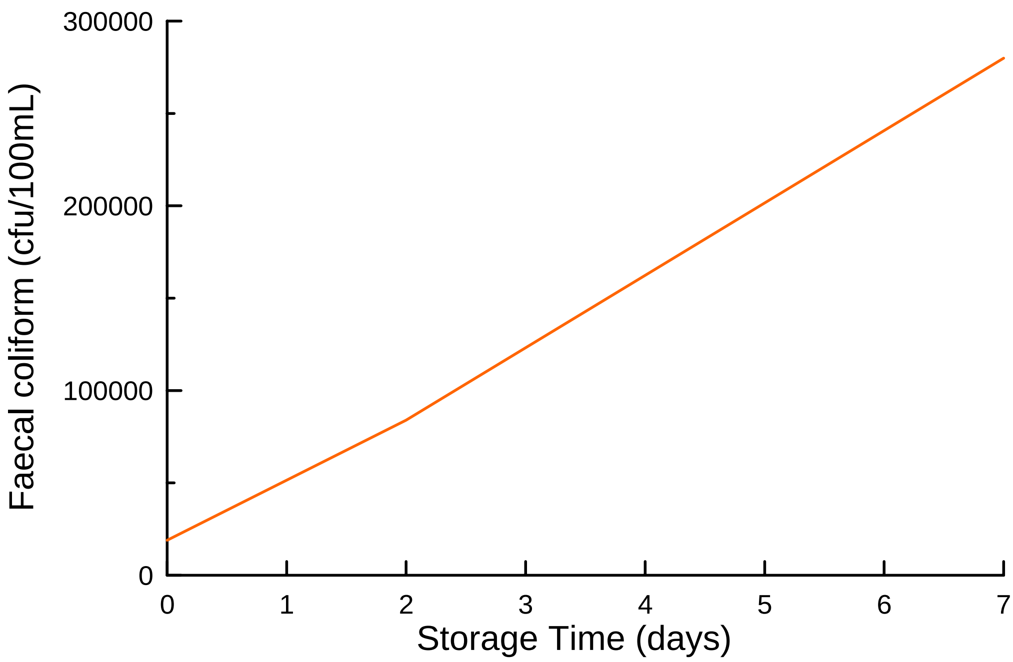

Figure 19: *Change in faecal coliforms when samples were stored for seven days. Data shown are for a household that had a couple and a baby.*

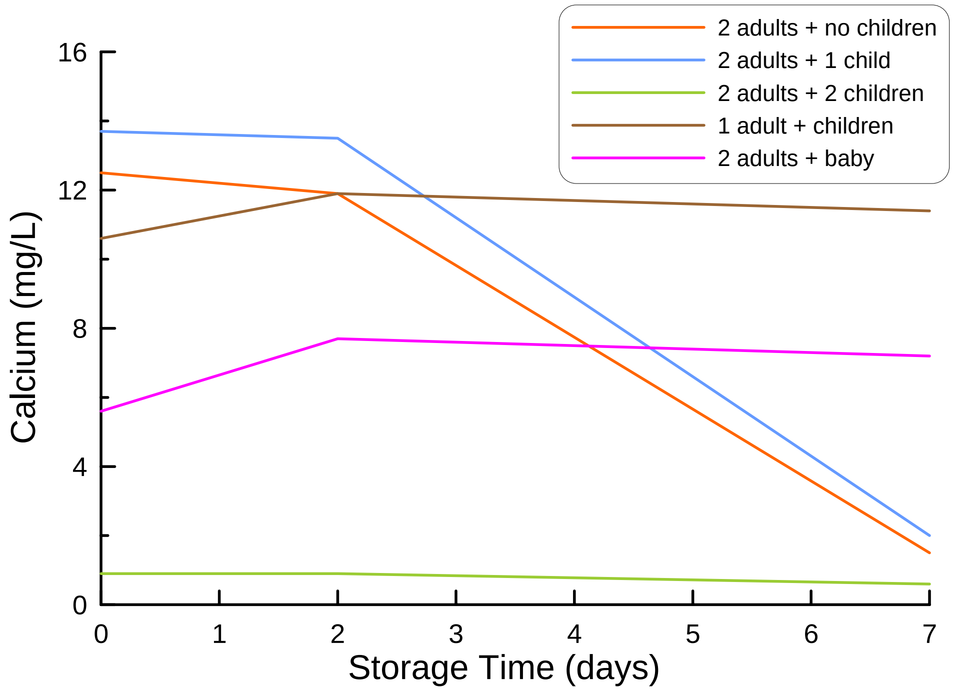

Figure 20: *Change in Ca concentration when samples were stored for seven days.*

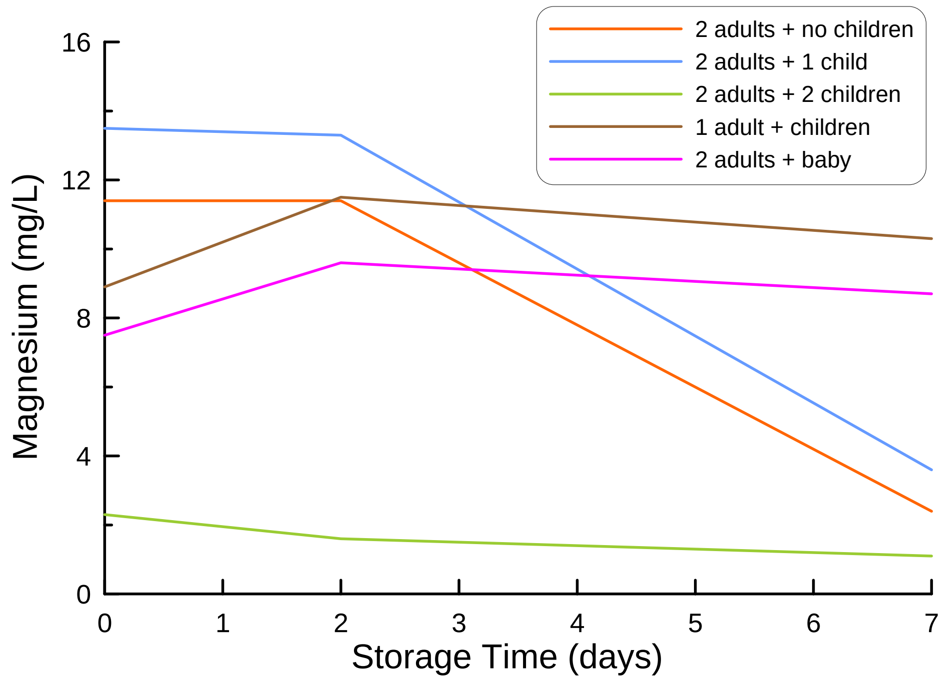

Figure 21: *Change in Mg concentration when samples were stored for seven days.*

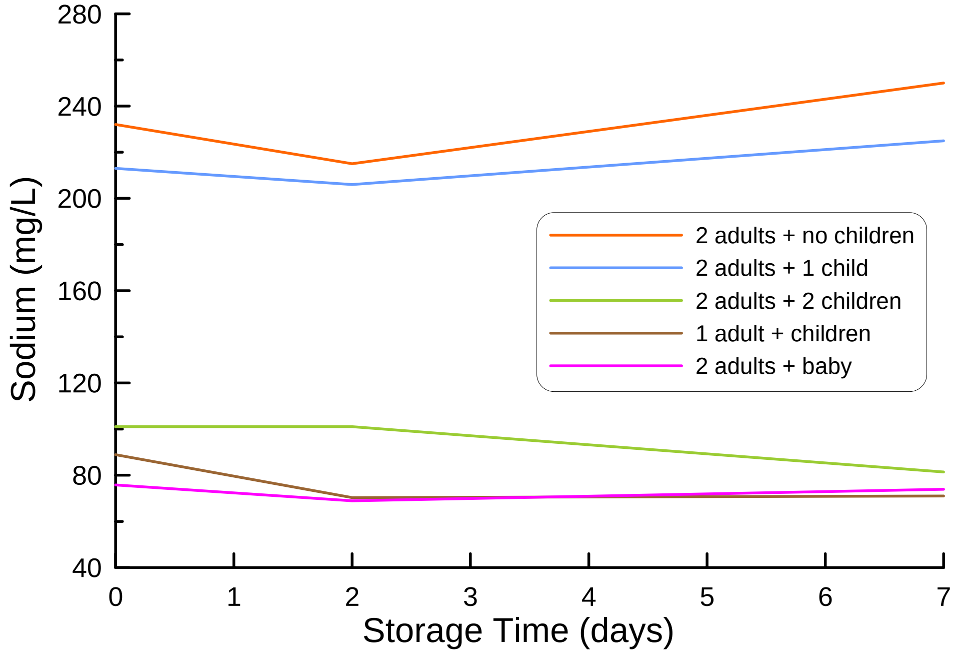

Figure 22: *Change in Na concentration when samples were stored for seven days.*

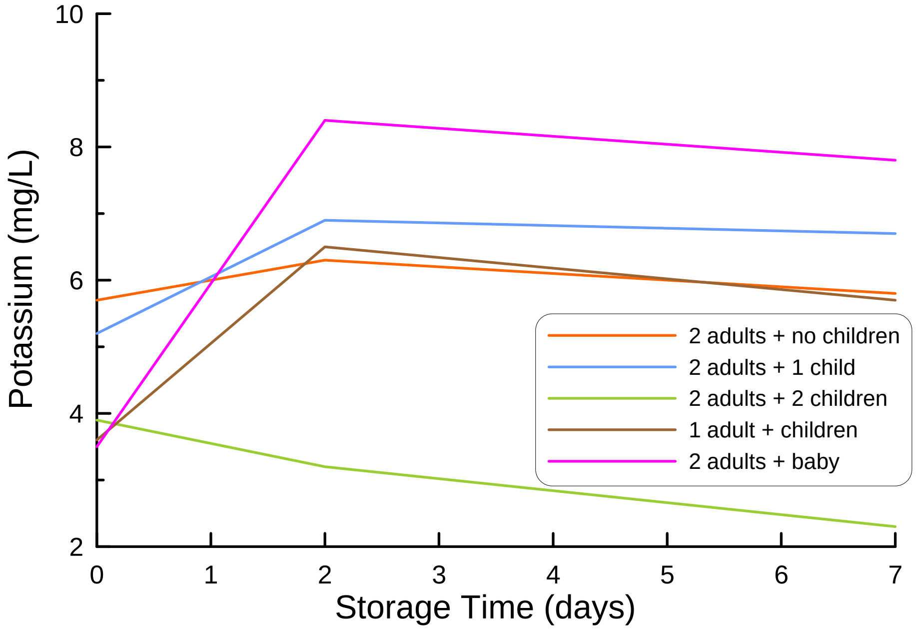

Figure 23: *Change in K concentration when samples were stored for seven days.*

4.7 Effect of detergent type on laundry grey water quality

Different detergents had a significant effect on the pH of the grey water. Liquid detergents produced grey water with lower pH. Table 18 shows the average water characteristics and their significance levels. The lower the significance level, the more significant the difference between the averages is. The code “ns” denotes that the averages are not significantly different. While not statistically significant (at the 90% level) there is some evidence to suggest that liquid detergents produced grey water with lower Ca and Na concentrations, lower salinity levels (EC) and lower sodium adsorption ratio (SAR).

Table 18: *Effect of detergent type on laundry grey water characteristics.*

Characteristic	**Unit**	**Detergent Type**		**Significance Level ***
		Liquid (n = 8)	*Powder (n = 22)*	
TSS	mg/L	103.8	99.5	ns
EC	❍s/cm	769	1135	ns
pH	-	8.1	9.6	0.01
Total N	mg/L	13.5	11.4	ns
Total P	mg/L	14.2	24.2	ns
BOD_5	mg/L	264.5	213.7	ns
Ca	mg/L	10.6	22.0	ns
Na	mg/L	84.4	211.9	ns
Mg	mg/L	7.7	8.5	ns
K	mg/L	6.5	5.2	ns
SAR	-	8.3	20.9	ns

5.0 RESULTS – soil impacts of irrigation with grey water

Leaching studies were performed using two different water qualities (differentiated by their EC), consistent with “average” and “poor” quality water from laundries. Solutions with electrical conductivities of 1.0 dS/m and 2.0 dS/m were used, with SAR values of 9.2 and 23.1 respectively. After leaching with the “grey water” solutions, the soils were then leached with deionised water, simulating the application of low salinity water (eg rain water) to the soil after prolonged irrigation with laundry grey water.

The rate of flow of water through soils – and any changes in flow rate through time – is a strong indicator of changes in soil structure, and was used in this study as an indicator of effects of grey water on soil stability.

5.1 Flow rates of the 1.0 dS/m water solution

Figures 24-28 show measured rates of water flow through the five soils sampled. The blue line is the flow rate of the laundry water solution and the red line is the flow rate measured when deionised water was applied.

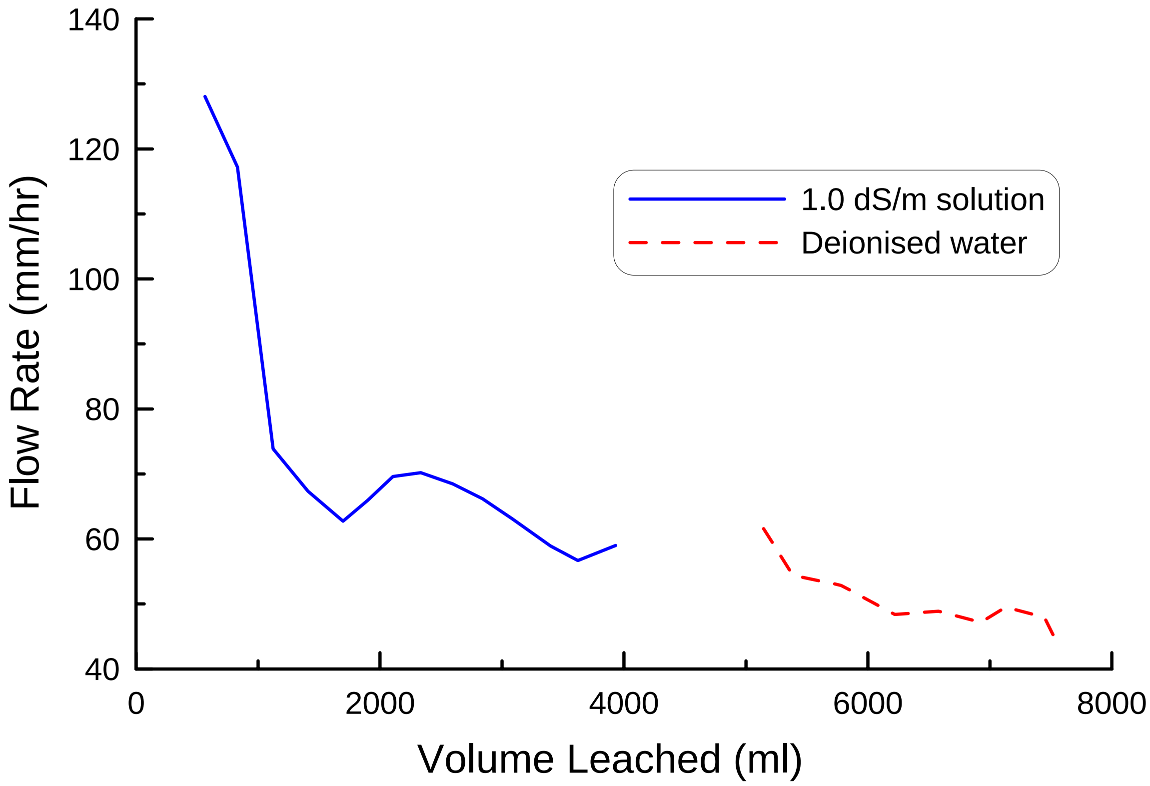

Figure 24: *Flow rate of leachate through the Charlton-Beauaraba soil core using the 1.0 dS/m solution followed by application of deionised water.*

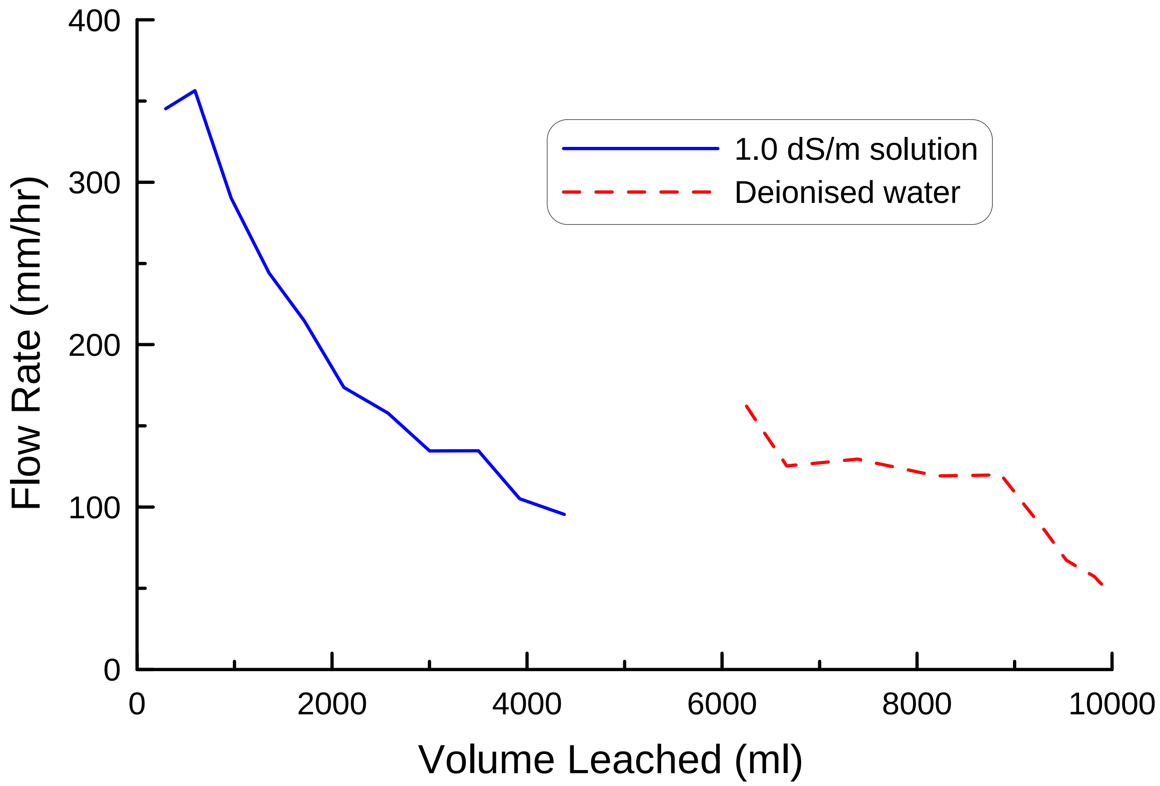

Figure 25: *Flow rate of leachate through the Charlton-Craigmore soil core using the 1.0 dS/m solution followed by application of deionised water.*

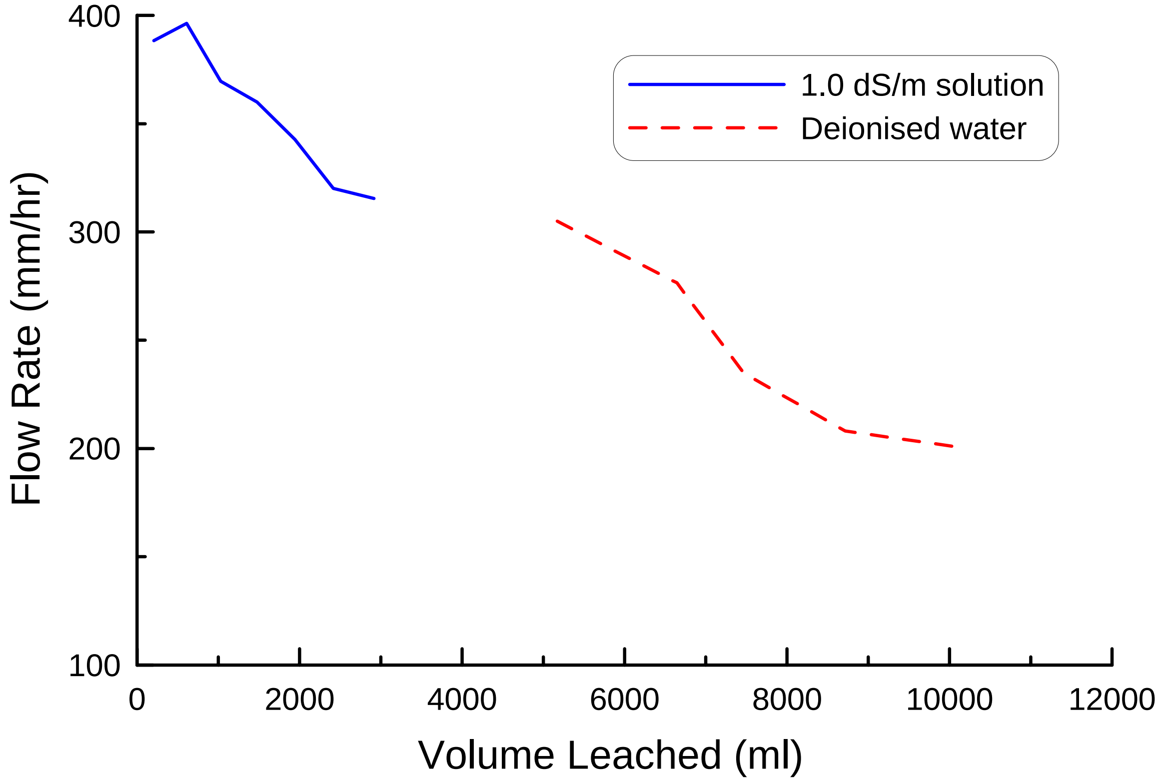

Figure 26: *Flow rate of leachate through the Toowoomba-Gabbinbar soil core using the 1.0 dS/m solution followed by application of deionised water.*

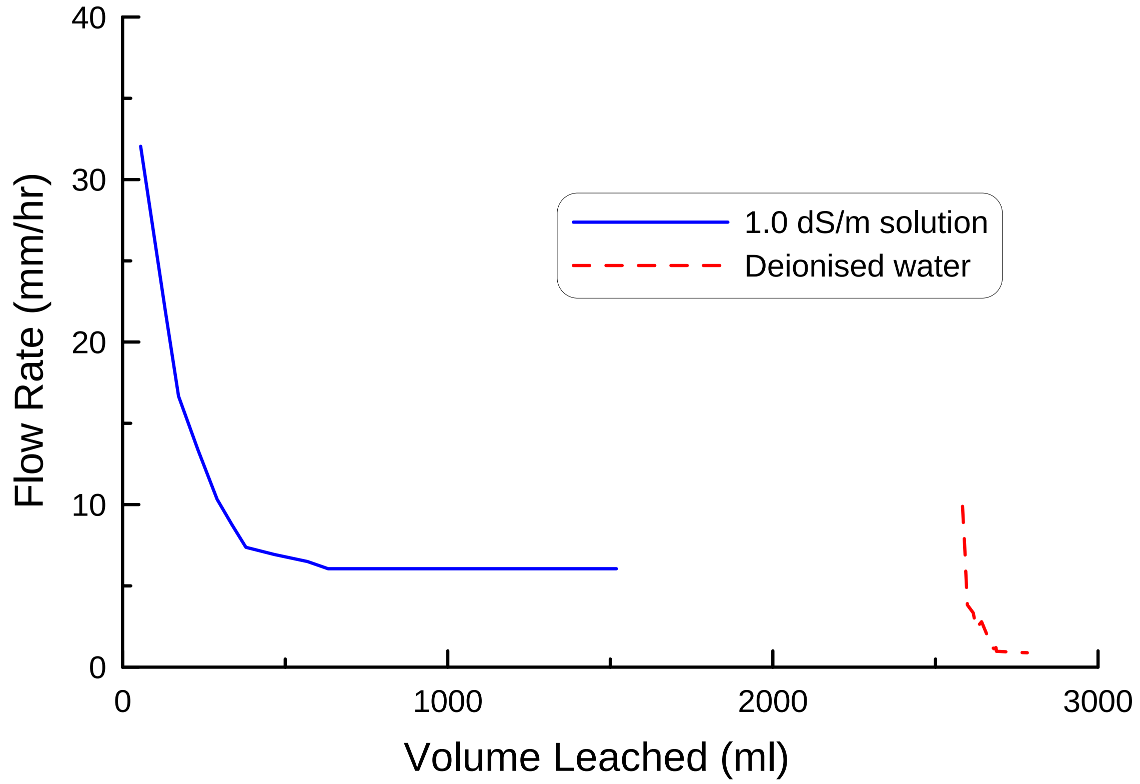

Figure 27: *Flow rate of leachate through the Ruthven-Middle Ridge soil core using the 1.0 dS/m solution followed by application of deionised water*

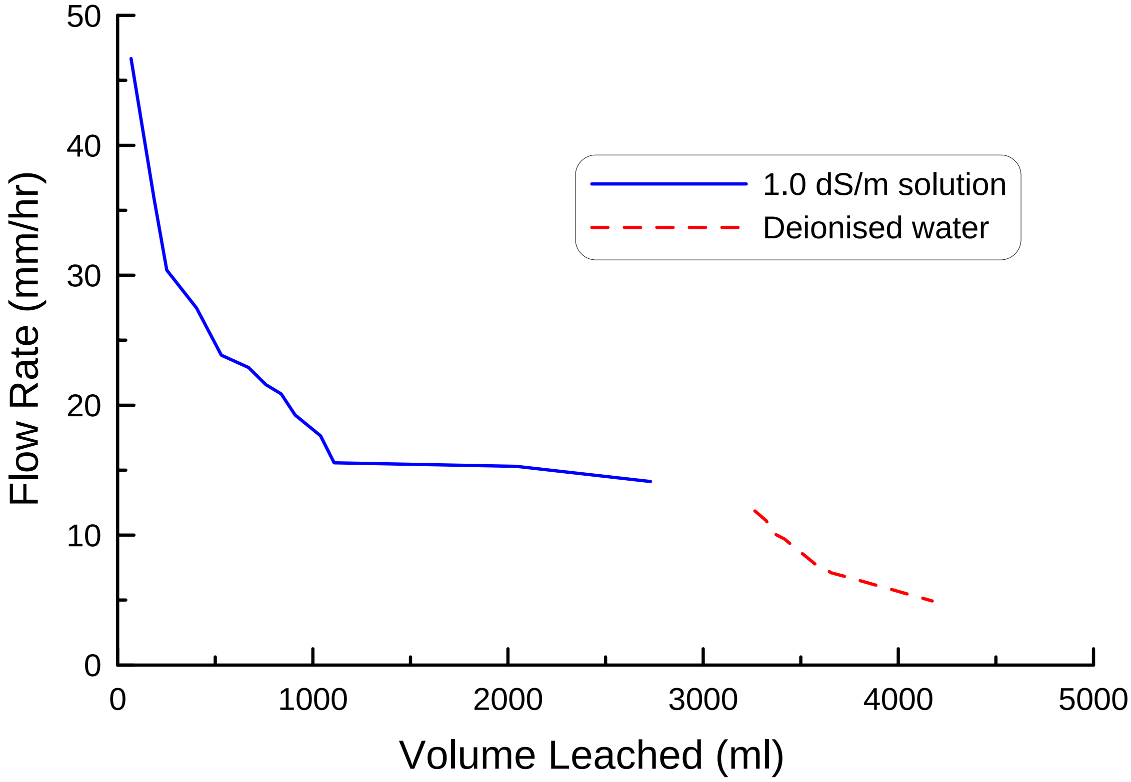

Figure 28: *Flow rate of leachate through the Drayton-Kynoch soil core using the 1.0 dS/m solution followed by application of deionised water.*

The rate of flow of leachate through TG was much higher than measured for the other four soils due to the way in which it was prepared. The black soils had higher initial and final flow rates when compared with the red soils. The final flow rates measured for the black soils were similar as were those measured for the red soils (excluding TG). The final flow rates did not reach a steady state and could be expected to be less than that measured.

The application of deionised water markedly reduced the rate of water flow through the Ruthven-Middle Ridge soil but did not reduce flow rates through the other four soils beyond the trend set during leaching with the saline solution.

5.2 Flow rates of the 2.0 dS/m water solution

Figures 29-33 show measured rates of flow of leachate through the five soils sampled, using the 2.0 dS/m leaching solution. The blue line is the flow rate for the “grey water” solution and the red line is the flow rate measured when deionised water was applied.

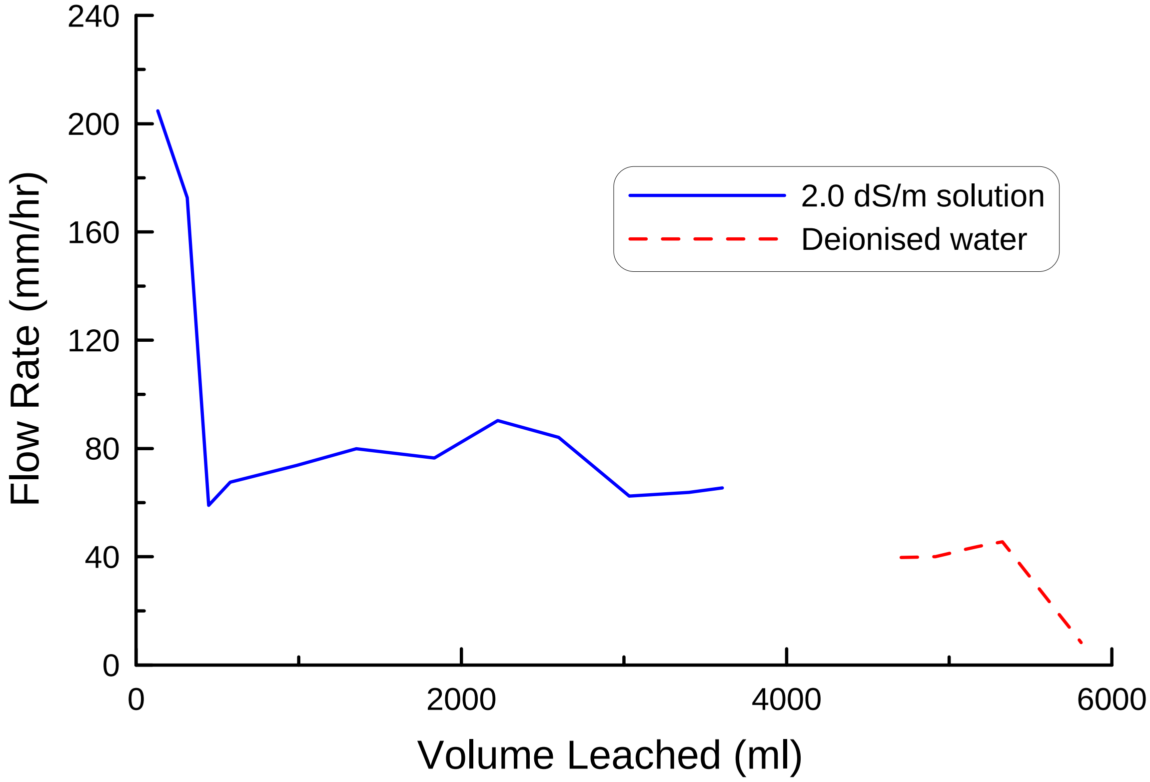

Figure 29: *Flow rate of leachate through the Charlton-Beauaraba soil core using the 2.0 dS/m solution followed by application of deionised water.*

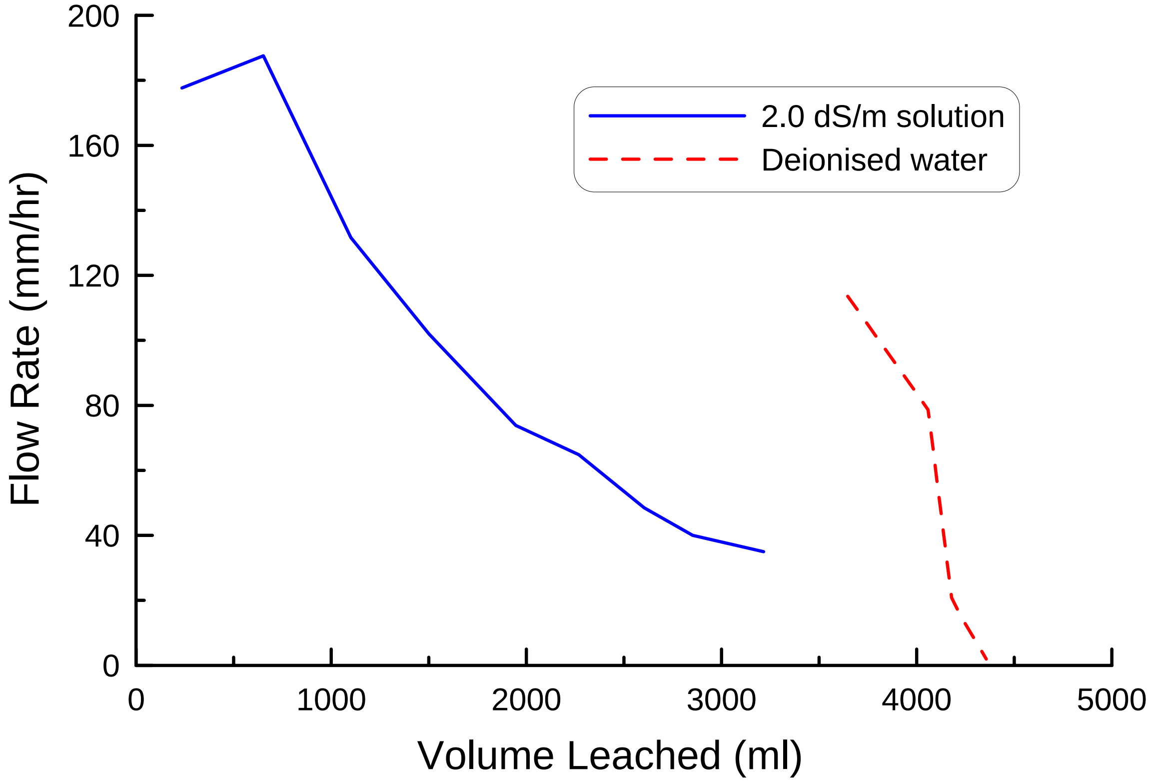

Figure 30: *Flow rate of leachate through the Charlton-Craigmore soil core using the 2.0 dS/m solution followed by application of deionised water.*

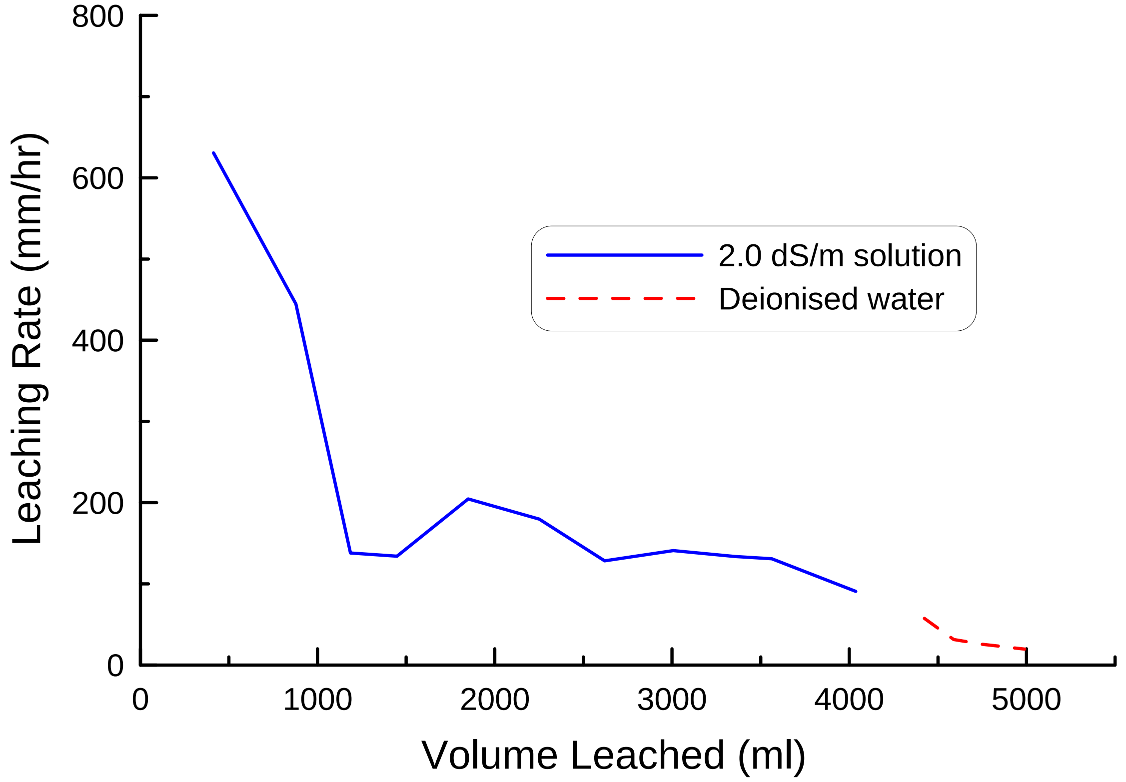

Figure 31: *Flow rate of leachate through the Toowoomba - Gabbinbar soil core using the 2.0 dS/m solution followed by application of deionised water.*

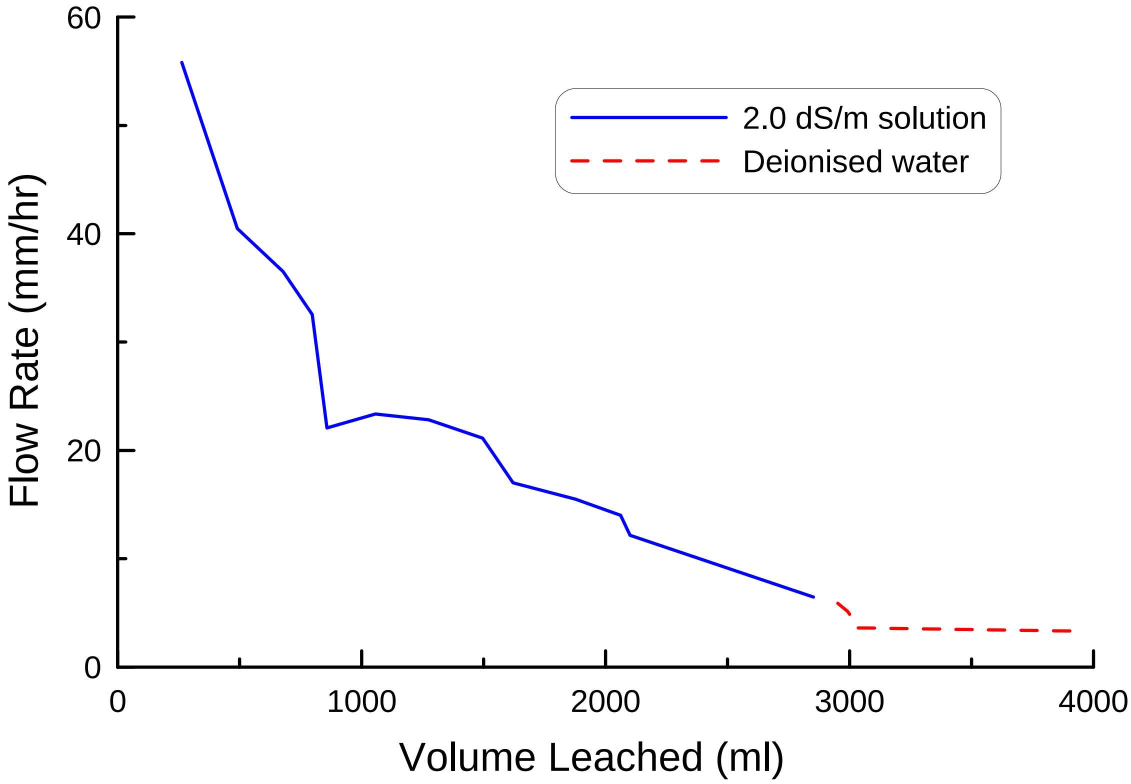

Figure 32: *Flow rate of leachate through the Ruthven-Middle Ridge soil core using the 2.0 dS/m solution followed by application of deionised water.*

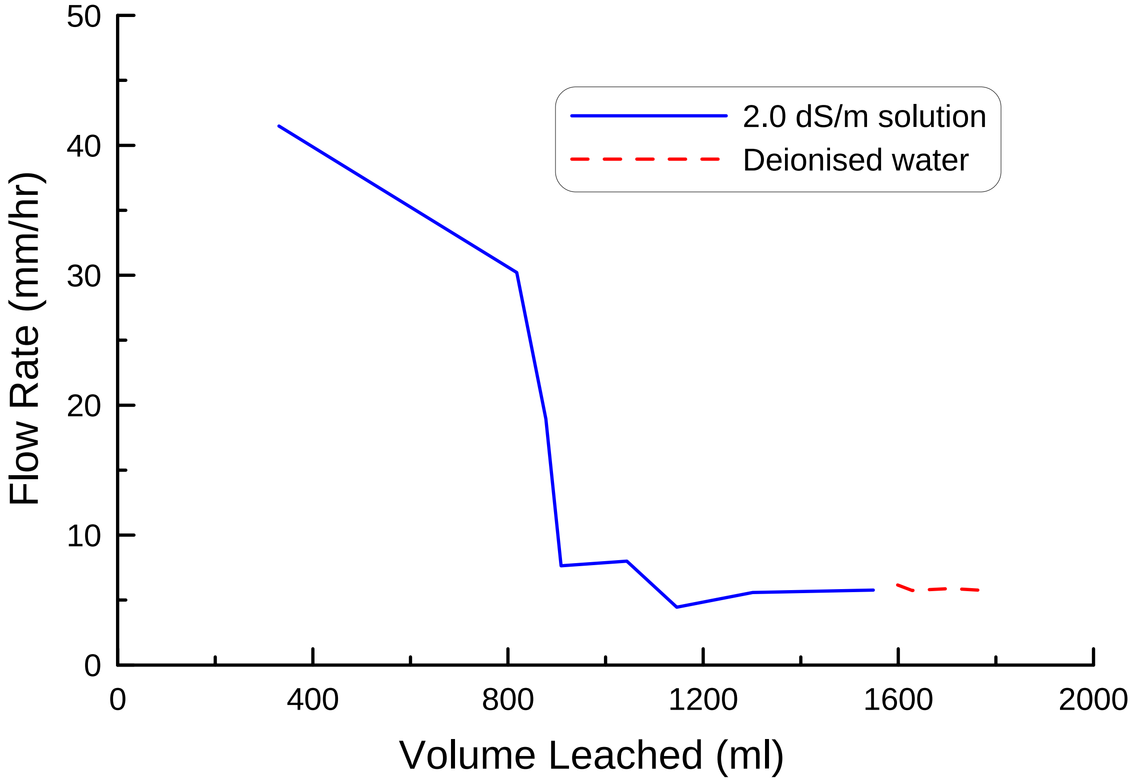

Figure 33: *Flow rate of leachate through the Drayton-Kynoch soil core using the 2.0 dS/m solution followed by application of deionised water.*

Flow rates through the soils leached with 2.0 dS/m solution again showed little impact of water quality on flow rates through the soils, except for CC, which showed a rapid decrease in leaching rate when deionised water was added. This indicates that some clay dispersion and blocking of soil pores occurred once the deionised water reduced salt concentrations in pore water in the soil.

Flow rates through the red soils and black soils were consistently lower than those measured with the 1.0 dS/m solution. The lower flow rates were also recorded for less solution passing through the soil. The higher EC, higher SAR water reduced flow rates through all soils, even before deionised water was applied. This indicates that the 2.0 dS/m solution had a low enough EC and high enough SAR to impact on the stability of the soil, even before application of deionised water.

5.3 Stability of disturbed soils leached with laundry water

Figure 34 is an example of the clay dispersion that occurred when the Emerson dispersion test was performed on a soil that had been previously leached with solutions of differing EC and SAR. The four containers (from left to right) show the level of dispersion for an unleached sample, a sample leached with a 2.0 dS/m (SAR = 23.1) solution, a sample leached with a 1.5 dS/m (SAR = 23.1) solution and a sample leached with a 1.0 dS/m (SAR = 9.2) solution.

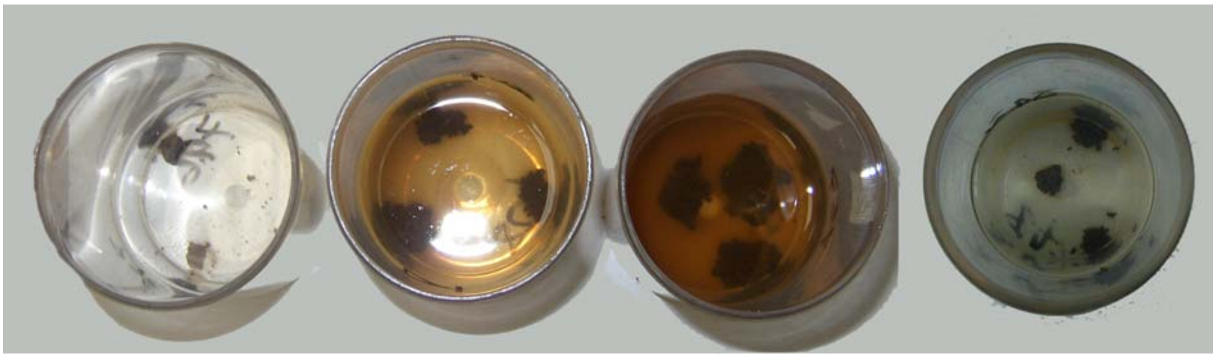

Figure 34: *Example of clay dispersion that occurs at different EC and SAR*

Table 19 shows that clay dispersion did occur in disturbed samples, even though the same soil did not noticeably disperse in its undisturbed state. Dispersion occurred in both the red and the black soils to varying degrees and at varying rates. The amount of dispersion was not as great in the soils leached with the 1.0 dS/m (SAR = 9.2) solution as it was for soils leached with solutions of greater EC and SAR. Soils leached with solutions of high SAR and lower EC dispersed more than the soils leached with water of the same SAR and higher EC.

Table 19: *Dispersion of clay in soil samples that were leached with solutions of varying EC and SAR.*

Soil Association	Clay Dispersion in Disturbed Soils					
	2.0 dS/m (SAR = 23.1)		1.5 dS/m (SAR = 23.1)		1.0 dS/m (SAR = 9.2)	
	Degree	Rate	Degree	Rate	Degree	Rate
CB	Medium	Slow	Medium	Rapid	Slight	Medium
CC	Strong	Rapid	Strong	Rapid	None	-
TG	Medium	Rapid	Strong	Rapid	Medium	Medium
RM	Slight	Slow	Slight	Rapid	Slight	Slow
DK	Strong	Rapid	Strong	Rapid	None	-

5.4 Impacts of "grey water" addition on exchangeable sodium in soils

For undisturbed samples that had had the "average quality grey water" applied, measured exchangeable sodium percentages were – for most of the soils – considerably lower than expected. After passage of 15 pore volumes, soil exchangeable sodium would be expected to be in equilibrium with the irrigation water, and (on the basis of published relationships) to be in the order of 11%. The data in Table 20 show that only two of the five soils reached ESP values close to 11%. Both were red soils with relatively low Cation Exchange Capacity (CEC), and one had been disturbed.

However, although lower CEC would hasten attainment of equilibrium ESP, the differences in CEC between the soils are not great enough to explain the differences in ESP shown in Table 20 after passage of 15 pore volumes of leachate. It can be concluded that some of the soils, including cracking clays, show extremely inefficient cation exchange when leached with sodic waters. This is undoubtedly due to stable macropores which conduct water through the soil rapidly with little opportunity for cation exchange, and it is not surprising that the soil showing greatest accumulation of exchangeable sodium is the one which was disturbed and had lost its stable macropores. Therefore, for situations where undisturbed soils in relatively good condition are irrigated with grey water, it appears that development of high exchangeable sodium levels in some soils will be relatively slow. Increases in soil sodicity are likely to be much more rapid where disturbed soils are irrigated.

Table 20: *Effect of irrigation with water of SAR 9.2 on soil ESP (exchangeable sodium as a percentage of Cation Exchange Capacity (CEC))*

Soil Association	ESP prior to leaching	ESP after leaching	Soil group	Soil CEC (m.eq./100g)
CB	0.7	3.7	Heavy clay	55
CC	1.0	3.0	Heavy clay	27
TG[A]	1.2	13.9	Clay (red)	15
RM	0.8	9.3	Clay loam (red)	17
DK	0.6	4.2	Clay (red)	20

[A]: Disturbed sample

5.5 Effects of passage through soil samples on leachate properties

Measurements on leachate after passage through the soil samples generally showed pH and EC approaching input values after passage of 3-7 pore volumes. The one exception was the Toowoomba-Gabbinbar soil, for which leachate remained of lower pH and EC than that of the water applied even after passage of 15 pore volumes. As the TG soil sample was mildly disturbed and showed the highest level of change in exchangeable sodium due to leaching of all the soils, it would be expected that that soil sample should have had greatest impact on leachate properties. It appears that leachate moved through the other soil samples with considerably less interaction with the soil. Cation and nutrient data generally indicate similar rates of equilibration between soils and leachate to that shown by EC and pH.

5.6 Disposal areas required to utilise nutrients and water

Table 21 shows reported values (ANZECC, 2000) for annual N and P removal by kikuyu, a common grass in Toowoomba. It also shows the annual water requirement for kikuyu assuming that the grass' total water requirement is met (i.e. the grass is not stressed due to under watering).

Table 21: *Annual nitrogen and phosphorus removal by cutting kikuyu grass*

Grass	N removal (g/m^2)	P removal (g/m^2)	Water requirements (L/m^2)
Kikuyu	78	9	1600

Table 22 shows land areas required to sustainably dispose of the nitrogen and phosphorus found in grey water and of the water itself, based on average and maximum nutrient and water loadings as collected earlier in this project. The calculation of the required land area for the disposal of laundry grey water is based on an evaporation rate for Toowoomba City of 2000 mm/y and a crop factor of 0.8 (Allen *et al.* 1998). The crop factor is used to convert the evaporation rate into crop evapotranspiration. For most grasses, the typical crop factor value is 0.8 – 0.9.

It should be noted that annual water use will – in practice – vary considerably, as there will be wet and dry years, and wet and dry periods within years. During the wet periods, irrigation using grey water would probably be reduced or discontinued.

Table 22: *Minimum area required to use all nitrogen, phosphorus and water supplied annually by laundry grey water, assuming average water use in all years.*

Loading	Minimum Area Required		
	Nitrogen	Phosphorus	Water
Average	5 m^2	94 m^2	25 m^2
Maximum	13 m^2	510 m^2	50 m^2

The potential for a household to sustainably dispose of **all** of the laundry water it produces should be considered in terms of its component streams:

- Water
- Phosphorous
- Nitrogen
- Soluble salts

Information on the laundry water quality (Table 10) and on potential use of its components by grass (Tables 21 and 22) indicates that, at this stage, the major factor determining the land area required for irrigation of all of a given household's laundry water is Phosphorous. A significant issue for development of guidelines will be to determine whether to base them on maximum (worst-case) loadings, or on average loadings. There is potential for use of low-P detergents to drastically reduce the concentrations of P in laundry grey water, but it would be impractical to make use of such detergents a condition of grey water use for irrigation of gardens or lawns.

Red soils in the Toowoomba area have considerable capacity to store and immobilise P, with some data showing capacity to store up to 1.5 t/ha of P in the surface 300 mm of soil, and up to 6.0 t/ha of P in the sub-surface 300-600 mm layer. If all laundry grey water produced (assumed 760 L/week) with the maximum concentration of 93 mg/L P was applied to the 94 m^2 of lawn considered suitable for grey water with average P concentrations, then the equivalent accumulation of P (after P uptake by plants) would be equivalent to approximately 343 kg/ha of P, and the surface soil's sorption capacity would be exceeded in 4-5 years. It would take a further 17-18 years to exceed the sorption capacity of the 300-600 mm layer, and considerably longer to exceed the P sorption capacity of the soil layers below that. This suggests that the consequences of application of grey water with higher than average concentrations of P could take considerable time to achieve any significant off-site impacts. In practice, the high Na concentrations generally associated with high P in laundry grey water would cause significant soil damage and reduce soil permeability to unacceptable levels long before the P sorption capacity of the profile was exceeded. (Samples with high P tend to be high in SAR as well (Figures 34 and 35 –Section 6.1).

5.7 Practical implications of watering with laundry grey water

The Queensland State Government, in its amended legislation (Queensland Government, 2005, s. 46) states that grey water use on sewered land must be performed using subsurface irrigation systems. Many residents are currently using buckets or hoses directly from the washing machine, and it is considered likely that the use of buckets may be allowed. The requirement for subsurface irrigation is in response to concern that grey water can contain bacteria harmful to humans. Faecal coliforms were found in significant quantities in samples from one of the 15 laundries sampled in this study, suggesting that although such bacteria can occur, the prevalence of faecal bacteria seems to be overstated when laundry grey water is considered separate from other grey water sources.

Laundry grey water contains organic suspended solids, which are a source of phosphorus and nitrogen in addition to that found in the detergents. It is highly likely that the presence of suspended solids will encourage growth of algae within irrigation pipes, making regular maintenance necessary. This maintenance may include line flushing with clean water and chlorination to kill algae.

Any automated system (anything other than a bucket or hose) will need a filter to remove suspended solids from the water before it enters the irrigation system. Once drip irrigation systems are blocked, they are very difficult to unblock. Emitter blockages will create areas of high and low concentrations of salts. If a system has some emitters blocked, then some areas will receive more than the designed amount of nutrient and salt, and other areas will receive no irrigation water, nutrient or salt at all. This leads to variable growth and uneven distribution of the nutrient and salt within the disposal area.

An automated system will need to consist of an overflow to the sewer when the system is unusable, a sump, a pump, a filter, subsurface irrigation pipe and a controller. A system of this nature will typically cost approximately $2000 to install in a household backyard. For a minimum irrigated area of 25-50 m^2, this cost is relatively high.

There is potential for irrigation with grey water to cause damage to soil structure together with increases in soil pH that would reduce or prevent growth of some plant species. The extent to which those soil changes occur will depend on the types and concentrations of detergent used in a given household. However, given the costs and management requirements associated with subsurface irrigation, the potential to use grey water for permanent irrigation of lawns and gardens is likely to be unattractive to a large majority of householders. Occasional opportunistic use via hoses or buckets is likely to be more acceptable, though householders should be aware of the potential soil and plant impacts of such use.

6.0 CONCLUSIONS

6.1 Grey water quality and quantity

The volume of grey water from front loading machines is less than that from top loading machines. While this does seem obvious, the reduced volume resulted in increased concentrations of suspended solids and nitrogen in front loading machines. Higher EC and P were observed in grey water from front loading machines, but this difference was not statistically significant. The concentration of suspended solids and nitrogen appears to be a function of the cleanliness of the clothes put into the wash whereas the concentration of phosphorus and salts is a function of the type and concentration of detergent used.

All but a few households produced water with a very low or low salinity rating (DNR, 1997). Two households produced water with a medium salinity rating. The suspended solids concentration was high but can be reduced with effective filtration. Total N was low and should not cause problems.

Sodium levels in laundry grey water are generally high when compared to calcium, magnesium and potassium (indicated by SAR). Water with SAR values above 6.0 is of concern. Approximately two-thirds of samples analysed exceed this value. Irrigation with water of high SAR and relatively low EC can cause clay particles in the soil to disperse, resulting in hard-set surfaces, reduced infiltration rates, increased soil strength and reduced plant germination, growth and vigour.

High SAR in the samples taken is clearly linked to the concentration of detergent used (Figure 34), with sample EC being a measure of the amount of soluble salt (detergent) added to the wash water. In contrast, although total P in the wash water shows a general relationship with EC, the correlation is much weaker (Figure 35), illustrating that detergent type as well as its concentration affects the concentration of P in laundry grey water.

Faecal coliforms were only high in laundry grey water from households with babies, where faecal contamination of clothing is more likely. The residual chlorine in Toowoomba water, the relatively high temperature of the wash water (if hot water is used for washing) and the composition of detergents appear to effectively reduce the number of colony forming units.

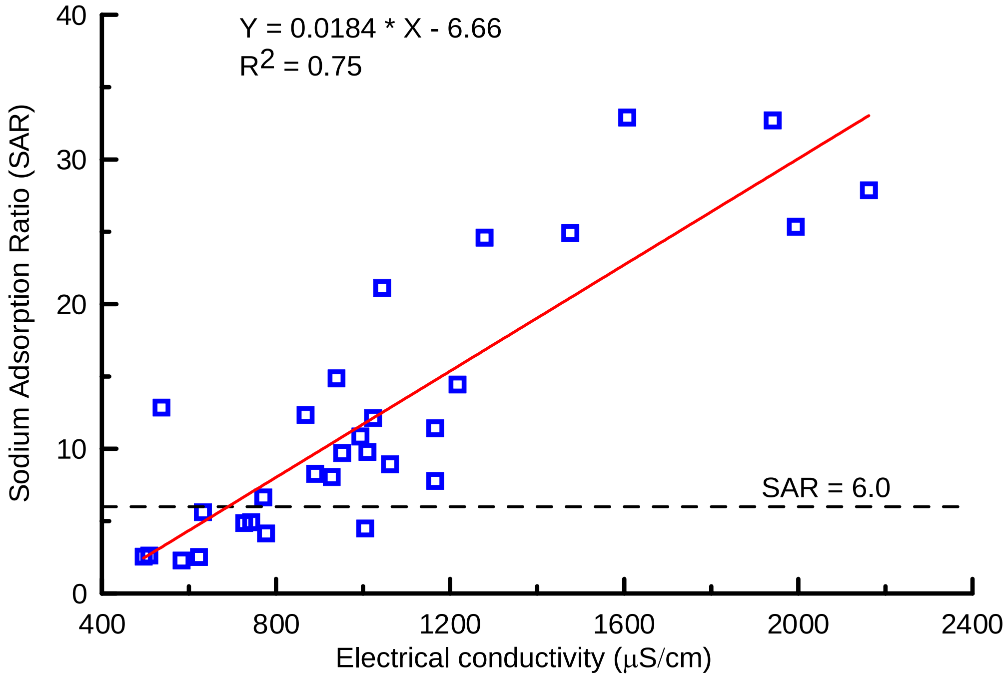

Figure 34: *Relationship between EC and SAR for the samples of grey water taken*

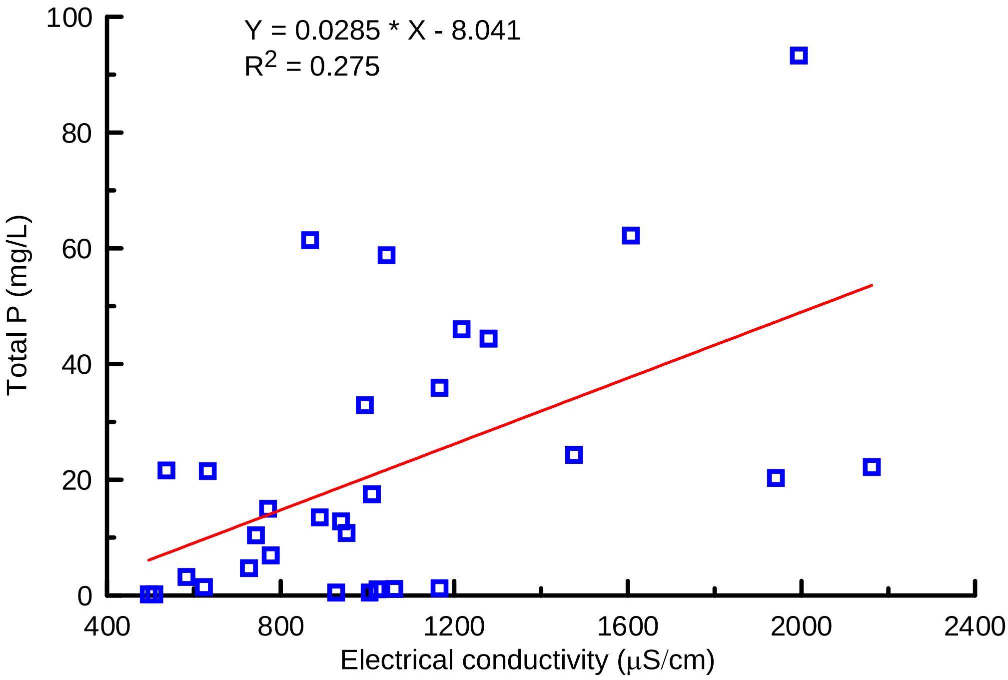

Figure 35: *Relationship between EC and Total P for the samples of grey water taken*

6.2 Potential soil impacts

The high pH, frequently high SAR and moderate EC of laundry grey water create significant risk of damage to soil properties as a result of long-term use of this water for irrigation. Unlike P and N, which are used and removed by plants, cations found in grey water are not used by plants in large quantities, and will accumulate in the soil as the plants use water and nutrients, leading to increases in clay dispersion and unstable soil structure.

Unstable soil structure and clay dispersion typically lead to drastically reduced infiltration of rain, water logging if soils are wet, poor soil aeration, and hard-setting when soils are dry. The result of this structural degradation is poor plant growth and germination. Application of water with high pH will drastically reduce the growth of plants adapted to acidic conditions; such plants include azaleas and blue couch (though green couch and kikuyu are much more tolerant of high pH). Figure 36 illustrates the impact that high pH can have on plant growth. These azaleas grown in Toowoomba have been irrigated with grey water.

Figure 36: *The stunted growth and yellow leaves of this azalea are typical symptoms of high pH soils.*

The need for any subsurface irrigation system installed to incorporate filters to deal with suspended solids and the potential for such systems to malfunction due to blockages further adds to the difficulties and costs associated with laundry grey water use. Simpler systems, such as buckets or hoses, will be cheaper and less demanding to manage, though the potential for soil and plant damage will remain. The minimum area that could be irrigated (25-50 m^2) is relatively small relative to the likely costs of installing a suitable irrigation system.

The flow rates of leachate through all soils leached with the 2.0 dS/m solution were consistently lower than those measured using the 1.0 dS/m solution. The 2.0 dS/m (SAR = 23.1) solution did impact on soil structure. This demonstrates that laundry water has the capacity to adversely affect soil structure. Emerson dispersion tests on disturbed samples showed that leaching with the 2.0 dS/m and 1.5 dS/m solutions (these solutions had higher SAR) caused considerable soil dispersion; leaching with the 1.0 dS/m (lower SAR) solution causing a smaller increase in soil dispersion.

It is difficult for householders to determine the amount of sodium and salt in the detergents they are using as that information is not shown on the detergent packets. It is therefore difficult for householders to choose detergents that have lower sodium contents and low salinities. Householders can and should select detergents that contain low amounts of phosphorus or no phosphorus at all.

While faecal contamination of laundry grey water is not as prevalent as many would suggest, there is a risk of it containing faecal coliform levels of concern. The Queensland State Government has responded to this risk by stating that any grey water use on land in sewered areas must be achieved using subsurface irrigation to minimise the risk of the grey water coming into contact with humans.

A typical backyard does have the capacity to safely dispose of the amount of nutrient and water found in typical laundry grey water if low P and no P detergents are used. The amount of phosphorus found in laundry detergents varies considerably and grey water with high P concentrations can lead to an over supply and consequent accumulation of P in the soil profile. However, considerable quantities of P can be stored in the soil profile, and for situations where P in laundry grey water was high, it is likely that soil deterioration due to accumulation of exchangeable Na would prevent further irrigation with grey water long before P accumulation exceeded soil sorption capacity. (High-P water is likely to also have a high SAR.)

Overall, the installation of backyard irrigation systems to use laundry grey water is likely to be unattractive to most householders, given the potential impacts of the water on the soil and on plant growth, and the cost and complexity of the irrigation system required. Opportunistic use via simpler delivery systems may be more widely acceptable and practicable, but the potential for damage to soils and plants will require householders to adopt suitable types and quantities of detergents, and possibly apply remedial treatments to soils where necessary.

7.0 References

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