University of Southern Queensland

Faculty of Engineering and Surveying

# Hydraulic conductivity response of soils to synthetic laundry greywater

A dissertation submitted by

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towards the degree of

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# Abstract


Laundry greywater is an important water resource that may be used for irrigation of residential lawns and gardens. The extent of reuse of this resource is dependent on the hydraulic properties of soil. This project was undertaken with the aim to experimentally determine the extent to which soil properties and the properties of laundry greywater (e.g. pH, EC and ion composition) influence saturated hydraulic conductivity using three soil types sourced from Toowoomba, Bundaberg and Surat regions of Queensland, and synthetic greywater made from powder and liquid laundry detergents (PLD and LLD).

To determine how hydraulic conductivity of these soils is affected when exposed to laundry greywater, simultaneous comparison was made using tap water (TW). For all experimental work, three replicated soil cores of the three types of soils were exposed to three types of water (TW, PLD and LLD). Additional measurements included evaluation of suspended colloids and ions in the leachate collected during hydraulic conductivity measurements.

Results show that hydraulic conductivity of all soils relating to this experiment are lowered substantially. Results show that hydraulic conductivity is lowered substantially when the soil cores are irrigated with either of the two laundry detergents, particularly with the powder laundry detergent. A reduction in hydraulic conductivity of up to 98% resulted from the irrigation of soil cores with the synthetic greywater. The threat of contamination of groundwater is reduced due to the filtering and purification of the greywater during drainage. This process removed harmful salts and Sodium from the irrigation water. However these will accumulate with sustained irrigation and lead to poor soil quality due to dispersion and salinity.

Direct reuse of synthetic laundry greywater is not sustainable on these types of soils.

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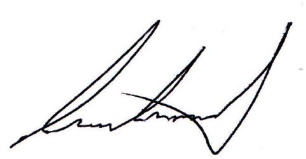

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# List of Abbreviations

| | |
|---|---|
| **BD** | Bulk density in $g.cm^{-3}$ |
| **Ca** | Element, Calcium |
| **CEC** | Cation exchange capacity in $meq.100g^{-1}$ of soil |
| **DDL** | Diffused double layer |
| **EC** | Electrical conductivity $\mu S.cm^{-1}$ ($1000 \mu S.cm^{-1} = 1 dS.m^{-1}$) |
| **ESP** | Exchangeable sodium percentage |
| **IW** | Irrigation water |
| **K** | Element, Potassium |
| **K** | Hydraulic conductivity in $mm.h^{-1}$ |
| **$K_{sat}$** | Saturated hydraulic conductivity in $mm.h^{-1}$ |
| **LLD** | Liquid laundry detergent |
| **Mg** | Element, Magnesium |
| **Na** | Element, Sodium |
| **pH** | logarithm of hydrogen ion activity in water or soil solution |
| **PLD** | Powder laundry detergent |
| **QWD** | Queensland Water Directorate |
| **SAR** | Sodium adsorption ratio |
| **SEQ** | South East Queensland |
| **TRC** | Toowoomba Regional Council |
| **TW** | Tap water |
| **UI** | Un-irrigated |

# Glossary of Terms

**Adsorption (Chemistry)** The process by which atoms, molecules, or ions are taken up and retained on the surfaces of solids by chemical or physical binding.

**Aggregate** A soil structure unit formed by biological and physical agents in which soil primary particles (i.e., sand, silt, clay), along with colloidal and particulate organic and inorganic materials, are grouped together to form larger secondary particles. A group of soil particles cohering in such a way that they behave mechanically as a discrete unit.

**Alkali** A substance having marked basic properties in contrast to acid.

**Buffering** The process that constrains the shift in pH when acids or bases are added. Or more generally, processes that constrain shifts in the dissolved concentration of any ion when it is added to or removed from the system.

**Bulk Density (soil)** The mass of dry soil per unit bulk volume, thus often termed "dry bulk density". Bulk volume is determined before the soil is dried to constant mass at 105 °C. Also called "apparent density".

**Cation Exchange Capacity (CEC)** The total amount of exchangeable cations that a soil can adsorb; sometimes called "total exchangeable capacity," "base exchange capacity," or "cation adsorption capacity". It is expressed in centimoles of charge per kilogram of soil or of other adsorbing material (e.g. clay).

**Dispersion (soils)** The process of disrupting and destroying the structure or aggregation of the soil so that each particles is separate.

**Electrical Conductivity (EC)** The reciprocal of electrical resistivity. The conductivity of electricity through water or an extract of soil; expressed in decisiemens or siemens per meter (dS/m) at 25 °C. It is a measure of soluble salt content in solution.

**Exchangeable Sodium Percentage (ESP)** Amount of exchangeable Sodium expressed as a percentage of total exchangeable cations.

**Flux** The rate of movement of a quantity (e.g., mass or volume of liquid) across a given area.

**Hydraulic Conductivity (K)** The rate at which water passes through a soil material under unit gradient.

**Ion-Exchange** The exchange of ions of the same charge between an aqueous solution and a solid in contact with it.

**Leaching** The removal of soluble materials (e.g., humus, bases, and sesquioxides) from one horizon or zone in soil to another by water movement in the profile. Over time, the upper layer of a leached soil can become increasingly acidic and mineral-deficient.

**Porosity** The volume percentage of the total bulk density of soil not occupied by solid particles. The volume of pores in a sample divided by the sample volume.

**Saturated** Generally, occupying all of a capacity. With respect to water, it is the condition of a soil when all pores are filled with water.

**Sodium Adsorption Ratio (SAR)** The relationship of soluble Sodium (Na) to soluble Calcium (Ca) plus Magnesium (Mg) in water or the soil solution, expressed by the equation:
$SAR = [Na] / [Ca + Mg] / 2$, where the concentration of ions, denoted by square brackets, are in millimoles per litre.

**Soil Bulk Density** The dry mass (weight) of soil per unit bulk volume.

**Soil Core** A volume of soil forced into a cylindrical apparatus.

**Soil Structure** The combination or arrangement of primary soil particles into secondary units or peds. The units are characterised and classified on the basis of size, shape and degree of distinctness.

**Soil Texture** The relative proportion of the various soil separates – sand, silt and clay – that make up the soil texture classes as described the textural triangle.

**Surfactant** A substance added to a liquid to increase its spreading or wetting properties by reducing its surface tension.

# Chapter 1
# Introduction

## 1.1 Background

Australia is one of the driest continents in the world. With average annual evaporation exceeding rainfall the need for proper water resource management is ever present. Several options currently exist which would expand water supply, reduce water consumption and/or recycle water. Reuse of laundry greywater can be considered as a realistic solution because it can supplement domestic irrigation of lawns and gardens. This option is also attractive as it is expected to reduce loading on wastewater treatment plants.

With past experimental work on laundry greywater focussed on reuse for Toowoomba soils (Misra & Sivongxay 2009), there is a need to expand this knowledge to other regions, particularly in the western and coastal districts of Queensland. By gauging the effects of laundry greywater reuse on these soils a better understanding of the sustainability of laundry greywater reuse in wider regions can be obtained.

Soil and water are dynamic mediums for the interaction of several physical and chemical processes. The introduction of certain water qualities to soils can significantly reduce water infiltration capacity or hydraulic conductivity, especially under highly sodic conditions. Greywater is known to be high in Sodium content. For this reason several physical and chemical characteristics of soil and water and their changes during hydraulic conductivity experiments will be analysed in this research. This will assist in further developing the knowledge of soil and water interactions under application of greywater.

## 1.2 Research Aim and Objectives

### 1.2.1 Research Aim

The aim of this project was to study the behaviour of three regional soil types to sustained irrigation with greywater by determining the variation in hydraulic conductivity of these soils when exposed to tap water and two types of synthetic laundry greywater.

### 1.2.2 Research Objectives

The objectives of this research project were as follows:

- Undertake a review of the extent to which laundry greywater can be reused in residential areas for maintaining garden beds and lawns.
- Prepare soil cores for three types of soils from various regions of varying soil characteristics to simulate the conditions of a recently established residential garden bed.
- Compare pH and EC of tap water and synthetic greywater made from powder and liquid detergents. Use these types of water for infiltration into soil for measurements of hydraulic conductivity of three types of soil from selected regions.
- Test drainage water (leachate) and the soil for changes in pH and EC from application of tap water and synthetic greywater.
- Analyse experimental data to discuss how application of tap water and synthetic greywater affect hydraulic conductivity, pH and EC of the soils used.

## 1.3 Justification

The justification of this project arises from the need for water to be used more efficiently. Being able to reuse wastewater for domestic irrigation can reduce the strain on good quality (potable) water intended for drinking. By reducing the water used for domestic irrigation, it is possible to improve water efficiencies. Past work was focussed primarily on Toowoomba soils, since South East Queensland (SEQ) was experiencing a severe water crisis. This project aims to broaden the horizon by testing the hypothesis that the reuse potential of greywater for domestic irrigation in regionally separate areas is identical to that of SEQ.

## 1.4 Scope

The experiments undertaken will attempt to maintain soil conditions that best align with the characteristics of a freshly cultivated garden bed with minimal compaction. This experimental condition of using synthetic greywater was chosen because it could be easily controlled in most experiments. Tap water was also used as a further control because it has a standard quality that the project is aiming to substitute by applying a surrogate of greywater (synthetic greywater).

## 1.5 Concluding comments

This dissertation aims to test the changes in hydraulic conductivity from application of synthetic greywater compared with tap water for three regionally diverse soil types. These tests are important as various regions of South East Queensland have been suffering from a recent water crisis with a high level of water restrictions to reduce household water use. Since various forms of wastewater can be separately collected and distributed, this research can now apply to various regions of Queensland.

# Chapter 2
# Literature Review

## 2.1 Introduction

This chapter will review the literature that is relevant to this topic to provide a framework for the methods and experiments undertaken in this project. The chapter will also provide a brief overview of the characteristics being tested by the project experiments.

Despite recent rain, dam levels in South East Queensland are still at dangerously low levels. Toowoomba is particularly under pressure with the dams that service the inland city, Cressbrook, Perseverance and Cooby Dams being at the corresponding levels of 8%, 11% and 12% (TRC 2009). Better water resource management must become commonplace if the growth and development of our country is to continue.

Table 2.1: Dam levels as of 10-05-2009 (adapted from Sunwater & TRC websites)

| Storage | Level |
|---|---|
| Fred Haigh Dam | 31% |
| Paradise Dam | 74% |
| Cooby Dam | 12% |
| Leslie Dam | 14% |
| Perseverance Dam | 11% |
| Cressbrook Dam | 8% |

Currently desalination plants are being constructed coupled with cities using water recycling to a certain degree. These are however energy intensive processes and desalination is only useful to those populations near coastal areas. It is evident that a simpler process is needed to bridge the gap for domestic water use. A study by Loh

& Coghlan (2001) in the city of Perth found that the average domestic household laundry water use was 11%, while the average domestic household watering accounted for 54% of the total. By using the laundry water to supplement the outside watering of gardens and lawns domestic water consumption could be reduced by the 11% used in the laundry. This seems to be the simplest way to recycle water on the domestic scale as any reuse of black water or greywater with kitchen and bathroom waste is high in contaminants ranging from high levels of organic matter to pathogens. Laundry water is relatively clean and does not contain as many pathogens. This makes it ideal for untreated reuse.

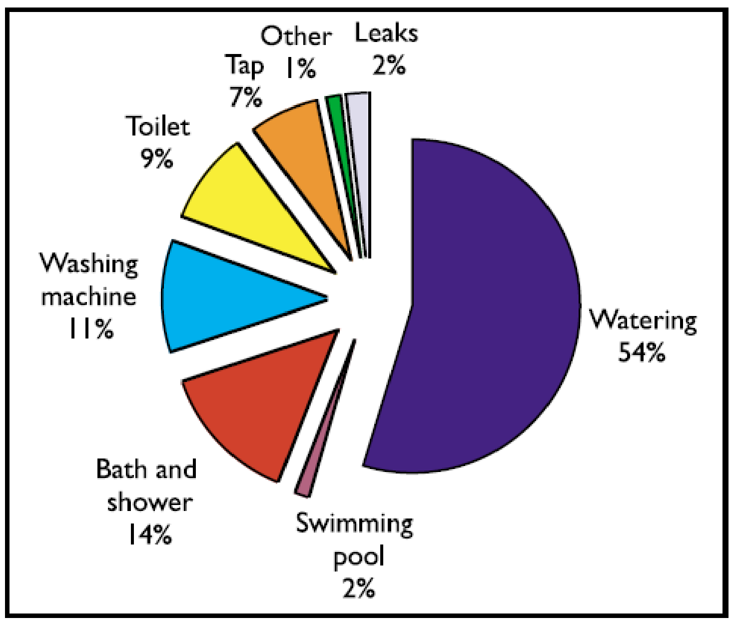


Figure 2.1: Water usage within a single residential household (Loh & Coghlan 2001)

## 2.2 What is Greywater?

Greywater is all of the wastewater produced in the domestic household, excluding toilet water. Typically this includes bath, shower, sink, dishwasher and washing machine wastewater (Weil-Sharfran et. al. 2006). It does not include toilet wastewater, as this is termed blackwater and is full of unwanted impurities such as pathogens, toilet paper and faecal matter.

### 2.2.1 Importance

Most of the wastewater generated in a domestic household, without a septic system and excluding irrigation water, inevitably has to be piped back to the water treatment plant. This includes water that is of minimal concern to public health. The potential exists to harvest this water, particularly greywater and reuse for irrigation of lawns and gardens. Loh & Coghlan (2001) found that water consumption that can result in greywater genesis from taps, bathroom, and laundry sources accounts for 32% of water use in a single domestic household. Exterior water consumption for watering of lawns and gardens accounts for 54% of the total water use. A major reduction in potable water use is possible by reusing the discarded greywater to supplement irrigation water.

### 2.2.2 Guidelines of Greywater Reuse

Several regulatory guidelines exist for greywater reuse in Queensland. According to the amended Plumbing and Drainage Act 2002, the reuse of domestic greywater in a sewered area is accepted under the Act. However, it is specified that no greywater originating from the kitchen shall be reused (QWD Fact Sheet 2006). The collection and distribution methods for domestic greywater vary. Bucket collection and distribution is classed as a legal action, so too is a flexible pipe fitted to a washing machine. The latter method was previously an offence under the Plumbing and Drainage Act 2002. Where, as a consequence of reuse, greywater creates either odour, danger or health risks, the continuation of this practice shall not occur. In fact it is illegal to reuse greywater where it results in an odour being generated.

### 2.2.3 Benefits and Concerns

Several benefits of recycling domestic greywater exist. By substituting potable water use for recycled greywater for household irrigation the total water consumption can be reduced. This has two extra benefits. For one it reduces the amount of water being piped back to wastewater treatment plants thereby reducing the load on these facilities and the energy used to run them. And secondly, any reduction in potable water use translates onto water treatment plants. This means they would not need to produce as much potable water and water resources would be conserved for longer. Greywater reuse may also reduce the increasing intensity of water restrictions. As well as support larger populations with less water infrastructure (e.g. bores, water and sewage treatment plants).

While the benefits of reusing greywater may appear attractive for domestic use there are several potential ramifications of continued application of this quality of water through irrigation. Some of these include:

- Sodium accumulation
- Surfactant residue
- Pathogen accumulation

The watering of lawns and gardens with untreated greywater presents a potential risk to not only soil structure and plant growth potential, but also to human health. This is due to the presence of pathogens within wastewater. Its use on ornamental plants is preferable because this limits the likelihood of human exposure. Any use on plants intended for human consumption is not encouraged. Surprisingly the major pathogens detrimental to human health, those being Giardia and Cryptospordium, were not found in greywater samples. As well, no greywater irrigation user has reported any illnesses related to these pathogens (Howard et. al. 2005). It would appear that the potential risks to human health from greywater irrigation are very low.

## 2.3 Direct Greywater Reuse Alternatives

Before there is too much depth of information revealed regarding direct reuse of greywater, the question of what other alternatives to greywater exist arises. These alternatives may be practical if the direct application of greywater reuse isn't sustainable for soil and/or plant growth, especially with the government offering a rebate scheme for purchase, installation and approval of domestic greywater recycling systems. When selecting greywater recycling systems several systems exist. Greywater recycling systems that offer the benefit of partial reclamation of water quality come in all shapes and sizes. The selection of such a system is a decision best left to the individual, mainly based on cost factors.

For those properties not connected to a municipal wastewater collection system, i.e. sewage collection system, they must rely on a septic tank system. Treatment of this septic water occurs and the treated water is commonly used for the irrigation of lawns and gardens. Internally there are bacteria that decompose much of the unwanted contaminants within the waste water, these bacteria rely on a specific detention time to operate effectively, if water flow is too high through the septic system (non-pump out systems) problems can arise. Therefore it is beneficial to restrict water consumption in the household to support the septic system. By utilizing the direct reuse option for domestic greywater the restriction of water into a septic system would be significantly lowered. Additionally, if required, the greywater reuse alternatives soon to be mentioned can be implemented to assist. A number of chemicals can be harmful to septic systems. It is beneficial to limit these as a means of maximising the effectiveness of the system. The added benefit of removing harmful chemicals, present in greywater, which are detrimental to septic system effectiveness, is a desirable outcome.

Until recently, greywater reuse in Queensland has been illegal for domestic households within sewered areas. In an effort to increase water use efficiencies in the domestic household, the Queensland Government is currently offering Home WaterWise rebates within SEQ for the purchase and installation of below or above ground greywater recycling systems. This rebate may spread to other regions within the state (QWD Factsheet 2006).

To get a basic idea of what greywater reuse systems there are available three systems were reviewed including, a simple diverter system representing a direct reuse comparison.

The simple diverter system, called the Eco-Care Waste Water Diverter Valve, is a typical direct reuse system. It utilizes a flexible pipe and valve that diverts water from any exterior outlet pipe, this carries the raw greywater to the garden or lawn. This system is primitive and is the lowest cost option besides filling up buckets from the washing machine discharge. The dangers of reusing raw greywater are reiterated by the warning in the product description that the installation of this product is at the owner's risk. This system costs less than $100. A diagram of this system is shown in Figure 2.2.

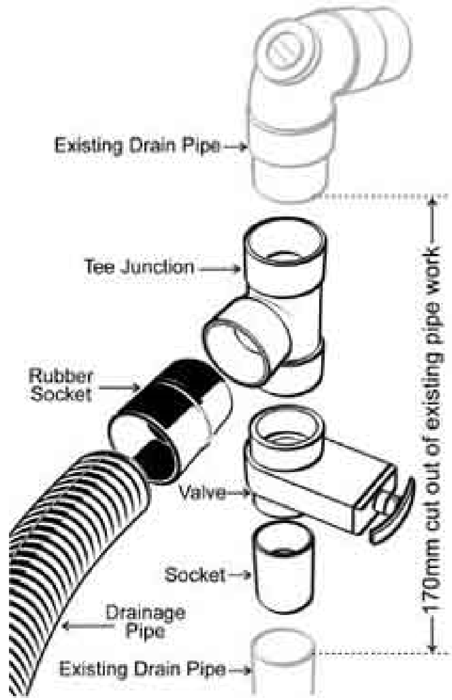


Figure 2.2: Eco-Care Waste Water Diverter Valve (Eco Friendly Products 2009)

Filtering greywater to restore water quality is a preferable option to at least limit colloids and other larger contaminants present in raw greywater. The Matala Gator Pro utilises a progressive filtering system before pumping the greywater onto lawns and gardens. This system has the option of redirecting flow into the sewer and costs under $1000.

Figure 2.3: Matala Gator Pro Greywater Diverter (Eco Friendly Products 2009)

The second greywater reuse system is the H2grO, it implements a stainless steel filter screen to remove large contaminants from the greywater. A storage tank collects the greywater, which runs through the filter, and all filtered material is fee to run off the angled filter into the sewer pipe. Its irrigation outlets are buried beneath the garden or lawn and consist of pods that do not clog with poor water quality. The system is itself buried so that all water outlets in the household can be collected from. This system can cost between $2000-3500 for the manual or electric switch models. Both models use a pump to empty the storage tank through the irrigation outlets.

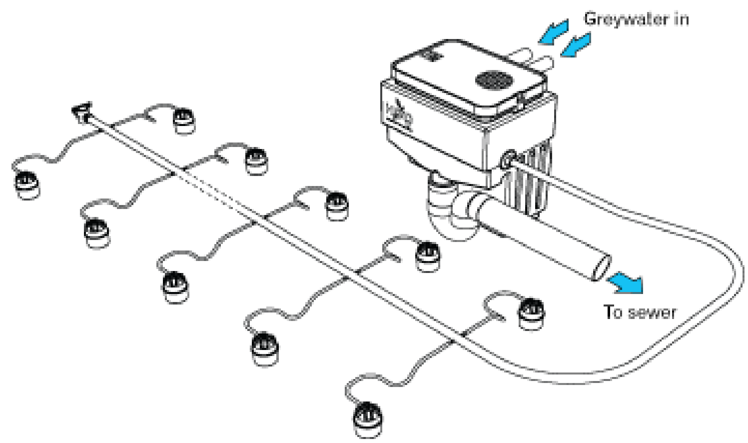


Figure 2.4: H2grO - Greywater for Gardens (Eco Friendly Products 2009)

Although these technologies are effective at restoring water quality before the greywater is used to irrigate lawns and gardens these systems also require a substantial investment. In comparison, the idea of irrigating lawns and gardens with raw greywater sounds a great deal more attractive to the everyday person. Whether the direct reuse of raw greywater is sustainable or safe needs to be further investigated.

## 2.4 Properties of Laundry Greywater

Greywater from the laundry can vary in quality because of a number of factors. The amount of detergent used per wash and the type of detergent can cause this variation. Laundry greywater is usually highly saline, high in suspended solids, high in sodium and of an alkaline pH. Also this water can contain small populations of faecal coliforms which may pose a risk to public health (Howard et. al. 2005).

When considering synthetic greywater some of these additional constituents will not be present in the solution. Generally laundry detergents are based on a wide range of ingredients grouped into four main groups. These groups are surfactants, builders, bleaching agents and auxiliary agents (Smulders 2002).

The ingredients typical in laundry detergents are specifically formulated to disperse soils and oils. These include lipids and other organic materials. In high enough concentrations laundry detergent chemicals can have an adverse effect on organic membranes. This is of concern when reusing greywater in the natural environment.

### 2.4.1 Surfactants

Since surfactants can be considered the most crucial detergent component it is useful to have a closer look at what they are. A surfactant is added to liquids to reduce its surface tension in order to increase its wetting properties (Gregorich et. al. 2001). There are four classes of surfactants, anionic, non-ionic, cationic and amphoteric surfactants. Classification of a surfactant into one of these classes is reliant upon what charge is held in the chain-carrying section of the molecule after dissociation in aqueous solution (Smulders 2002).

Most detergents contain large amounts of Anionic surfactants. These typically carry sodium within their molecular structure possibly to help in the dispersion processes that detergents are used for. This sodium may have an impact upon soil dispersive properties.

### 2.4.2 Other Ingredients

Salts are present, in one form or another, in many detergents. Several builders are used in detergents. One of these is sodium triphosphate which is a salt. Also powder detergents typically contain the salt filler Sodium sulphate.

Additionally Alkalies ranging from soda ash to potash were a constituent of laundry detergent. They are used to precipitate particular ions which contribute to water hardness. By increasing the pH, soil and fibres increase their negative charge and contribute to repulsion characteristics (Smulders 2002). These days ion exchange replaces the precipitation process in laundry detergent manufacturing, and as a result, water soluble molecules are formed instead of precipitates which fall from the water solution and form substance deposits.

## 2.5 Soil Properties Affected by Water Quality

### 2.5.1 Chemical Properties

Soil solution pH is considered important in determining what chemical processes will occur. The activity of protons within the soil solution is controlled by the pH. A highly acidic soil environment releases many dangerous trace elements which are solubilised and can leach from the soil. Alkaline soil solutions generally facilitate the abundance of base cations, for example calcium. Generally, under these circumstances $CaCO_3$ precipitates from alkaline solutions because of their tendency to absorb $CO_2$.

The electrical conductivity (EC) of a soil is directly related to its concentration of dissolved salts. This is one of the properties used to assess soil sodicity and salinity, where the other method is to measure the concentration of calcium, magnesium and sodium. A quantifiable scale of a saline soil is not very useful because of the range of tolerances between plants. Any effects on soil electrical conductivity in response to greywater application are all relative to the original value obtained for that soil. Although some standards have been set to label a soil saline if it exceeds 4 dS/m, or 4000 µS/cm (Essington 2004).

The total amount of exchangeable cations held within a given mass of soil can be termed the Cation Exchange Capacity (CEC). Exchangeable cations are those that are removed from the soil by a solution containing a neutral salt (Essington 2004). High clay and organic matter compositions can greatly affect CEC. An increase in pH can increase the CEC of a soil. Since the pH of greywater is high the application may increase the CEC of a given soil.

Cations and anions can be removed from soil by the process of leaching. If the greywater is not fully saturated with ions then this leaching could occur.

### 2.5.2 Physical Properties

Soil is composed of mineral particles broken down from parent material through the processes of weathering. Factors influencing the weathering can determine what properties a soil will have. These mineral particles can be classified into size proportions which give the soils texture. Texture can be grouped by size into sand, loam or clay. The transmission of water through soil is governed largely by the proportion of texture size, high transmission for sand and low transmission for clays.

In soil, particles are held together and form aggregates. These can be considerably larger than just a basic particle and form with the help of binding agents such as clay or humus. Aggregates are part of soil structural properties. Soil behaviour is partially governed by its structure relating to pore size or voids (Singer & Munns 2006). The shape and size of a soil aggregate can affect such things as water infiltration, water holding capacity and flow of water through soils.

Soils high in sodium, called sodic soils, lose their structure and can become impermeable. This is concerning because of the high levels of sodium present in laundry detergents. A method of prevention is to increase the soil salt concentration. Unfortunately this contributes to soil salinity and the aforementioned problems. Clay dispersion and swelling causing a reduction in hydraulic conductivity from pore clogging are a direct result of excess sodium in the exchange complex. Plant growth is inhibited by this change in soil characteristic due to soil air and water restriction. Different soils are likely to respond differently to laundry greywater because of their individual chemical and physical properties.

### 2.5.3 Hydraulic Conductivity

A measure of the ratio of the flux to the hydraulic gradient is the hydraulic conductivity. Flux is the volume of water flowing through a cross-sectional area per time period. Hydraulic gradient is the head drop per unit distance in the direction of flow (Hillel 1971).

According to Miyazaki (1993), Saturated and unsaturated hydraulic conductivity are associated with the degree of resistance from soil particles when water flows in pores. Many factors can influence these resistances such as the sizes, branching, jointings, forms, and tortuosities of pores. Viscosity of the water can also have an effect on resistance to flow, as well as soil volumetric water content. During unsaturated flow the water utilizes films of water on the surface of particles.

When the subsequent lowering of soil water surface tension occurs, as a result of detergent surfactants, a reduction in soil water retention may occur. The practical implications of this change in characteristic could mean that soil hydraulic conductivity will be greatly increased and water will tend to fall with ease through those soils irrigated with greywater containing surfactants. However, this increase in hydraulic conductivity may be slowed or even reversed by the presence of sodium in the detergents being applied sealing the soil pores through processes of dispersion.

The relationship of soluble sodium to soluble calcium plus magnesium in water or the soil solution is known as the Sodium adsorption ratio (SAR). Patterson (1996) found that hydraulic conductivity reduced as the SAR of the irrigation water increased. This is of concern because laundry greywater has a high SAR.

Previous research performed by Sivongxay (2005) concluded that the saturated hydraulic conductivity of the dominant soil type within Toowoomba, that being a Red Ferrosol, was decreased significantly as a result of the application of raw laundry greywater.

## 2.6 Potential Use of Greywater

There is the potential for using greywater in many applications such as toilet flushing, garden irrigation or irrigation of public amenities, for example parks and golf courses.

Installation of water treatment devices can be expensive and require a great amount of forward planning to integrate into a domestic home. Fane & Reardon (2009) suggest using sand filters and surge tanks to treat greywater before using it for toilet flushing. Other suggested treatment options for greywater reuse on lawns and gardens appear cumbersome, inconvenient and expensive. These reuse options assume that almost all constituents of greywater are to be used in the recycling process, they recommend excluding water from kitchen and dishwasher use. By limiting the wastewater to just that from a laundry source there would be less potential hazards from pathogens and solid waste, aside from the dirt washed from the clothes, therefore direct use on lawns and gardens may be possible.

## 2.7 Chapter Conclusion

This review has gone over the many facets of greywater, its applications and potential effects on soil chemical and physical processes. The measurement of these effects has also been looked at. Also, the review has given a brief insight into its effects on human health.

The review states that the direct reuse of laundry greywater poses the least risk to human health of all domestic wastewaters. Detrimental effects from physical and chemical processes within the wastewater may limit laundry greywater reuse as irrigation water.

Information contained in this review serves as a benchmark for what physical and chemical changes may occur when applying similar quality water to soils.

# Chapter 3
# Materials & Methods

## 3.1 Laundry Detergents

Typical varieties of laundry detergents are conglomerated into two major groups, either powder laundry detergent or liquid laundry detergent. These two types of detergents are used in washing machines because each have been formulated to work with a specific type of washing machine, i.e a front loader or top loader washing machine. Powder laundry detergents are predominantly used in front loading washing machines and liquid laundry detergents are better suited for top loading washing machines. Since each type of detergent has specific properties, both powder and liquid laundry detergents were chosen to test their effects on soil and water properties. Omo Matic Sensitive was chosen as the powder detergent and Dynamo 2x Ultra was chosen as the liquid laundry detergent for all experiments. The details of each detergent are listed below.

**Omo Matic Sensitive (Powder Laundry Detergent)**
Description: High efficiency and front loader concentrate
Manufactured by: Unilever Australasia, 20 Cambridge Street, EPPING, NSW, 2121, Australia
Ingredients: Anionic surfactants, non-ionic surfactants, Optical brightener/fluorescer, Alkalis, Sodium polyphosphate, Zeolite & polymer, Antifoam, Sodium sulphate

**Dynamo 2x Ultra (Liquid Laundry Detergent)**
Description: 2x Ultra is a double strength formulation that is 750 mL equivalent to 1.5 L of the normal strength (as written on bottle)
Manufactured by: Colgate-Palmolive Pty. Ltd., Level 14, 345 George Street, SYDNEY, NSW, 2000, Australia
Ingredients: Pentasodium Triphosphate (10-30%) – Detergent builder, Sodium tridecyl benzene sulphonate – linear (10-30%) – Anionic surfactant, Sodium ethoxylated lauryl alcohol sulphate (<10%) – Non-ionic surfactant, Triethanolamine lauryl sulphate (<10%) – Anionic surfactant, Perfume (<1%), Formaldehyde (<0.2%), Non-hazardous ingredients

In order to prepare synthetic greywater for experiments using these two types of detergents, there was a need to determine the realistic concentration of each detergent in a typical household greywater. This required a review of laundry washing machines currently available in Australian markets separated as front loader and top loader washing machines to determine water consumptions per wash. Information on front and top loader machine capacities was acquired through interpretation of a Choice Magazine article (Choice 2008). Typical water volumes used for each group of washing machines were averaged over the washing machines reviewed to obtain average water consumption per wash for either type of machine.

Most commercial laundry detergent manufacturers usually provide instructions on the volume of powder or liquid detergent required for a full wash including a scoop or cap to measure the volume of detergent. Since volumetric measurements are not as accurate as mass for preparation of solutions of a definite concentration, the following methods were used to measure the amount of detergents used per wash during preparation of synthetic greywater.

**Powder Laundry Detergent:**

- Three replicate measurements were made to determine the weight of a typical scoop of powder detergent. The scoop supplied with the detergent was brushed clean to ensure that there was minimal powder present in the scoop before each measurement.
- The scoop was then filled with powder to above the lip and levelled off with the straight edge of a spatula to ensure that its surface was flush with the top edge of the scoop.
- Care was taken to avoid any compaction of the powder detergent within the scoop.
- The weight of powder detergent for each of the three replicates was measured with an electronic balance to estimate the average weight of a scoop of powder detergent.

**Liquid Laundry Detergent:**

- Two methods were used to approximate the volume of liquid laundry detergent contained within a full cap that was supplied with the detergent as the measuring device. The first method involved measurement of volume and the second method was used to estimate the weight of liquid laundry detergent.

- First, the cap of the liquid detergent was washed and dried. A pipette was then used to draw detergent to fill the cap so that the top of the liquid's meniscus was levelled with the top edge of the cap. The volume of detergent used was measured and recorded. Three replicates measurements were made to determine the average volume of a full cap of liquid detergent.

- The second method involved weighing the dry cap and filling it with distilled water using a measuring cylinder to the same level as that used for measurements with liquid detergent. The cap was weighed again to determine the weight of water that could be converted to volume assuming the density of water as constant, i.e. 1 g of water occupies a volume of 1 mL. Three replicate measurements were performed with water.

- For determination of the weight a full cap of liquid detergent, the weight of a dry cap was taken before it was filled with the liquid detergent to the top edge of the cap. If overflow occurred, the measurement was repeated. The weight of the cap with liquid detergent was taken to estimate the weight of liquid detergent without the weight of the cap. Each measurement was repeated three times to obtain average weight of a full-cap of liquid detergent.

Using average mass of each detergent for a typical full wash volume, average concentration of each detergent was estimated in grams per litre. This allowed synthetic greywater solutions of the desired concentration to be prepared for irrigation of experimental soils.

Typically irrigation water was made by dissolving the known weight of laundry detergent in distilled water to a final volume of 1 L in a measuring cylinder. Synthetic greywater of powder detergent required shaking the required quantity of detergent with the distilled water in a mixing container (15 L plastic container) leaving it overnight for the air bubbles to settle. As for the liquid laundry detergent, the desired quantity of detergent was weighed in the cap and poured into the mixing container followed by repeated flushing of the cap to ensure removal of all detergent from the cap. Total volume of distilled water used in making each solution was recorded to derive the final concentration. A concentration of 1.44 and 0.62 g/L for the powder and liquid laundry detergents was used for the hydraulic conductivity experiments. Data detailing these measurements and calculations of concentration can be found in Appendix G.

Tap water was used as a control for comparison with synthetic greywater made from powder and liquid laundry detergents. For all experimental work, tap water was collected on the day of the hydraulic conductivity experiments.

## 3.2 Soils

All experiments involved three soil types. The location of the collected soil, its colour, field texture and classification are shown in Table 3.1. In this report, soils are referred to by their location, for example, Toowoomba is the soil sampled within the Toowoomba Region. Removing the soil samples involved using a spade to disturb the upper 10-15 cm of soil for collection. This is shown in Figure 3.1. After removal soil samples were stored in thick plastic bags to limit the likelihood of contamination. Table 3.1 contains information on each of the soils used for this research.

Figure 3.1: Method of soil sample collection

Table 3.1: Soil Information

| Soil Type | Location (GPS) | Colour | Field Texture | Soil Classification | Information Source |
|---|---|---|---|---|---|
| Toowoomba | 27°36'35.77" S<br>151°55'47.59" E | 2.5YR 4/4<br>Dusky Red | Clay loam | Red Ferrosol | Biggs et al. (2001)<br>Isbell (1996) |
| Bundaberg | 27°08'54.58" S<br>149°03'40.70" E | 10YR 3/1<br>Dark Brown | Sandy clay loam | Brown Dermosol | Donnollan et al. (1998)<br>Isbell (1996) |
| Surat | 24°52'31.62" S<br>151°18'16.11" E | 7.5YR 4/1<br>Brown Grey | Clay loam, sandy | Alluvial soils, Um 1 | CSIRO (1974)<br>Northcote (1971) |

## 3.3 Preparation of Soil Cores

10-20 kg of soil was collected from each of the field sites with spade and transported to the laboratory. Each soil was spread in several large metal trays and placed in a convection oven at 40 °C to simulate air drying. Large aggregates of the air-dry soil were broken by hand and, when required, were further ground with mortar and pestle. Soil was finally sieved to reduce all aggregates to <2 mm and stored in polyethylene bags. Disturbed soil cores were prepared to simulate the condition of a recently established garden bed as reported by Sivongxay (2005) by compacting soils to a bulk density of 1.05 g/cm$^3$.

Soil compaction can be effective when the soil is close to or slightly above its plastic limit. In order to raise a soil's water content from air dry to plastic limit, water content of air dry soil and at plastic limit was required. The moisture content of the air-dry, sieved soil was measured using the method 2A1 from Rayment and Higginson (1992). Plastic limit of each soil was measured using method 31-3.5 of Sowers et al. (1965). Once plastic limit was determined, all soils were wetted to plastic limit by adding distilled water to a known weight of air-dry soil and then mixed in a plastic container for overnight equilibration. Each soil was mixed the next day and compacted in PVC tubes (50.5 mm ID and 75 mm height) with a wooden plunger from the top. To maintain uniformity of compaction within each soil core the PVC tubes were flipped three times while soil was added to each. For this process, a non-capped PVC tube was used. Soil from the tube was forced into each PVC core using the wooden plunger, making certain both PVC tubes were aligned, once an adequate height & weight of moist soil was compacted. The bottom of each PVC tube was lined with a synthetic porous material and a coarse filter paper. Relevant calculations are shown in Appendix D. Included in Figure 3.2 below are photos of the soil cores and equilibrated soils.

Figure 3.2: Soil cores and equilibrated soil

## 3.4 Measurements of pH & EC of soil and water

Concentration of Hydrogen ions (pH) and electrical conductivity (EC) for each soil was measured using methods 4A1 and 4B1 of Rayment and Higginson (1992) as described previously by Sivongxay (2005). For these measurements, 20 g of air dry soil (<2 mm size) was combined with 100 mL of distilled water in a plastic beaker to prepare soil-water suspensions with a 1:5 soil-water ratio. The suspension in each beaker was stirred at five minute intervals using a glass rod over a period of one hour. Separate glass rods were used to stir separate soil and irrigation application batches to avoid cross contamination of suspensions as shown in Figure 3.3. A pre-calibrated pH meter (Orion 710A) and EC meter (TPS MC-84) were used for all measurements. The EC meter was calibrated by following the instructions given in the MC-84 manual using a salt solution of known EC. Each measurement of pH and EC were performed on three replicates of each soil. Details of the pH and EC of experimental soil is shown in Table 3.2.

A similar procedure was also used for the measurements of pH and EC of the infiltrating and drainage solutions (tap water and two types of synthetic greywater) and for the soil following irrigation with different types of water.

Figure 3.3: Performing 1:5 soil-water pH & EC experiment

Table 3.2: pH, EC and plastic limit of the experimental soil

| Soil Type | pH (1:5 Soil-water) | EC (µS/cm) (1:5 Soil-water) | Plastic Limit (%) |
|---|---|---|---|
| T | 7.017 | 48.533 | 28.27 |
| B | 7.128 | 29.500 | 20.24 |
| S | 7.203 | 45.100 | 28.27 |

## 3.5 Saturated Hydraulic Conductivity of Soils

### 3.5.1 Soils and Irrigation Solutions

A set of three soil core replicates were used for each of the three soil types. Each soil core was constructed from fine cloth, duct tape, filter paper and PVC pipe. The fine cloth was secured tightly to the bottom of each PVC pipe tube with a sufficient quantity of duct tape.

Three irrigation solutions were applied to each of the three soil types, tap water (TW), powder laundry detergent (PLD) & liquid laundry detergent (LLD). The tap water solution was implemented as a control solution. This seemed necessary to compare the results of the laundry detergents to a standardised household irrigation solution. The application of each irrigation solution to the soil cores was performed using the unsaturated soil cores described previously.

### 3.5.2 Leaching of Soil Cores

For uniformity during the hydraulic conductivity experiments a constant head device was used for the application of each irrigation solution. This constant head was delivered using an upturned flask filled with the each solution. Collection of the drainage water (leachate) was performed using a measuring cylinder where the volumes of leachate for each time interval were measured and recorded. Hydraulic conductivity measurements were taken until either a steady state of flow was achieved through each soil core or the hydraulic conductivity was reduced to an insignificant amount that no further measurements would have been practical. A steady state could be observed when the flow of water over the known time period was uniform. The identification of steady state using flux (cm/min) can be shown on a plot. Prediction of steady state was relatively easy since, besides the inconsistency of changing empty flasks supplying the irrigation solution, there was no other varying parameter other than time interval. Estimation of saturated hydraulic conductivity was done by measuring the volume of water passing through the soil core over a known time interval, these calculations utilised Darcy's Law for saturated flow of water through soil.

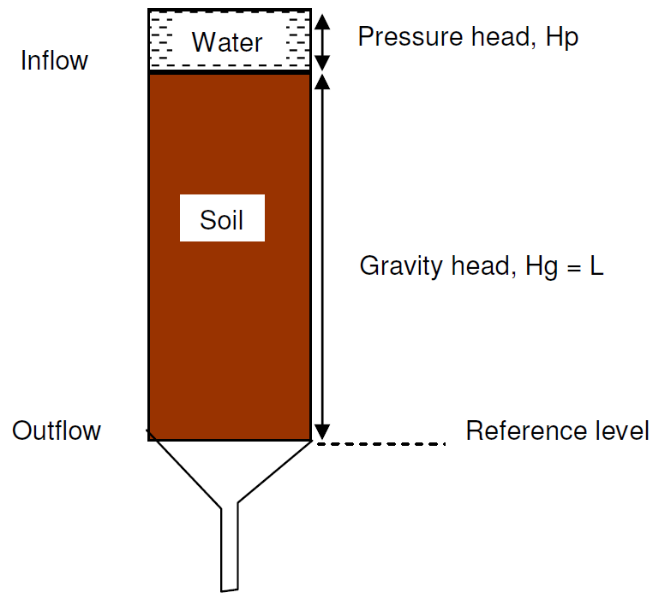


Figure 3.4: Hydraulic conductivity apparatus

Darcy's Law equation: $q = \frac{Q}{At} = \frac{K_{sat} \Delta H}{L}$ ,

where,

q = water flux (cm/min)

t = time interval (min)

Q = rate of discharge ($cm^3$/min)

A = cross sectional area of the soil column ($cm^2$)

$K_{sat}$ = saturated hydraulic conductivity

ΔH = hydrostatic pressure difference from top to bottom of soil column (cm)

L = length of the soil column (cm)

$\frac{\Delta H}{L}$ = hydraulic gradient

Hydraulic head difference (ΔH) = Total head at inflow – Total head at outflow

$$= (Hp - L) - 0$$

$$= Hp + L$$

The apparatus was held in place using retort stands so height was gained for the collection of drainage water from placement of funnels beneath each soil core during the experiments. This is shown clearly in Figure 3.5 below.

Figure 3.5: Hydraulic conductivity apparatus

To measure the hydraulic conductivity under a constant head a retort stand was used along with clamps to firmly hold the soil cores and flasks in position while the experiment was undertaken. A hydraulic head above the soil core surface of 1 cm was used for each setup. Once the solution had passed through the soil core a funnel directed the flow into the measuring cylinders for measurement. An initial volume of water saturated the soil cores before any volume of water could be collected and measured over the initial time interval. The expected result of this is that the initial time interval will have a lower hydraulic conductivity than the subsequent time intervals. Collection of leachate continued till steady state was obtained, for up to two and a half hours on some cores.

The collection of leachate also served another purpose other than to measure the flux and hydraulic conductivity. Each leachate batch was set aside for the measurement of pH and electrical conductivity. It was practically impossible to collect adequate leachate to satisfy the usual factor of pore volume for all soil cores, so this guideline was ignored. The main concern of collecting an adequate volume of leachate was where enough had to be collected to fill the measuring cylinders for determination of pH and electrical conductivity.

### 3.5.3 Physical Properties

Whilst conducting measurements of the saturated hydraulic conductivity an unexpected physical bi-product resulted. Visually noticeable soil colloids accumulated within the collected leachate samples. This contamination was particularly evident within the Toowoomba soil (Red Ferrosol). Colloid contamination was considerably less for the other soils. A method to remove the soil colloids using filter paper was initiated. The decision was made to abandon this method to maintain uniformity within the leachate results. Further information on colloid measurements and results are included in the Results and Discussion chapter and in Appendix H.

### 3.5.4 Chemical Properties of Soil

A range of chemical properties of the soil including exchangeable cations was analysed at a commercial analytical laboratory (SGS Agritech, Toowoomba). This laboratory used the standard methods from Rayment and Higginson (1992) for all chemical analysis.

Once again, three replicate samples of each soil were used for all analyses. From these analyses, the cation exchange capacity (CEC) and the exchangeable sodium percentage (ESP) of the soil was calculated. Sodium adsorption ratio (SAR) was also determined using these results. Cation exchange capacity was the sum of exchangeable cations, Calcium (Ca), Magnesium (Mg), Potassium (K) and Sodium (Na). These data are summarised in the table below.

Table 3.3: Chemical properties of the soils used for testing

| Soil Type | CEC ($mmol_c kg^{-1}$) | ESP (%) | SAR |
|---|---|---|---|
| T | 136.0 | 1.049 | 0.176 |
| B | 115.2 | 1.164 | 0.178 |
| S | 338.0 | 1.105 | 0.295 |

Cation Exchange Capacity (CEC), Exchangeable Sodium Percentage (ESP) and Sodium Adsorption Ratio (SAR) was calculated using the following equations.

$$\text{CEC} = \sum exchangeable\_cations$$

Exchangeable cations are Ca, K, Mg and Na. These values are expressed as $mmol_c kg^{-1}$.

$$\text{ESP} = \frac{Exchangeable\_sodium}{CEC}$$

$$\text{SAR} = \frac{[Na^{+}]}{\sqrt{0.5 \times [Ca^{2+} + Mg^{2+}]}}$$

### 3.5.5 Chemical Properties of Water

Both of the two laundry detergents are of high pH and EC compared to tap water. Powder laundry detergent has a significantly higher SAR than both the tap water and liquid laundry detergent. A summary of the water properties is shown in the table below.

Table 3.4: Chemical properties of water used for testing

| **Type of Irrigation Water** | **pH** | **EC (µS/cm)** | **SAR** |
|---|---|---|---|
| TW | 7.614 | 397.333 | 1.711 |
| PLD | 10.049 | 1243.666 | 68.839 |
| LLD | 9.326 | 247.666 | 9.705 |

Include how leachate was analysed. Leachate was filtered at the SGS Agritech lab using a PVDF membrane filter to remove suspended colloids. This filter is effective at filtering colloids > 45 µm. Collection of data for colloid concentration within the leachate samples was performed for the powder laundry detergent leachate replicates. Visual observation of the leachate during collection instigated this experiment. This involved adding a known volume of unfiltered leachate into an oven dish and weighing. These samples were then put in the oven to dry at 105 °C for twenty four hours. They were again weighed and a concentration of colloids within the leachate was evaluated using the known values of leachate volume that was collected from the hydraulic conductivity experiments. The soil colloid concentrations for the powder laundry detergents are contained within the table below. Further details of these calculations can be found in Appendix H.

Table 3.5: Soil leachate colloid concentration

| Sample | Colloid Concentration ($g.cm^{-3}$) |
|---|---|
| TLP1L | 0.9739 |
| TLP2L | 0.9898 |
| TLP3L | 0.9964 |
| BLP1L | 0.9806 |
| BLP2L | 0.9682 |
| BLP3L | 0.9833 |
| SLP1L | 0.9722 |
| SLP2L | 1.0365 |
| SLP3L | 0.9856 |

# Chapter 4
# Consequential Effects

## 4.1 Risk Assessment

| Hazard | Likelihood | Exposure | Severity | Control |
|---|---|---|---|---|
| **Lab Work** | | | | |
| Slips, trips and falls | Slight | Occasionally | Minor Injury – Bruise or Cut | Ensure floor is kept clear |
| Fire | Very Slight | Very Rare | High – Possible Death | Follow fire evacuation procedures |
| Electricity | Very Slight | Very Rare | High – Possible Death | Don’t interfere with electrical equipment |
| Equipment Damage | Slight | Regularly | Minor Equipment Damage | Get shown how to use equipment |
| Oven Heat | Significant | Regularly | Minor Injury – Burn | Use oven gloves to remove heated equipment |
| Dropping heavy equipment on foot | Slight | Regularly | Minor Injury – Bruise, abrasion | Take care carrying equipment |
| Chemical contact | Slight | Occasionally | Minor Injury – Burns, Irritation | Wash hands after handling chemicals |
| **Soil Sampling** | | | | |
| Sunburn | Significant | Rarely | Minor Injury – Burn | Wear sunscreen, limit exposure |
| Damaging equipment | Very Slight | Rarely | Minor Equipment Damage | Use equipment carefully |
| Repetitive Strain Injury | Significant | Occasionally | Minor Injury | Take regular breaks |

## 4.2 Ethical Responsibility

It is my ethical responsibility to conduct and present the procedures and results of this project without bias. This responsibility extends to the proper referencing of sources of data and opinions to give credit where it is due.

I am responsible for the correct presentation of results and include error relevant to the measurement or calculation.

# Chapter 5
# Results & Discussion

## 5.1 Soil Physical & Chemical Properties

The three soils that were used for these experiments are a Red Ferrosol, Brown Dermosol and an Alluvial Clay. These represented three distinctly separate regions within Queensland, a South East, Coastal and Western Queensland region. As mentioned these soils were sampled from Toowoomba, Bundaberg and Surat.

All values that have been discussed are the mean replicate values for each measurement. Standard error (SE) has been included as the '±' sign, this is indicated after the mean values. Properties of the un-irrigated and irrigated soils included bulk density, pH, EC, CEC, ESP and SAR. These properties are discussed further in the following sections.

### 5.1.1 Soil Compaction

The mean compacted core bulk density of the Toowoomba, Bundaberg and Surat soil types were 1.030 ± 0.004, 1.049 ± 0.002 and 1.030 ± 0.003 g/cm$^3$. All soil core bulk densities were consistent with the highest and lowest bulk density being 1.056 and 1.007 g/cm$^3$ respectively. Appendix D contains all bulk density results recorded during compaction of the soil cores.

### 5.1.2 Soil pH & EC

Soil pH of the unirrigated soil ranged from 7.017 ± 0.0498 µS/cm to 7.203 ± 0.666 µS/cm for the Toowoomba and Surat soils respectively. Generally the pH of the soil increased after irrigation using TW, PLD and LLD. However, the irrigation of the Bundaberg soil with LLD slightly reduced the pH to a value of 7.065 ± 0.303. This is not attributable to any standard error since it was within the limits of all other pH measurements for this experiment. In all but one instance, the irrigation water pH influenced the soil pH relative to the strength of irrigation water pH. For example, an irrigation solution with a high pH resulted in the highest pH increase within the soil after irrigation, and vice versa. The one instance where this did not occur was in the Surat soil PLD irrigation, however overall there was an increase in soil pH above that of the original value.

The Bundaberg soil had the lowest EC of the soils at just 29.50 ± 0.586 µS/cm. Soil EC values after irrigation are indicative of the EC of the irrigation water. Irrigation water with a high EC resulted in soil with a high EC. The Toowoomba soil had the highest soil EC measured of 114.33 ± 7.419 µS/cm when irrigated with the PLD solution. A summary of the soil pH and EC is represented in Table 5.1.

Table 5.1: Soil pH & EC before and after irrigation with TW, PLD and LLD

| | | pH | EC (µS/cm) | SE-pH | SE-EC |
|---|---|---|---|---|---|
| T | Unirrigated | 7.017 | 48.53 | 0.0498 | 1.477 |
| | TW | 7.140 | 52.30 | 0.0428 | 0.643 |
| | PLD | 7.492 | 114.33 | 0.0416 | 7.419 |
| | LLD | 7.396 | 40.67 | 0.0638 | 0.657 |
| | | | | | |
| B | Unirrigated | 7.128 | 29.50 | 0.0193 | 0.586 |
| | TW | 7.224 | 37.33 | 0.0434 | 3.593 |
| | PLD | 7.485 | 64.97 | 0.0265 | 0.328 |
| | LLD | 7.065 | 26.39 | 0.0335 | 0.303 |
| | | | | | |
| S | Unirrigated | 7.203 | 45.10 | 0.0115 | 0.666 |
| | TW | 7.563 | 52.30 | 0.0248 | 0.961 |
| | PLD | 7.624 | 102.13 | 0.0206 | 3.622 |
| | LLD | 7.792 | 68.47 | 0.1392 | 10.874 |

### 5.1.3 Soil CEC, ESP & SAR

A soil high in clay typically has a high CEC than soils at lower clay contents. An exception to this is where soils may have lower clay contents supplemented by higher humus content (Singer & Munns 2006). CEC was highest in the Surat Soil, CEC 338.0 ± 0.3186 $mmol_c$ $kg^{-1}$, and lowest in the Bundaberg soil, CEC 115.2 ± 6.1991 $mmol_c$ $kg^{-1}$. According to Patterson and Graaff (2001), soils with a high CEC are more prone to the deleterious impacts from high sodium than those with a lower CEC.

Singer & Munns (2006) explain that a sodic soil is that which has an ESP of more than 10%. Clay soils having high sodium contents are susceptible to swelling and dispersion, reducing hydraulic conductivity and permeability. Saturated hydraulic conductivity is typically lower than 1 mm/h for clay soils having an ESP > 5% (Hubble 1984). All of the soils examined in these experiments had an ESP < 5%.

The Bundaberg soil had the highest ESP of all soils tested, 1.164 ± 0.1624%. Therefore, none of the three soils tested can be classified as having a high susceptibility to swelling and dispersion in their natural state.

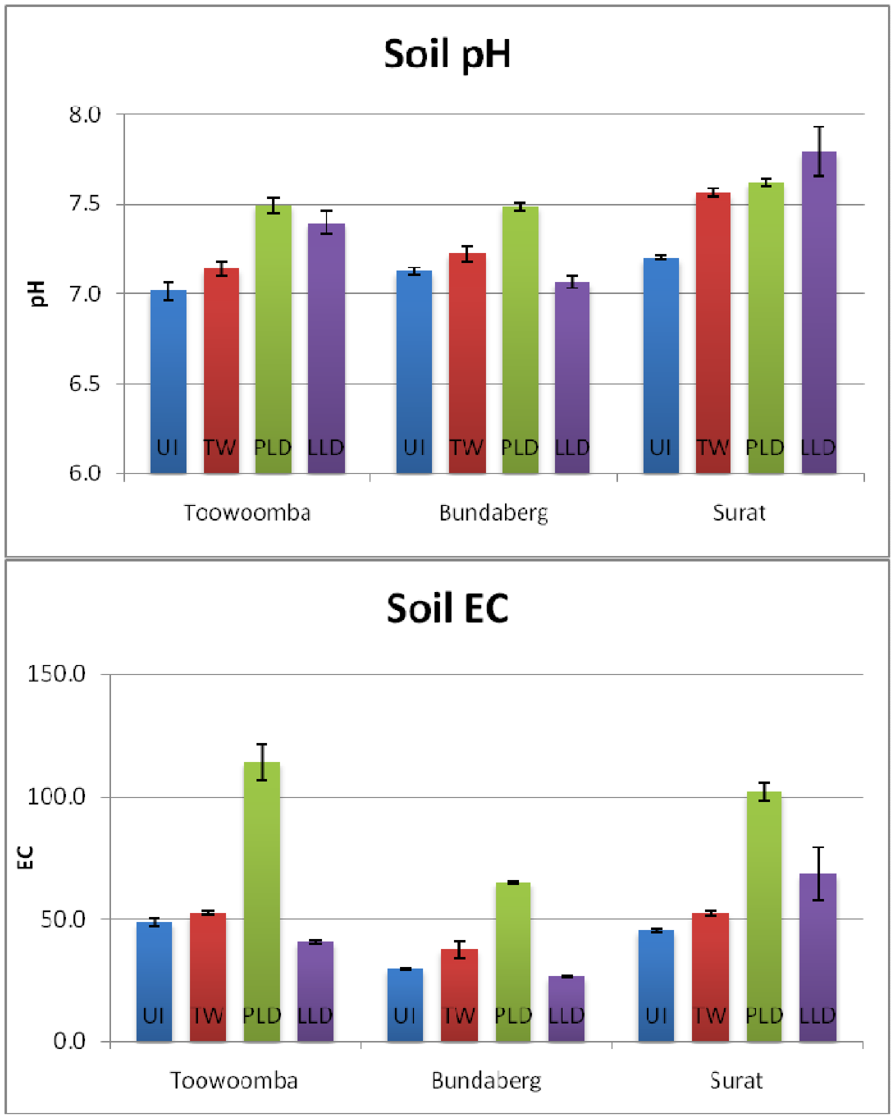


Figure 5.1: Soil pH & EC before and after irrigation

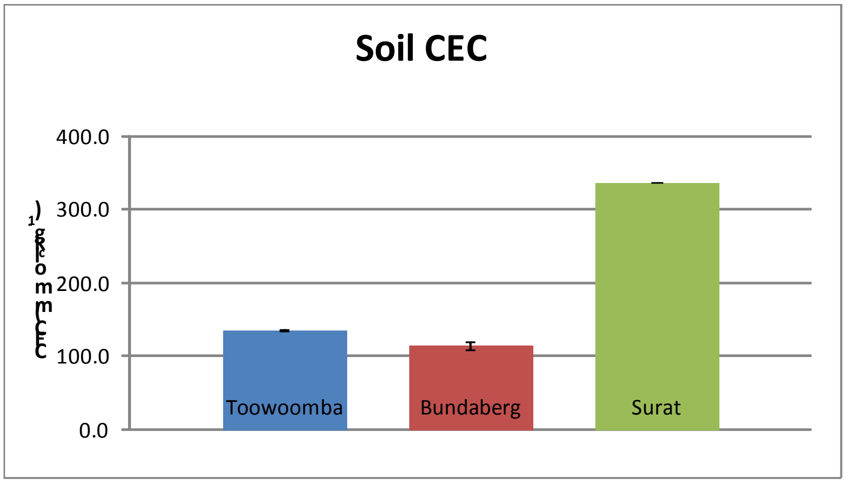


Figure 5.2: Soil CEC (before irrigation)

## 5.2 Saturated Hydraulic Conductivity ($K_{sat}$)

For irrigation of the three soils with the three separate irrigation solutions of tap water, powder laundry detergent and liquid laundry detergent the saturated hydraulic conductivity ($K_{sat}$) was calculated. Firstly there was the flux which is graphed below in the units of cm/min. A second calculation derived the hydraulic conductivity, which is measured in mm/h. The average 25 minute hydraulic conductivity is shown in Figure 5.3. The 25 minute hydraulic conductivity was used as a control measure to allow accurate comparison across each of the soils. A final hydraulic conductivity value was not practical for comparison of the soils due to some of the soil cores blocking up and having a final hydraulic conductivity at or near zero. The percentage reduction in hydraulic conductivity between TW and detergent irrigations are quite significant. The Bundaberg soil exhibited the highest reduction under irrigation of the LLD solution, a reduction in $K_{sat}$ of 98.17% resulted. Irrigation of the soils with both detergents, PLD and LLD, had the consequence of reducing $K_{sat}$ by a minimum of 69.27%. An exception to this observation is where there was an increase in $K_{sat}$ for the Surat soil under irrigation of the PLD solution. Mean values indicate this abnormal value, but this increase in $K_{sat}$ is only observed in one of the three soil core replicates for this irrigation. This is reinforced by the calculated $K_{sat}$ SE of 402.26 mm/h. Several factors would have contributed to this increase in $K_{sat}$, however the formation of flow paths during compaction would be a likely cause of this outlier. Investigation using the discharge per time interval, available in Appendix H, reveals that this soil core exhibited a high discharge for the duration of the hydraulic conductivity experiment compared with its replicates.

Soil structure is disrupted through irrigation with water high in sodium and this usually leads to dispersion. Under these conditions a soil may maintain its soil structure if salt concentration (EC) within the soil or water is at a high enough concentration (Singer & Munns 2006). The PLD irrigation solution has a high sodium concentration and EC and may contribute somewhat to any resiliency the Surat soil has to dispersion and severe reductions in hydraulic conductivity to the degree the other soils experienced. This soil also has the highest CEC of the soils tested and would allow the salts to stabilise soil particles. Table 5.2 outlines the mean 25 minute hydraulic conductivity of each soil and Figure 5.3 compares the hydraulic conductivity across all soil types subjected to each irrigation water type.

Table 5.2: $K_{sat}$ (25 min) of soils & percentage change in comparison with TW

| Toowoomba | | | % Change from TW |
|---|---|---|---|
| | Ksat (25 min) mm/h | SE | |
| TW | 376.59 | 78.12 | |
| PLD | 107.84 | 22.38 | -71.36 |
| LLD | 123.25 | 53.61 | -67.27 |
| | | | |
| **Bundaberg** | | | % Change from TW |
| | Ksat (25 min) mm/h | SE | |
| TW | 450.19 | 97.27 | |
| PLD | 17.12 | 4.53 | -96.20 |
| LLD | 8.23 | 0.45 | -98.17 |
| | | | |
| **Surat** | | | % Change from TW |
| | Ksat (25 min) mm/h | SE | |
| TW | 354.33 | 37.85 | |
| PLD | 453.61 | 402.26 | 28.02 |
| LLD | 130.09 | 50.69 | -63.29 |

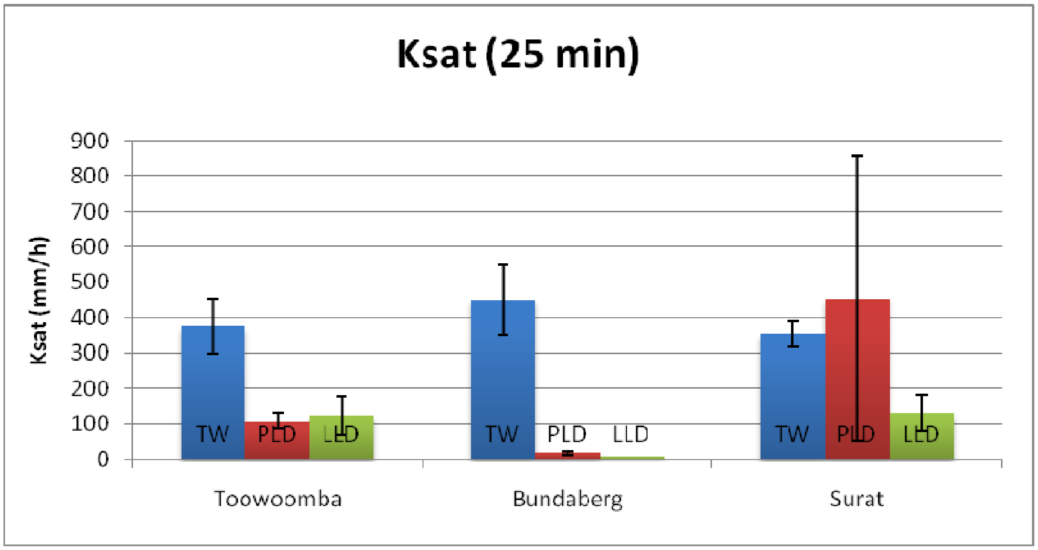


Figure 5.3: $K_{sat}$ (25 min) of soils under irrigation of tap water (TW), powder laundry detergent (PLD) & liquid laundry detergent (LLD) using a constant head

A significant reduction in saturated hydraulic conductivity of all the soil cores, compared to those cores irrigated with tap water, is the result of using either of the two laundry detergent solutions.

Figure 5.4 outlines the average flux over time for the soils irrigated with each of the solutions. The reduction in flux across the entire irrigation time period using laundry detergent further reinforces the hydraulic conductivity data.

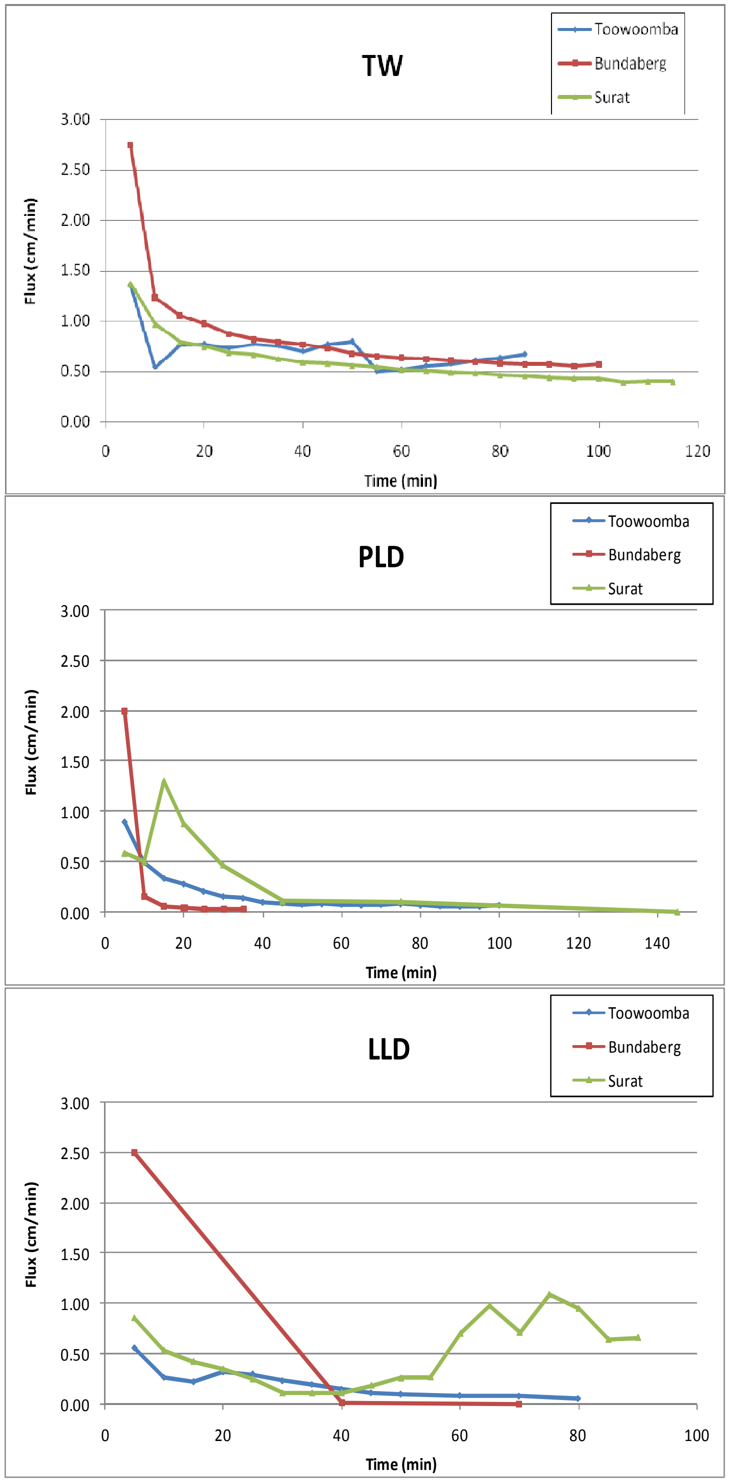


Figure 5.4: Average Soil flux variation during hydraulic conductivity experiments

## 5.3 Properties of Drainage Water

### 5.3.1 Irrigation Water Properties

Samples of the irrigation solutions were set aside for measurement of the pH, EC and SAR. The same laboratory analysis that was applied to the soil leachate samples was also applied to the irrigation solution samples. A photo of these samples in their containers is shown in Figure 5.5.

Figure 5.5: Drainage water samples

Previous research has hypothesised that soil can act as a filtering medium for the purification of water, especially useful is the retainment of salts within the soil (Misra & Sivongxay 2009). The results found from measuring the pH, EC and SAR of the irrigation and drainage water for TW, PLD and LLD support this hypothesis. For the tap water sample a pH of 7.614 ± 0.0218 was measured, this was considered low compared with the laundry detergents. PLD had the highest pH reading of 10.0487 ± 0.0113. The EC of the PLD was some magnitudes higher than that of TW, having an EC of 1243.667 ± 13.932 μS/cm compared to that of TW being 397.33 ± 32.733 μS/cm. Taking into account the SAR of all irrigation solutions, PLD once again had the highest value at 68.839 ± 0.5643, whereas TW and LLD had a low

SAR in comparison, with TW being the lowest, having an SAR of 1.711 ± 0.0271. By looking at the concentrations of sodium to the other exchangeable cations in the irrigation waters, and the relationship between SAR and EC, the PLD solutions have a considerable concentration of sodium salts. In fact sodium is a key ingredient in the powder detergent used for these experiments (Unilever Australasia, Epping).

Changes in soil properties were expected from irrigation with the PLD since it had the highest pH, EC and SAR of all irrigation solutions being applied to the soils. This is considerably different from the initial values of these soil properties.

Table 5.3: Irrigation water pH, EC & SAR

| | pH | SE pH | EC (µS/cm) | SE EC | SAR | SE SAR |
|---|---|---|---|---|---|---|
| TW | 7.6140 | 0.0218 | 397.33 | 32.7329 | 1.711 | 0.0271 |
| PLD | 10.0487 | 0.0113 | 1243.67 | 13.9324 | 68.839 | 0.5643 |
| LLD | 9.3263 | 0.0208 | 247.67 | 4.8419 | 9.705 | 0.6207 |

### 5.3.2 Drainage Water Properties

Considerable changes in pH, EC and SAR between the irrigation water and drainage water were observed. The Toowoomba soil was the most effective at lowering these water properties reducing the PLD irrigation water to a pH of 7.338 ± 0.0913, EC of 529 ± 37.166 µS/cm, and an SAR of 5.5202 ± 1.3004. This soil had the same purifying effect on all irrigation waters. These results are shown in Table 5.4 and Figure 5.6 & 5.7.

Table 5.4: Drainage water pH, EC & SAR

| | pH | SE pH | EC (μS/cm) | SE EC | SAR | SE SAR |
|---|---|---|---|---|---|---|
| TTWL | 7.137 | 0.0413 | 406.00 | 27.934 | 1.3968 | 0.2229 |
| BTWL | 7.270 | 0.0675 | 369.67 | 3.844 | 1.5626 | 0.0236 |
| STWL | 7.710 | 0.1261 | 430.00 | 2.887 | 1.7024 | 0.0093 |
| TLPL | 7.338 | 0.0913 | 529.00 | 37.166 | 5.5202 | 1.3004 |
| BLPL | 8.928 | 0.2768 | 780.00 | 60.583 | 10.7890 | 1.4480 |
| SLPL | 8.539 | 0.6093 | 760.67 | 161.737 | 7.6503 | 4.5543 |
| TLLL | 6.901 | 0.0308 | 141.00 | 11.676 | 1.1077 | 0.2150 |
| BLLL | 7.440 | 0.1145 | 158.33 | 4.055 | 2.4819 | 0.3270 |
| SLLL | 7.223 | 0.2620 | 136.33 | 14.859 | 1.6836 | 0.4923 |

A reduction in sodium concentration occurred within the drainage water compared to before it was applied to the soil. Especially for Toowoomba soil drainage water. Other exchangeable cations of Ca, Mg and K were increased substantially after the laundry detergent irrigation solutions interacted with the soil columns. To a lesser degree, the same changes were found to occur in the tap water. From this information it is hypothesised that the sodium is being exchanged within the soil for other exchangeable cations. These cations of Ca, Mg and K are then displaced into the irrigation solution according to concentration gradients. Taking into account CEC, changes in concentration of each exchangeable cation in the drainage water are proportional to the difference in CEC of the soils. Distinction between these changes in both the Toowoomba and Bundaberg soils is difficult due to their similarity in CEC in comparison with the significantly higher values of CEC for the Surat soil. Variations in replicate results at such low concentrations also contribute to this problem. Contamination of samples at these low concentrations is a highly probably scenario contributing to these slight variations.

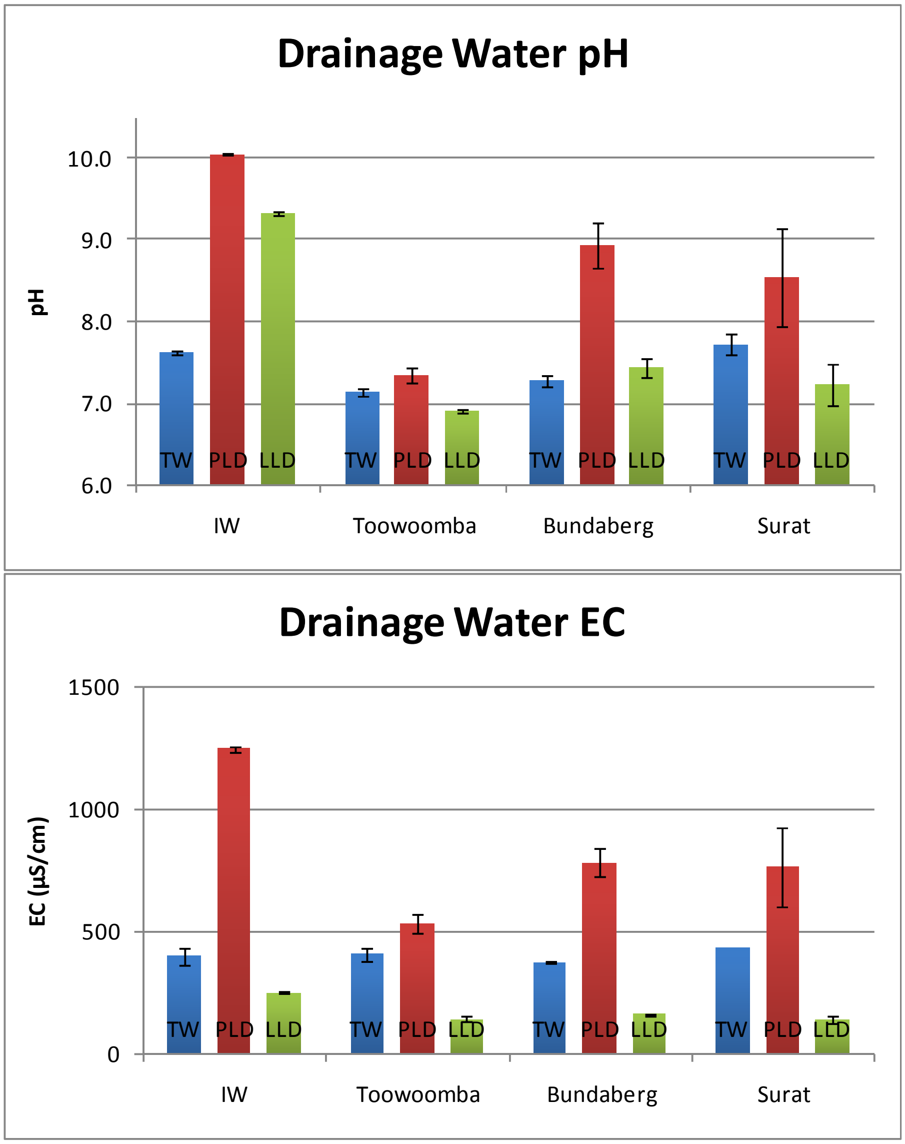


Figure 5.6: Irrigation solution & leachate pH and EC

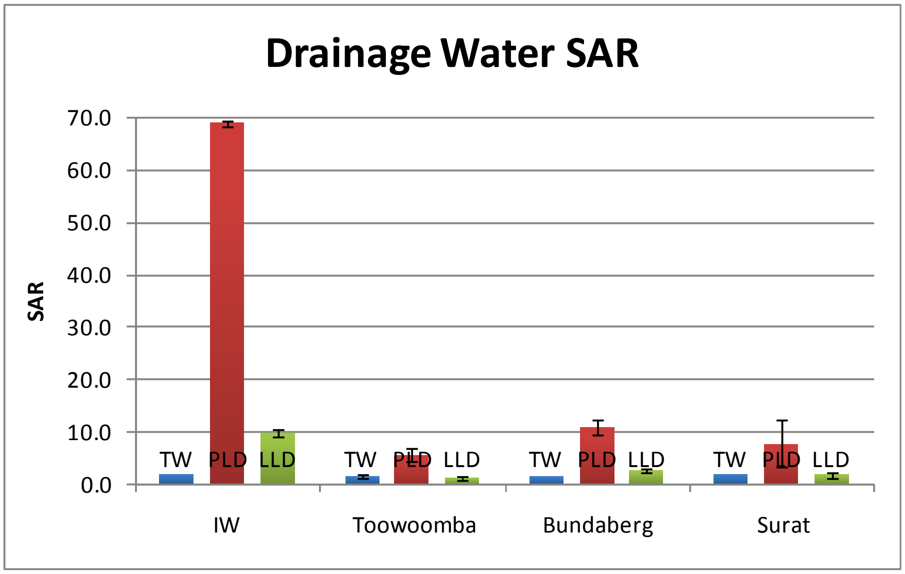


Figure 5.7: Irrigation solution & leachate SAR

### 5.3.3 Concentration of Colloids

Movement of colloids within soils can contribute to a reduction in hydraulic conductivity through the physical blocking of pores, reducing flow paths. The attempts to stop soil colloids from contaminating the drainage water by using fine cloth and filter paper were ineffective. Visual observation of the drainage water, especially for the Toowoomba soil, showed there were unacceptable concentrations of soil colloids. Using the method of dispensing a known volume of drainage water, weighing and oven drying the samples, a concentration of colloids was determined for the PLD set of drainage water. The Surat soil had the highest concentration of soil colloids at 0.9981 ± 0.01961 g/cm$^3$, however all concentrations were reasonably similar. It is particularly interesting that while the Toowoomba soil drainage water had visually noticeable colloid contamination, represented by a deep red colour, the other soils had similar colloid concentrations. Information became available on the filtering methods undertaken during the lab analysis after the PLD drainage water colloid concentration was evaluated. Therefore no other colloid results are available. Details of calculated colloid concentrations can be found in Table 5.5.

Table 5.5: Colloid Concentration of PLD drainage water

| Sample | Total Conc. of Colloids (g/cm$^3$) | Mean | SE (n = 3) |
|---|---|---|---|
| TLP1L | 0.9739 | | |
| TLP2L | 0.9898 | | |
| TLP3L | 0.9964 | 0.9867 | 0.006664 |
| BLP1L | 0.9806 | | |
| BLP2L | 0.9682 | | |
| BLP3L | 0.9833 | 0.9774 | 0.004651 |
| SLP1L | 0.9722 | | |
| SLP2L | 1.0365 | | |
| SLP3L | 0.9856 | 0.9981 | 0.01961 |

Figure 5.8: Visible colloids present in Toowoomba soil PLD drainage water sample

# Chapter 6
# Conclusions & Recommendations

## 6.1 Completion of Objectives

Successful execution of this research project has resulted in the following objectives being achieved:

- Literature relating to the possible effects that laundry greywater may have on the soil and water physical and chemical interactions was reviewed. This review also investigated the purpose of conducting such a research project on greywater reuse, particularly for irrigation of domestic lawns and gardens.

- Three regionally separate soils were obtained for preparation of soil cores to conduct experiments designed to replicate the conditions of a freshly established residential garden bed. Experimental techniques were studied and methods outlined for the successful analysis of all soil and water interactions relevant to hydraulic conductivity through application of prepared solutions to the soils.

- Comparison of pH, EC and chemical characteristics of the soils, tap water and the prepared synthetic greywater made from powder and liquid detergents. Determination of the hydraulic conductivity of each soil according to which solution is applied and investigation of what soil and water characteristics result in changes in hydraulic conductivity.

- Testing of drainage water (leachate) and the soil for changes in pH and EC from application of tap water and synthetic greywater was conducted. Both the drainage water and soil changed significantly in their chemical and physical properties during the hydraulic conductivity experiments.

- Analysis of experimental data to discuss how application of tap water and synthetic greywater affect hydraulic conductivity, pH and EC of the soils used was performed. Experimental data was analysed to enable discussion of how irrigation using tap water and synthetic greywater affect hydraulic conductivity, pH, EC and other physical and chemical properties of the soils.

## 6.2 Summary and Conclusions

This research project was undertaken in an attempt to understand the effects of synthetic laundry greywater on the hydraulic properties of three regionally separate soils each collected from Toowoomba, Bundaberg and Surat.

Hydraulic conductivity is reduced by up to 98% from applying either the powder or liquid laundry detergent synthetic greywater solutions to any of the three soils. The unexpected increase in average hydraulic conductivity of the Surat soil of 28% during irrigation using the powder laundry detergent occurred due to flow paths being created during compaction. This data should therefore be disregarded. The main cause of the reduction in hydraulic conductivity is the high Sodium content present in laundry detergents leading to dispersion of soil aggregates within the soil cores, blocking water flow paths through the soil column.

Observation of soil properties before and after irrigation indicates there are substantial filtering and purification processes occurring within each of the soils. A reduction in Sodium concentrations resulted from this filtering and purification, whereas concentrations of the remaining exchangeable cations of Calcium, Magnesium and Potassium increased in the drainage water. These changes are in comparison to the original irrigation water quality.

Observation of the soil drainage water characteristics (pH, EC & SAR) revealed that the soils acted as a buffer to reduce high pH, EC and SAR, effectively filtering the irrigation water. The exchange of Sodium with other cations within the soil means there is an increase in drainage water quality at the expense of soil quality. High Sodium in soils is linked to dispersion characteristics. Applying this knowledge to the scenario of irrigating lawns and gardens using this quality of synthetic laundry greywater significant dispersion of soil aggregates would occur. This is what contributes to the reduction in hydraulic conductivity.

Possible reclamation of low quality saline and Sodic water through use of soils as a filtering medium is an outcome of irrigating these soils with greywater. Removing the level of hazard this water would have on groundwater. Unfortunately this benefit comes at the cost of destruction of soil structure.

## 6.3 Future Research Recommendations

Future investigation will be necessary to adequately scope the impacts that all aspects of laundry detergents can have on soil properties. There is also the opportunity to assess the effects of laundry detergent irrigation have on the growth of plants. A greater knowledge must be obtained of how to reverse the negative effects on soil hydraulic properties that have been shown within this document. Only that way can we visualize whether supplemented irrigation using greywater is a sustainable practice. The following are a set of recommended directions that future research could investigate:

- Conduct all experiments undertaken to a completely new set of regionally separate soils. This will gauge whether the negative effects of irrigating with synthetic greywater is specific to a set of regional soil types.

- Different irrigation sequences should be run through the soils that have been tested in these experiments. This will reinforce any assumptions of how soils would react to rainfall events after synthetic greywater irrigation.

- The addition of field density soil cores for each of the regional soils tested will facilitate the complete comparison of this research with that done by Amphone Sivonxay in 2005. The scope of this research project omitted any soil field densities and all investigations were based upon using soil of a bulk density similar to that of a freshly cultivated garden bed. This does not allow direct comparison between the results of past research.

- Use of a diverse range of household washing products for irrigation of soil. For example using shower gels, or dishwashing detergents. This will determine if some types of greywater are more suitable than others for domestic irrigation.

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# Appendix A:
# Project Specification

## ENG4111/2 Research Project

## PROJECT SPECIFICATION

| | |
|---|---|
| For: | **Brendan Sankowsky** |
| Topic: | Hydraulic conductivity response of soils to synthetic laundry greywater |
| Supervisor: | Dr Rabi Misra |
| Sponsorship: | Faculty of Engineering & Surveying |
| Project Aim: | Study the physical behaviour of various regional soil types to sustained irrigation with greywater by determining the variation in hydraulic conductivity of these soils when exposed to tap water and synthetic laundry grey water. |

Scope of Project:

- Undertake review of the extent to which laundry greywater can be reused in residential areas for maintaining garden beds and lawns.
- Undertake a literature review to determine the capacity of household washing machines to estimate the ideal concentration of laundry detergents during a wash. Use similar concentration of laundry detergents to prepare synthetic greywater for the experiments.
- Prepare soil cores for 3 types of soils from various regions of varying soil characteristics to simulate the conditions of a recently established residential garden bed.
- Compare pH and EC of tap water and synthetic greywater made from powder and liquid detergents. Use these types of water for infiltration into soil for measurements of hydraulic conductivity of 3 types of soils from various regions of varying soil characteristics.
- Test drainage water (leachate) and the soil for changes in pH and EC from application of tap water and synthetic grey-water.
- Analyse experimental data to discuss how application of tap water and synthetic greywater affect hydraulic conductivity, pH and EC of the soils used.

If time permits:

- Undertake additional measurements to determine the changes in soil water characteristics during wetting (sorption) and drying (desorption).
- Analysis of chemical characteristics of tap water, synthetic greywater, soils and leachates.

AGREED ________________ (student) ________________ (supervisor)

Date: 25/ 3 / 2009 Date: 25 / 3 / 2009

Assistant Examiner: ________________ 30/3/2009. 01/04/09

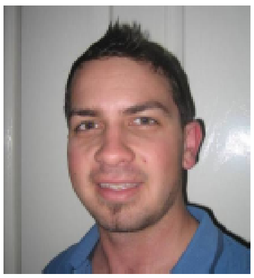
# Appendix B:
# Extended Abstract

Paper number: Own Topic

Course ENG 4903 Professional Practice: Project Conference, 2009

# HYDRAULIC CONDUCTIVITY RESPONSE OF SOILS TO SYNTHETIC LAUNDRY GREYWATER

Sponsorship: University of Southern Queensland



**Brendan SANKOWSKY**

Degree:
Bachelor of Engineering (Environmental)

Supervisor:
Dr Rabi Misra

## 1. INTRODUCTION

Greywater includes all the wastewater produced in a household, excluding the toilet water. Due to the volume and quality of this wastewater, there is a high potential tor reuse this wastewater to supplement household irrigation. There is however some concerns associated with sustained use of this water. With past experimental work focussing on laundry water reuse applied to Toowoomba soils there remains a need to expand this knowledge to new regions, particularly in the western and coastal districts. By examining the hydraulic conductivity response of laundry water on these soils, a better understanding of the viability of using laundry water to supplement domestic irrigation can be obtained.

## 2. AIM

The aim of this project was to study the behaviour of various soil types to sustained irrigation with greywater by determining the variation in hydraulic conductivity of these soils when these are exposed to tap water and synthetic laundry greywater.

## 3. METHOD

- Three soils were sampled from Toowoomba, Bundaberg and Surat.
- Solutions of synthetic greywater was made using laundry detergents and applied to soil cores. Tap water was also applied as control.
- Saturated hydraulic conductivity of soil cores was compared between soils and various infiltrating solutions.
- pH and EC of soil, applied solutions and the drainage water (leachate) was measured.
- Samples of all soil and water were analysed for Na, Ca, Mg and K in a laboratory.
- Results were analysed to discuss how laundry greywater can be applied in a sustainable manner to diverse soils.

## 4. RESULTS AND CONLUSION

Saturated hydraulic conductivity (K) decreased for all the three soils with synthetic greywater (prepared from powder and liquid laundry detergents) compared with tap water. K was in the order Toowoomba > Surat > Bundaberg. After application of synthetic greywater to all soils, pH and EC increased when compared with soil not previously irrigated.

## 5. ACKNOWLEDGEMENT

I would like to thank Dr Rabi Misra for all his help and support throughout the project. I am also grateful to the laboratory technical staff, Dan Eising and Nishant Pradhan for providing the necessary equipment and facilities.

# Appendix C:
# Sample Labels

**Appendix C: Sample Labels**

| Soil Labels | | | |
|---|---|---|---|
| **Soil** | **Water** | **Replicate** | **Label** |
| Toowoomba | Tap | 1 | TTW1 |
| | | 2 | TTW2 |
| | | 3 | TTW3 |
| | Powder | 1 | TLP1 |
| | | 2 | TLP2 |
| | | 3 | TLP3 |
| | Liquid | 1 | TLL1 |
| | | 2 | TLL2 |
| | | 3 | TLL3 |
| Bundaberg | Tap | 1 | BTW1 |
| | | 2 | BTW2 |
| | | 3 | BTW3 |
| | Powder | 1 | BLP1 |
| | | 2 | BLP2 |
| | | 3 | BLP3 |
| | Liquid | 1 | BLL1 |
| | | 2 | BLL2 |
| | | 3 | BLL3 |
| Surat | Tap | 1 | STW1 |
| | | 2 | STW2 |
| | | 3 | STW3 |
| | Powder | 1 | SLP1 |
| | | 2 | SLP2 |
| | | 3 | SLP3 |
| | Liquid | 1 | SLL1 |
| | | 2 | SLL2 |
| | | 3 | SLL3 |

| Water Leachate Labels | | | |
|---|---|---|---|
| **Soil** | **Water** | **Replicate** | **Label** |
| Toowoomba | Tap | 1 | TTW1L |
| | | 2 | TTW2L |
| | | 3 | TTW3L |
| | Powder | 1 | TLP1L |
| | | 2 | TLP2L |
| | | 3 | TLP3L |
| | Liquid | 1 | TLL1L |
| | | 2 | TLL2L |
| | | 3 | TLL3L |
| Bundaberg | Tap | 1 | BTW1L |
| | | 2 | BTW2L |
| | | 3 | BTW3L |
| | Powder | 1 | BLP1L |
| | | 2 | BLP2L |
| | | 3 | BLP3L |
| | Liquid | 1 | BLL1L |
| | | 2 | BLL2L |
| | | 3 | BLL3L |
| Surat | Tap | 1 | STW1L |
| | | 2 | STW2L |
| | | 3 | STW3L |
| | Powder | 1 | SLP1L |
| | | 2 | SLP2L |
| | | 3 | SLP3L |
| | Liquid | 1 | SLL1L |
| | | 2 | SLL2L |
| | | 3 | SLL3L |

# Appendix D:
# Bulk Density, Air Dry Moisture, Plastic Limit & Core Moisture Contents

## Appendix D: Bulk Density & Plastic Limit

Bulk density measurements of Toowoomba Soil

| Soil | Core | Core Diameter (cm) | Core Fill Height (cm) | Core Area ($cm^2$) | Core Fill Volume ($cm^3$) | Core Weight (g) | Core + Soil Weight (g) | Actual Weight of Wet Soil (g) | Average Measured Moisture Content (%) | Required Bulk Density ($g/cm^3$) | Actual Bulk Density ($g/cm^3$) | Actual Oven Dry Soil Weight (g) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Toowoomba | TTW1 | 5.05 | 6 | 20.030 | 120.18 | 48.35 | 210.49 | 162.14 | 29.1 | 1.05 | 1.045 | 125.59 |
| | TTW2 | 5.05 | 6 | 20.030 | 120.18 | 48.71 | 209.02 | 160.31 | 29.1 | 1.05 | 1.033 | 124.18 |
| | TTW3 | 5.05 | 6 | 20.030 | 120.18 | 48.13 | 204.39 | 156.26 | 29.1 | 1.05 | 1.007 | 121.04 |
| | TLP1 | 5.05 | 6 | 20.030 | 120.18 | 48.33 | 211.26 | 162.93 | 31.7 | 1.05 | 1.029 | 123.71 |
| | TLP2 | 5.05 | 6 | 20.030 | 120.18 | 48.70 | 209.41 | 160.71 | 31.7 | 1.05 | 1.015 | 122.03 |
| | TLP3 | 5.05 | 6 | 20.030 | 120.18 | 48.11 | 204.39 | 162.41 | 31.7 | 1.05 | 1.026 | 123.32 |
| | TLL1 | 5.05 | 6 | 20.030 | 120.18 | 48.31 | 210.23 | 161.92 | 29.75 | 1.05 | 1.038 | 124.79 |
| | TLL2 | 5.05 | 6 | 20.030 | 120.18 | 48.69 | 210.58 | 161.89 | 29.75 | 1.05 | 1.038 | 124.77 |
| | TLL3 | 5.05 | 6 | 20.030 | 120.18 | 48.11 | 204.39 | 161.85 | 29.75 | 1.05 | 1.038 | 124.74 |
| | | | | | | | | | | | | |
| **Average Bulk Density per soil ($g/cm^3$)** | | | | | | | | | | | 1.030 | |
| **SE (n = 9)** | | | | | | | | | | | 0.004 | |
| | | | | | | | | | | | | |
| **Average Oven Dry Soil Weight (g)** | | | | | | | | | | | | 123.80 |
| **SE (n = 9)** | | | | | | | | | | | | 0.488 |

Bulk density measurements of Bundaberg Soil

| Soil | Core | Core Diameter (cm) | Core Fill Height (cm) | Core Area (cm²) | Core Fill Volume (cm³) | Core Weight (g) | Core + Soil Weight (g) | Actual Weight of Wet Soil (g) | Average Measured Moisture Content (%) | Required Bulk Density (g/cm³) | Actual Bulk Density (g/cm³) | Actual Oven Dry Soil Weight (g) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bundaberg | BTW1 | 5.05 | 6 | 20.030 | 120.18 | 49.47 | 202.29 | 152.82 | 20.46 | 1.05 | 1.056 | 126.86 |
| | BTW2 | 5.05 | 6 | 20.030 | 120.18 | 50.28 | 203.17 | 152.89 | 20.46 | 1.05 | 1.056 | 126.92 |
| | BTW3 | 5.05 | 6 | 20.030 | 120.18 | 49.17 | 202.11 | 152.94 | 20.46 | 1.05 | 1.056 | 126.96 |
| | BLP1 | 5.05 | 6 | 20.030 | 120.18 | 49.26 | 200.81 | 151.55 | 20.59 | 1.05 | 1.046 | 125.67 |
| | BLP2 | 5.05 | 6 | 20.030 | 120.18 | 50.07 | 201.40 | 151.33 | 20.59 | 1.05 | 1.044 | 125.49 |
| | BLP3 | 5.05 | 6 | 20.030 | 120.18 | 48.97 | 200.49 | 151.52 | 20.59 | 1.05 | 1.046 | 125.65 |
| | BLL1 | 5.05 | 6 | 20.030 | 120.18 | 49.42 | 201.26 | 151.84 | 20.81 | 1.05 | 1.046 | 125.68 |
| | BLL2 | 5.05 | 6 | 20.030 | 120.18 | 50.26 | 202.02 | 151.76 | 20.81 | 1.05 | 1.045 | 125.62 |
| | BLL3 | 5.05 | 6 | 20.030 | 120.18 | 49.15 | 200.95 | 151.80 | 20.81 | 1.05 | 1.046 | 125.65 |
| | | | | | | | | | | | | |
| **Average Bulk Density per soil (g/cm³)** | | | | | | | | | | | 1.049 | |
| **SE (n = 9)** | | | | | | | | | | | 0.002 | |
| | | | | | | | | | | | | |
| **Average Oven Dry Soil Weight (g)** | | | | | | | | | | | | 126.06 |
| **SE (n = 9)** | | | | | | | | | | | | 0.216 |

Bulk density measurements of Surat Soil

| Soil | Core | Core Diameter (cm) | Core Fill Height (cm) | Core Area ($cm^2$) | Core Fill Volume ($cm^3$) | Core Weight (g) | Core + Soil Weight (g) | Actual Weight of Wet Soil (g) | Average Measured Moisture Content (%) | Required Bulk Density ($g/cm^3$) | Actual Bulk Density ($g/cm^3$) | Actual Oven Dry Soil Weight (g) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Surat | STW1 | 5.05 | 6 | 20.030 | 120.18 | 48.82 | 207.49 | 158.67 | 28.68 | 1.05 | 1.026 | 123.31 |
| | STW2 | 5.05 | 6 | 20.030 | 120.18 | 47.52 | 210.35 | 162.83 | 28.68 | 1.05 | 1.053 | 126.54 |
| | STW3 | 5.05 | 6 | 20.030 | 120.18 | 48.21 | 208.10 | 159.89 | 28.68 | 1.05 | 1.034 | 124.25 |
| | SLP1 | 5.05 | 6 | 20.030 | 120.18 | 49.03 | 210.63 | 161.60 | 30.13 | 1.05 | 1.033 | 124.18 |
| | SLP2 | 5.05 | 6 | 20.030 | 120.18 | 47.69 | 208.81 | 161.12 | 30.13 | 1.05 | 1.030 | 123.81 |
| | SLP3 | 5.05 | 6 | 20.030 | 120.18 | 48.39 | 209.79 | 161.40 | 30.13 | 1.05 | 1.032 | 124.03 |
| | SLL1 | 5.05 | 6 | 20.030 | 120.18 | 48.98 | 207.49 | 161.72 | 31.95 | 1.05 | 1.020 | 122.56 |
| | SLL2 | 5.05 | 6 | 20.030 | 120.18 | 47.68 | 210.35 | 161.81 | 31.95 | 1.05 | 1.020 | 122.63 |
| | SLL3 | 5.05 | 6 | 20.030 | 120.18 | 48.38 | 208.10 | 161.77 | 31.95 | 1.05 | 1.020 | 122.60 |
| | | | | | | | | | | | | |
| | | | | | | | | | | **Average Bulk Density per soil ($g/cm^3$)** | 1.030 | |
| | | | | | | | | | | **SE (n = 9)** | 0.003 | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | **Average Oven Dry Soil Weight (g)** | 123.77 |
| | | | | | | | | | | | **SE (n = 9)** | 0.416 |

Soil Air Dry Moisture Content Results

| **Soil Area** | **Dish** | **Replicate** | **Dish + Lid** | **Dish + Lid + Soil (air dry)** | **Soil (moist)** | **Dish + Lid + Soil (oven dry)** | **Soil (oven dry)** | **Moisture Content (%)** |
|---|---|---|---|---|---|---|---|---|
| Toowoomba | M9 | #1 | 41.830 | 55.530 | 13.700 | 55.110 | 13.280 | 3.163 |
| | M76 | #2 | 39.840 | 52.320 | 12.480 | 51.940 | 12.100 | 3.140 |
| | M6 | #3 | 41.100 | 52.040 | 10.940 | 51.710 | 10.610 | 3.110 |
| | | | | | | | | |
| Average Air Dry Moisture Content (%) | | | | | | | | 3.14 |
| SE % (n = 3) | | | | | | | | 0.02 |
| | | | | | | | | |
| Bundaberg | M2 | #1 | 41.300 | 57.680 | 16.380 | 57.420 | 16.120 | 1.613 |
| | M68 | #2 | 39.690 | 51.230 | 11.540 | 51.060 | 11.370 | 1.495 |
| | M77 | #3 | 38.320 | 54.130 | 15.810 | 53.900 | 15.580 | 1.476 |
| | | | | | | | | |
| Average Air Dry Moisture Content (%) | | | | | | | | 1.53 |
| SE % (n = 3) | | | | | | | | 0.04 |
| | | | | | | | | |
| Surat | M19 | #1 | 41.500 | 53.700 | 12.200 | 53.130 | 11.630 | 4.901 |
| | M25 | #2 | 40.970 | 49.380 | 8.410 | 49.010 | 8.040 | 4.602 |
| | M42 | #3 | 41.220 | 53.150 | 11.930 | 52.570 | 11.350 | 5.110 |
| | | | | | | | | |
| Average Air Dry Moisture Content (%) | | | | | | | | 4.87 |
| SE % (n = 3) | | | | | | | | 0.15 |
| | | | | | | | | |

Soil Plastic Limit Determination

| Soil Type | Replicate | Dish + Lid | Dish + Lid + Soil (moist) | Soil (moist) | Dish + Lid + Soil (oven dry) | Soil (oven dry) | Moisture Content (%) |
|---|---|---|---|---|---|---|---|
| Toowoomba | 1 | 41.86 | 72.44 | 30.58 | 65.78 | 23.92 | 27.84 |
| | 2 | 38.32 | 45.63 | 7.31 | 44.02 | 5.70 | 28.25 |
| | 3 | 39.69 | 49.46 | 9.77 | 47.28 | 7.59 | 28.72 |
| | | | | | | | |
| | | Mean Plastic Limit Moisture Content (%) | | | | | 28.27 |
| | | | | SE % (n = 3) | | | 0.25 |
| | | | | | | | |
| | | | | | | | |
| Bundaberg | 1 | 38.37 | 58.86 | 20.49 | 55.55 | 17.18 | 19.27 |
| | 2 | 41.22 | 49.50 | 8.28 | 48.10 | 6.88 | 20.35 |
| | 3 | 40.99 | 50.63 | 9.64 | 48.95 | 7.96 | 21.11 |
| | | | | | | | |
| | | Mean Plastic Limit Moisture Content (%) | | | | | 20.24 |
| | | | | SE % (n = 3) | | | 0.53 |
| | | | | | | | |
| | | | | | | | |
| Surat | 1 | 41.35 | 55.22 | 13.87 | 52.34 | 10.99 | 26.29 |
| | 2 | 41.31 | 52.67 | 11.36 | 50.11 | 8.80 | 29.09 |
| | 3 | 41.51 | 49.78 | 8.27 | 47.90 | 6.39 | 29.42 |
| | | | | | | | |
| | | Mean Plastic Limit Moisture Content (%) | | | | | 28.27 |
| | | | | SE % (n = 3) | | | 0.99 |
| | | | | | | | |

Averaged core moisture contents taken before and after core compaction

| Tap Water Cores | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Sample | Dish | Dish + Lid (g) | Dish + Lid + Wet Soil (g) | Dish + Lid + Oven Dry Soil (g) | Moisture conent (%) | Average Moisture Content (%) |
| Before | Toowoomba | M77 | 38.37 | 77.36 | 68.51 | 29.36 | |
| After | Toowoomba | M26 | 41.31 | 82.14 | 73.00 | 28.84 | 29.10 |
| Before | Bundaberg | M25 | 41.03 | 64.41 | 60.51 | 20.02 | |
| After | Bundaberg | M9 | 41.87 | 69.28 | 64.54 | 20.91 | 20.46 |
| Before | Surat | M31 | 41.57 | 82.68 | 73.78 | 27.63 | |
| After | Surat | M62 | 39.58 | 68.69 | 62.02 | 29.72 | 28.68 |
| | | | | | | | |
| **Powder Laundry Detergent Cores** | | | | | | | |
| | Sample | Dish | Dish + Lid (g) | Dish + Lid + Wet Soil (g) | Dish + Lid + Oven Dry Soil (g) | Moisture conent (%) | Average Moisture Content (%) |
| Before | Toowoomba | M26 | 41.30 | 80.64 | 71.35 | 30.92 | |
| After | Toowoomba | M31 | 41.57 | 98.48 | 84.87 | 31.43 | 31.17 |
| Before | Bundaberg | M9 | 41.88 | 71.23 | 66.19 | 20.73 | |
| After | Bundaberg | M25 | 41.03 | 81.67 | 74.77 | 20.45 | 20.59 |
| Before | Surat | M62 | 39.56 | 82.61 | 72.77 | 29.63 | |
| After | Surat | M77 | 38.37 | 85.06 | 74.11 | 30.64 | 30.13 |
| | | | | | | | |
| **Liquid Laundry Detergent Cores** | | | | | | | |
| | Sample | Dish | Dish + Lid (g) | Dish + Lid + Wet Soil (g) | Dish + Lid + Oven Dry Soil (g) | Moisture conent (%) | Average Moisture Content (%) |
| Before | Toowoomba | M26 | 41.87 | 82.50 | 72.99 | 30.56 | |
| After | Toowoomba | M77 | 38.36 | 75.79 | 67.39 | 28.94 | 29.75 |
| Before | Bundaberg | M9 | 41.30 | 87.68 | 79.66 | 20.91 | |
| After | Bundaberg | M62 | 39.58 | 89.35 | 80.81 | 20.71 | 20.81 |
| Before | Surat | M6 | 41.30 | 87.89 | 75.71 | 35.40 | |
| After | Surat | M45 | 41.12 | 85.84 | 75.92 | 28.51 | 31.95 |
| | | | | | | | |
| Standard Error (SE) | | | | | Toowoomba | | 0.433 |
| | | | | | Bundaberg | | 0.071 |
| | | | | | Surat | | 0.670 |

# Appendix E:
# Calculation of moist soil for cores

**Appendix E: Calculation of moist soil for cores**

Soil compaction calculations (TTW1)

The quantity of moist soil used for compaction of each core was calculated as follows.

1. Core area $= \pi \times \frac{Core\_diameter^2}{4}$

   $= \pi \times \frac{5.05^2}{4}$

   $= 20.030\ cm^2$

2. The desired height of soil column (6 cm) was multiplied by the area to obtain the volume of soil column.

   Soil Vol. $= 6 \times 20.030 = 120.18\ cm^3$

3. A desired bulk density of 1.05 $g/cm^3$ was multiplied by the desired soil volume to derive the weight of oven dry soil required for each core.

   Oven dry soil weight $= 1.05 \times 120.18 = 126.186$ g

4. This weight was adjusted according to the air dry moisture content of the soil. Air dry moisture content of the Toowoomba soil was 3.14%.

   Air dry soil weight $= 126.187 \times (100 + 3.14)/100 = 130.149$ g

5. Weight of soil wet to its plastic limit was calculated. Toowoomba soil had a plastic limit of 28.27% moisture content.

   Plastic limit soil weight $= 28.27 \times$ Oven dry soil weight (per core)

   $= 28.27 \times 126.187 = 161.860$ g

6. The weight of water that has to be added to the air dry soil was determined by subtracting the plastic limit soil weight from the air dry soil weight.

   Water added to air dry soil $= 161.860 - 130.149 = 31.71$ g

7. This weight of water was converted to a volume using 1 g = 1 $cm^3$. A pipette was used to wet each soil with the appropriate volume of water for equilibration overnight. For equilibration and compaction, a safeguard of preparing enough soil for four soil cores of each soil type was used. This ensured adequate soil quantity during compaction.

Soil Compaction

| Soil | Sample | Core Diameter (cm) | Soil Height (cm) | Area (cm²) | Volume (cm³) | Required Bulk Density (g/cm³) | Oven Dry Soil Weight (g) | Avg. Air Dry Moisture Content (%) | Air Dry Soil factor | Weight of Air Dry Soil (g) | Avg. Plastic Limit (%) | Weight of Wet Soil (g) | Weight of Water Added (g) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Toowoomba | TTW1 | 5.05 | 6 | 20.030 | 120.18 | 1.05 | 126.1866 | 3.14 | 1.0314 | 130.1488 | 28.27 | 161.860 | 31.711 |
| | TTW2 | 5.05 | 6 | 20.030 | 120.18 | 1.05 | 126.1866 | 3.14 | 1.0314 | 130.1488 | 28.27 | 161.860 | 31.711 |
| | TTW3 | 5.05 | 6 | 20.030 | 120.18 | 1.05 | 126.1866 | 3.14 | 1.0314 | 130.1488 | 28.27 | 161.860 | 31.711 |
| | | | | | | | | | | | | | |
| Total weights used for equilibration of soil moisture before compaction (g) 4x moist core weight | | | | | | | | | | 520.5954 | | 647.4381 | 126.8428 |
| | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| Bundaberg | BTW1 | 5.05 | 6 | 20.030 | 120.18 | 1.05 | 126.1866 | 1.53 | 1.0153 | 128.1172 | 20.24 | 151.727 | 23.610 |
| | BTW2 | 5.05 | 6 | 20.030 | 120.18 | 1.05 | 126.1866 | 1.53 | 1.0153 | 128.1172 | 20.24 | 151.727 | 23.610 |
| | BTW3 | 5.05 | 6 | 20.030 | 120.18 | 1.05 | 126.1866 | 1.53 | 1.0153 | 128.1172 | 20.24 | 151.727 | 23.610 |
| | | | | | | | | | | | | | |
| Total weights used for equilibration of soil moisture before compaction (g) 4x moist core weight | | | | | | | | | | 512.469 | | 606.907 | 94.43804 |
| | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| Surat | STW1 | 5.05 | 6 | 20.030 | 120.18 | 1.05 | 126.1866 | 4.87 | 1.0487 | 132.3319 | 28.27 | 161.860 | 29.528 |
| | STW2 | 5.05 | 6 | 20.030 | 120.18 | 1.05 | 126.1866 | 4.87 | 1.0487 | 132.3319 | 28.27 | 161.860 | 29.528 |
| | STW3 | 5.05 | 6 | 20.030 | 120.18 | 1.05 | 126.1866 | 4.87 | 1.0487 | 132.3319 | 28.27 | 161.860 | 29.528 |
| | | | | | | | | | | | | | |
| Total weights used for equilibration of soil moisture before compaction (g) 4x moist core weight | | | | | | | | | | 529.3275 | | 647.4381 | 118.1106 |
| | | | | | | | | | | | | | |

# Appendix F:
# Soil pH, EC & Chemical Results

## Appendix F: Soil pH, EC & Chemical Results

Soil pH for Un-irrigated and Irrigated Soil

| | | **pH** | **EC** | **Mean values** | | **SE (n = 3)** | |
|---|---|---|---|---|---|---|---|
| | | | (□S/cm) | pH | EC | pH | EC |
| **Toowoomba Soil** | T1 | 7.112 | 49.7 | | | | |
| | T2 | 6.997 | 50.3 | | | | |
| | T3 | 6.943 | 45.6 | 7.02 | 48.53 | 0.05 | 1.48 |
| | TTW1 | 7.225 | 53.3 | | | | |
| | TTW2 | 7.103 | 51.1 | | | | |
| | TTW3 | 7.091 | 52.5 | 7.14 | 52.30 | 0.04 | 0.64 |
| | TLP1 | 7.411 | 99.5 | | | | |
| | TLP2 | 7.516 | 122.1 | | | | |
| | TLP3 | 7.549 | 121.4 | 7.49 | 114.33 | 0.04 | 7.42 |
| | TLL1 | 7.49 | 41 | | | | |
| | TLL2 | 7.274 | 41.6 | | | | |
| | TLL3 | 7.423 | 39.4 | 7.40 | 40.67 | 0.06 | 0.66 |
| **Bundaberg Soil** | B1 | 7.162 | 29.7 | | | | |
| | B2 | 7.095 | 28.4 | | | | |
| | B3 | 7.127 | 30.4 | 7.13 | 29.50 | 0.02 | 0.59 |
| | BTW1 | 7.14 | 44.5 | | | | |
| | BTW2 | 7.249 | 34.2 | | | | |
| | BTW3 | 7.284 | 33.3 | 7.22 | 37.33 | 0.04 | 3.59 |
| | BLP1 | 7.527 | 64.5 | | | | |
| | BLP2 | 7.492 | 65.6 | | | | |
| | BLP3 | 7.436 | 64.8 | 7.49 | 64.97 | 0.03 | 0.33 |
| | BLL1 | 7.012 | 27 | | | | |
| | BLL2 | 7.127 | 26.1 | | | | |
| | BLL3 | 7.056 | 26.08 | 7.07 | 26.39 | 0.03 | 0.30 |
| **Surat Soil** | S1 | 7.198 | 46.0 | | | | |
| | S2 | 7.186 | 43.8 | | | | |
| | S3 | 7.225 | 45.5 | 7.20 | 45.10 | 0.01 | 0.67 |
| | STW1 | 7.517 | 54.2 | | | | |
| | STW2 | 7.571 | 51.1 | | | | |
| | STW3 | 7.602 | 51.6 | 7.56 | 52.30 | 0.02 | 0.96 |
| | SLP1 | 7.583 | 101.5 | | | | |
| | SLP2 | 7.642 | 108.7 | | | | |
| | SLP3 | 7.647 | 96.2 | 7.62 | 102.13 | 0.02 | 3.62 |
| | SLL1 | 8.065 | 90.2 | | | | |
| | SLL2 | 7.701 | 58.3 | | | | |
| | SLL3 | 7.609 | 56.9 | 7.79 | 68.47 | 0.14 | 10.87 |

Summarized Lab Results for Un-irrigated Soil Chemical

| | **Soil Type** | **Toowoomba** | | | **Bundaberg** | | | **Surat** | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Sample | **T1** | **T2** | **T3** | **B1** | **B2** | **B3** | **S1** | **S2** | **S3** |
| **Major Elements** | | | | | | | | | | |
| Potassium | mg/kg | 90 | 78 | 77 | 89 | 50 | 32 | 313 | 315 | 312 |
| **Secondary Elements** | | | | | | | | | | |
| Calcium | mg/kg | 1800 | 1812 | 1839 | 1767 | 1507 | 1527 | 4224 | 4206 | 4200 |
| Magnesium | mg/kg | 481 | 488 | 502 | 419 | 364 | 367 | 1345 | 1345 | 1340 |
| **Salinity** | | | | | | | | | | |
| Sodium | mg/kg | 60 | 49 | 58 | 42 | 58 | 55 | 138 | 139 | 161 |
| **Exchangeable Cations** | | | | | | | | | | |
| Ca/Mg Ratio | | 2.25 | 2.23 | 2.2 | 2.53 | 2.48 | 2.5 | 1.88 | 1.88 | 1.88 |
| Cation Exchange | | 13.5 | 13.54 | 13.83 | 12.74 | 10.96 | 11.01 | 33.73 | 33.65 | 33.67 |
| Exchangeable Calcium | meq/100g | 9 | 9.06 | 9.2 | 8.84 | 7.54 | 7.63 | 21.12 | 21.03 | 21 |
| Exchangeable Calcium Percent % | | 66.7 | 66.9 | 66.5 | 69.4 | 68.8 | 69.3 | 62.6 | 62.5 | 62.4 |
| Exchangeable Magnesium | meq/100g | 4.01 | 4.07 | 4.18 | 3.49 | 3.04 | 3.06 | 11.21 | 11.21 | 11.17 |
| Exchangeable Magnesium Percent % | | 29.7 | 30 | 30.3 | 27.4 | 27.7 | 27.8 | 33.2 | 33.3 | 33.2 |
| Exchangeable Potassium | meq/100g | 0.23 | 0.2 | 0.2 | 0.23 | 0.13 | 0.08 | 0.8 | 0.81 | 0.8 |
| Exchangeable Potassium Percent % | | 1.7 | 1.5 | 1.4 | 1.8 | 1.2 | 0.7 | 2.4 | 2.4 | 2.4 |
| Exchangeable Sodium | meq/100g | 0.26 | 0.21 | 0.25 | 0.18 | 0.25 | 0.24 | 0.6 | 0.6 | 0.7 |
| Exchangeable Sodium Percent % | | 1.9 | 1.6 | 1.8 | 1.4 | 2.3 | 2.2 | 1.8 | 1.8 | 2.1 |

Refined Un-irrigated Soil Chemical Results

| | Sample | Potassium | Calcium | Magnesium | Sodium |
|---|---|---|---|---|---|
| | | **$mmol_c kg^{-1}$** | **$mmol_c kg^{-1}$** | **$mmol_c kg^{-1}$** | **$mmol_c kg^{-1}$** |
| **Toowoomba** | T1 | 3.9 | 89.8 | 39.6 | 1.5 |
| | T2 | 3.4 | 90.4 | 40.1 | 1.3 |
| | T3 | 3.4 | 91.8 | 41.3 | 1.5 |
| **Bundaberg** | B1 | 3.9 | 88.2 | 34.5 | 1.1 |
| | B2 | 2.2 | 75.2 | 29.9 | 1.5 |
| | B3 | 1.4 | 76.2 | 30.2 | 1.4 |
| **Surat** | S1 | 13.6 | 210.8 | 110.7 | 3.5 |
| | S2 | 13.7 | 209.9 | 110.7 | 3.6 |
| | S3 | 13.6 | 209.6 | 110.2 | 4.1 |

CEC, ESP & SAR Results for Un-irrigated Soil Samples

| **CEC** | **Mean** | **SE** | | **ESP** | **Mean** | **SE** | | **SAR** | **Mean** | **SE** |
|---|---|---|---|---|---|---|---|---|---|---|
| **$mmol_ckg^{-1}$** | **CEC** | | | **%** | **ESP** | | | | **SAR** | |
| 134.8 | | | | 1.138 | | | | 0.191 | | |
| 135.2 | | | | 0.927 | | | | 0.155 | | |
| 137.9 | 136.0 | 0.9631 | | 1.076 | 1.047 | 0.0626 | | 0.182 | 0.176 | 0.0107 |
| 127.6 | | | | 0.842 | | | | 0.137 | | |
| 108.8 | | | | 1.363 | | | | 0.205 | | |
| 109.2 | 115.2 | 6.1991 | | 1.288 | 1.164 | 0.1628 | | 0.193 | 0.178 | 0.0208 |
| 338.6 | | | | 1.042 | | | | 0.278 | | |
| 337.8 | | | | 1.052 | | | | 0.281 | | |
| 337.5 | 338.0 | 0.3186 | | 1.220 | 1.105 | 0.0576 | | 0.326 | 0.295 | 0.0154 |

# Appendix G: Washing Machine Review & Laundry Detergent Concentrations

## Appendix G: Washing Machine Review & Laundry Detergent Concentrations

Front Loader Washing Machine Capacities

| Front Loader | | | |
|---|---|---|---|
| **Brand** | **Model** | **Type** | **Water used per 'normal' wash (L)** |
| **UP TO 5.5 KG** | | | |
| Miele | Novotronic W1511 | Front | 47 |
| Simpson | Eziloader 45S558E | Front | 62 |
| **6 - 7 KG** | | | |
| Asko | Quattro W6362 1600 rpm | Front | 64 |
| Miele | Honeycomb Care W3725 | Front | 50 |
| Blanco | BFW712 | Front | 61 |
| Blanco | BFW716 | Front | 61 |
| AEG Electrolux | Lavamat L74800 | Front | 60 |
| Asko | Quattro W6342 | Front | 53 |
| Miele | Honeycomb Care W1712 | Front | 51 |
| AEG | L62800 | Front | 61 |
| Asko | Quattro W6222 1200 rpm | Front | 52 |
| Bosch | Maxx Lifestyle WAE22460AU 1100 rpm (A) | Front | 64 |
| Electrolux | Eco Valve EWF1087 | Front | 61 |
| Simpson | Eziloader 45S710E | Front | 61 |
| **7.5 KG OR LARGER** | | | |
| Electrolux | Ultra Silencer EWF1495 | Front | 73 |
| LG | Inverter WD-1238C | Front | 67 |
| Bosch | Logixx 8 WAS32740AU | Front | 62 |
| Whirlpool | WFS1273AW | Front | 60 |
| Maytag | MAF8512AAW | Front | 73 |
| Whirlpool | WFS1285AW | Front | 73 |
| Whirlpool | WFS1071AW-7.5kg Antibacterial | Front | 59 |
| Whirlpool | WFS1072AW | Front | 59 |
| Ariston | Aqualtis AQXXD 149H | Front | 58 |
| Indesit | Moon Smart Solutions SIXL126 | Front | 54 |
| | | | |
| **Average Washing Machine Water Usage per 'normal' Wash (litres)** | | | **60.2500** |
| | | | |
| **Round to approximate volume (litres)** | | | **60** |

Top Loader Washing Machine Capacities

| Top Loader | | | |
|---|---|---|---|
| **Brand** | **Model** | **Type** | **Water used per 'normal' wash (L)** |
| **UP TO 5.5 KG** | | | |
| Fisher & Paykel | MW512 | Top / agitator | 132 |
| Fisher & Paykel | GW512 | Top / agitator | 131 |
| Simpson | Eziset 36S550M | Top / agitator | 115 |
| **6 - 7 KG** | | | |
| Fisher & Paykel | GW612 | Top / agitator | 157 |
| Fisher & Paykel | Aquasmart WL70T60C | Top / impeller | 66 |
| Fisher & Paykel | Aquasmart WL70T60D | Top / impeller | 66 |
| LG | Fuzzy Logic TurboDrum WF-T657 | Top / impeller | 164 |
| **7.5 KG OR LARGER** | | | |
| Fisher & Paykel | Aquasmart WL80T65CW1 | Top / impeller | 76 |
| Fisher & Paykel | Aquasmart WL80T65DW1 | Top / impeller | 76 |
| Whirlpool | 6ALSQ8000MW3 | Top / agitator | 157 |
| Whirlpool | 6ALSR7144MW3 | Top / agitator | 157 |
| Simpson | Ezisensor SWT955SA | Top / agitator | 92 |
| Electrolux | Water Aid EWT806 8kg | Top / agitator | 79 |
| Simpson | Eziset 750 22S750M | Top / agitator | 113 |
| | | | |
| **Average Washing Machine Water Usage per 'normal' Wash (litres)** | | | **112.9286** |
| | | | |
| **Round to approximate volume (litres)** | | | **113** |

Powder & Liquid Laundry Detergent Concentrations

| Powder (Front Loader) | | | | |
|---|---|---|---|---|
| | Replicate Measurements | | | |
| Weights (g) | #1 | #2 | #3 | Average |
| Scoop | 7.922 | 7.911 | 7.915 | 7.916 |
| Scoop + Powder | 94.565 | 94.758 | 93.572 | 94.299 |
| Powder | 86.643 | 86.847 | 85.657 | 86.382 |
| | | | | |
| Approx. Average Volume of Water per Wash (L) | 60 | | | |
| Approx. Average Weight of Powder per Wash (g) | 86.38 | | | |
| Concentration of Detergent in Water (g/L) | 1.44 | | | |
| | | | | |
| | | | | |
| Liquid (Top Loader) | | | | |
| | Replicate Measurements | | | |
| Weights (g) | #1 | #2 | #3 | Average |
| Cup | 13.458 | 13.267 | 13.259 | 13.328 |
| Cup + Liquid | 68.582 | 67.984 | 69.171 | 68.579 |
| Cup + Liquid Detergent | | | | 83.297 |
| Liquid - Water | 55.124 | 54.717 | 55.912 | 55.251 |
| Liquid Detergent/Cap (g) | | | | 69.969 |
| | | | | |
| Approx. Average Volume of Water per Wash (L) | 113 | | | |
| Approx. Average Weight of Liquid per Wash (g) | 69.97 | | | |
| Concentration of Detergent in Water (g/L) | 0.62 | | | |
| | | | | |
| Volume Calculated (mL) | 55.124 | 54.717 | 55.912 | 55.251 |
| Volume Measured - Water (mL) | 56.0 | 55.1 | 56.0 | 55.7 |

# Appendix H:
# Flux, $K_{sat}$, pH, EC, Colloid Concentration & Chemical Results of Leachate

# Appendix H: Flux, $K_{sat}$, pH, EC & Chemical Results of Leachate

Final Flux & Hydraulic Conductivity Results for all Soil Cores

| | | TTW1 | TTW2 | TTW3 | BTW1 | BTW2 | BTW3 | STW1 | STW2 | STW3 |
|---|---|---|---|---|---|---|---|---|---|---|
| t | min | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 |
| Average | mL/interval | 56 | 69 | 63 | 75.25 | 65 | 29.75 | 51.5 | 41 | 29.5 |
| Q | cm3/min | 11.2 | 13.8 | 12.6 | 15.05 | 13 | 5.95 | 10.3 | 8.2 | 5.9 |
| q | cm/min | 0.028 | 0.034 | 0.031 | 0.038 | 0.032 | 0.015 | 0.026 | 0.020 | 0.015 |
| Ksat | cm/min | 0.024 | 0.030 | 0.027 | 0.032 | 0.028 | 0.013 | 0.022 | 0.018 | 0.013 |
| Ksat | mm/h | 14.379 | 17.717 | 16.176 | 19.321 | 16.690 | 7.639 | 13.223 | 10.527 | 7.574 |
| | | | | | | | | | | |
| | | TLP1 | TLP2 | TLP3 | BLP1 | BLP2 | BLP3 | SLP1 | SLP2 | SLP3 |
| t | min | 20 | 20 | 20 | 20 | 20 | 20 | 125 | 60 | 125 |
| Average | mL/interval | 36 | 25 | 19 | 11 | 19 | 9 | 47 | 762 | 42 |
| Q | cm3/min | 1.8 | 1.25 | 0.95 | 0.55 | 0.95 | 0.45 | 0.376 | 12.7 | 0.336 |
| q | cm/min | 0.004 | 0.003 | 0.002 | 0.001 | 0.002 | 0.001 | 0.000 | 0.011 | 0.000 |
| Ksat | cm/min | 0.004 | 0.003 | 0.002 | 0.001 | 0.002 | 0.001 | 0.000 | 0.009 | 0.000 |
| Ksat | mm/h | 2.311 | 1.605 | 1.220 | 0.706 | 1.220 | 0.578 | 0.077 | 5.435 | 0.069 |
| | | | | | | | | | | |
| | | TLL1 | TLL2 | TLL3 | BLL1 | BLL2 | BLL3 | SLL1 | SLL2 | SLL3 |
| t | min | 35 | 20 | 35 | 75 | 70 | 75 | 30 | 20 | 40 |
| Average | mL/interval | 48 | 50 | 47 | 47.5 | 57.5 | 90.5 | 45 | 338 | 43 |
| Q | cm3/min | 1.371 | 2.500 | 1.343 | 0 | 0 | 0 | 1.500 | 16.900 | 1.075 |
| q | cm/min | 0.002 | 0.006 | 0.002 | 0 | 0 | 0 | 0.002 | 0.042 | 0.001 |
| Ksat | cm/min | 0.002 | 0.005 | 0.002 | 0 | 0 | 0 | 0.002 | 0.036 | 0.001 |
| Ksat | mm/h | 1.006 | 3.210 | 0.985 | 0 | 0 | 0 | 1.284 | 21.696 | 0.690 |

Toowoomba Soil, TW Irrigation, Flux, 25 minute Hydraulic Conductivity Results & Total Drainage Water Volume for all Soil Cores

| TTW1 | | | | | TTW2 | | | | | TTW3 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Discharge Q (cm³) | Difference per Interval (mL) | Time Period (min) | Elapsed Time (min) | Flux (cm/min) | Discharge Q (cm³) | Difference per Interval (mL) | Time Period (min) | Elapsed Time (min) | Flux (cm/min) | Discharge Q (cm³) | Difference per Interval (mL) | Time Period (min) | Elapsed Time (min) | Flux (cm/min) | Average Flux (cm/min) |
| 0 | 0 | 5 | 0 | 0.00 | 0 | 0 | 5 | 0 | 0.00 | 0 | 0 | 5 | 0 | 0.00 | 0.00 |
| 0 | 0 | 5 | 5 | 0.00 | 205 | 205 | 5 | 5 | 2.05 | 203 | 203 | 5 | 5 | 2.03 | 1.36 |
| 10 | 10 | 5 | 10 | 0.10 | 76 | -129 | 5 | 10 | 0.76 | 78 | -125 | 5 | 10 | 0.78 | 0.55 |
| 22 | 12 | 5 | 15 | 0.22 | 105 | 29 | 5 | 15 | 1.05 | 102 | 24 | 5 | 15 | 1.02 | 0.76 |
| 33 | 11 | 5 | 20 | 0.33 | 101 | -4 | 5 | 20 | 1.01 | 99 | -3 | 5 | 20 | 0.99 | 0.78 |
| 44 | 11 | 5 | 25 | 0.44 | 95 | -6 | 5 | 25 | 0.95 | 81 | -18 | 5 | 25 | 0.81 | 0.73 |
| 55 | 11 | 5 | 30 | 0.55 | 94 | -1 | 5 | 30 | 0.94 | 83 | 2 | 5 | 30 | 0.83 | 0.77 |
| 66 | 11 | 5 | 35 | 0.66 | 83 | -11 | 5 | 35 | 0.83 | 78 | -5 | 5 | 35 | 0.78 | 0.76 |
| 77 | 11 | 5 | 40 | 0.77 | 76 | -7 | 5 | 40 | 0.76 | 58 | -20 | 5 | 40 | 0.58 | 0.70 |
| 87 | 10 | 5 | 45 | 0.87 | 76 | 0 | 5 | 45 | 0.76 | 69 | 11 | 5 | 45 | 0.69 | 0.77 |
| 97 | 10 | 5 | 50 | 0.97 | 75 | -1 | 5 | 50 | 0.75 | 69 | 0 | 5 | 50 | 0.69 | 0.80 |
| 11 | 11 | 5 | 55 | 0.11 | 73 | -2 | 5 | 55 | 0.73 | 68 | -1 | 5 | 55 | 0.68 | 0.51 |
| 21 | 10 | 5 | 60 | 0.21 | 72 | -1 | 5 | 60 | 0.72 | 64 | -4 | 5 | 60 | 0.64 | 0.52 |
| 31 | 10 | 5 | 65 | 0.31 | 73 | 1 | 5 | 65 | 0.73 | 64 | 0 | 5 | 65 | 0.64 | 0.56 |
| 41 | 10 | 5 | 70 | 0.41 | 69 | -4 | 5 | 70 | 0.69 | 64 | 0 | 5 | 70 | 0.64 | 0.58 |
| 51 | 10 | 5 | 75 | 0.51 | 69 | 0 | 5 | 75 | 0.69 | 64 | 0 | 5 | 75 | 0.64 | 0.61 |
| 61 | 10 | 5 | 80 | 0.61 | 69 | 0 | 5 | 80 | 0.69 | 62 | -2 | 5 | 80 | 0.62 | 0.64 |
| 71 | 10 | 5 | 85 | 0.71 | 69 | 0 | 5 | 85 | 0.69 | 62 | 0 | 5 | 85 | 0.62 | 0.67 |
| | | | | | | | | | | | | | | | |
| | | Ksat (25min) mm/h | | 225.95 | | | Ksat (25min) mm/h | | 487.85 | | | Ksat (25min) mm/h | | 415.96 | |
| | | Total Volume ($cm^3$) | | 778 | | | Total Volume ($cm^3$) | | 1480 | | | Total Volume ($cm^3$) | | 1368 | |

Bundaberg Soil, TW Irrigation, Flux, 25 minute Hydraulic Conductivity Results & Total Drainage Water Volume for all Soil Cores

| BTW1 | | | | | BTW2 | | | | | BTW3 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Discharge Q ($cm^3$) | Difference per Interval (mL) | Time Period (min) | Elapsed Time (min) | Flux (cm/min) | Discharge Q ($cm^3$) | Difference per Interval (mL) | Time Period (min) | Elapsed Time (min) | Flux (cm/min) | Discharge Q ($cm^3$) | Difference per Interval (mL) | Time Period (min) | Elapsed Time (min) | Flux (cm/min) | Average Flux (cm/min) |
| 0 | 0 | 5 | 0 | 0.00 | 0 | 0 | 5 | 0 | 0.00 | 0 | 0 | 5 | 0 | 0.00 | 0.00 |
| 200 | 200 | 5 | 5 | 2.00 | 410 | 410 | 5 | 5 | 4.09 | 215 | 215 | 5 | 5 | 2.15 | 2.75 |
| 130 | -70 | 5 | 10 | 1.30 | 153 | -257 | 5 | 10 | 1.53 | 88 | -127 | 5 | 10 | 0.88 | 1.23 |
| 120 | -10 | 5 | 15 | 1.20 | 120 | -33 | 5 | 15 | 1.20 | 77 | -11 | 5 | 15 | 0.77 | 1.06 |
| 119 | -1 | 5 | 20 | 1.19 | 105 | -15 | 5 | 20 | 1.05 | 69 | -8 | 5 | 20 | 0.69 | 0.98 |
| 110 | -9 | 5 | 25 | 1.10 | 103 | -2 | 5 | 25 | 1.03 | 50 | -19 | 5 | 25 | 0.50 | 0.88 |
| 108 | -2 | 5 | 30 | 1.08 | 93 | -10 | 5 | 30 | 0.93 | 46 | -4 | 5 | 30 | 0.46 | 0.82 |
| 106 | -2 | 5 | 35 | 1.06 | 89 | -4 | 5 | 35 | 0.89 | 44 | -2 | 5 | 35 | 0.44 | 0.80 |
| 100 | -6 | 5 | 40 | 1.00 | 87 | -2 | 5 | 40 | 0.87 | 44 | 0 | 5 | 40 | 0.44 | 0.77 |
| 99 | -1 | 5 | 45 | 0.99 | 79 | -8 | 5 | 45 | 0.79 | 42 | -2 | 5 | 45 | 0.42 | 0.73 |
| 94 | -5 | 5 | 50 | 0.94 | 75 | -4 | 5 | 50 | 0.75 | 35 | -7 | 5 | 50 | 0.35 | 0.68 |
| 87 | -7 | 5 | 55 | 0.87 | 76 | 1 | 5 | 55 | 0.76 | 33 | -2 | 5 | 55 | 0.33 | 0.65 |
| 86 | -1 | 5 | 60 | 0.86 | 73 | -3 | 5 | 60 | 0.73 | 32 | -1 | 5 | 60 | 0.32 | 0.64 |
| 87 | 1 | 5 | 65 | 0.87 | 69 | -4 | 5 | 65 | 0.69 | 31 | -1 | 5 | 65 | 0.31 | 0.62 |
| 85 | -2 | 5 | 70 | 0.85 | 68 | -1 | 5 | 70 | 0.68 | 30 | -1 | 5 | 70 | 0.30 | 0.61 |
| 84 | -1 | 5 | 75 | 0.84 | 67 | -1 | 5 | 75 | 0.67 | 29 | -1 | 5 | 75 | 0.29 | 0.60 |
| 79 | -5 | 5 | 80 | 0.79 | 65 | -2 | 5 | 80 | 0.65 | 30 | 1 | 5 | 80 | 0.30 | 0.58 |
| 77 | -2 | 5 | 85 | 0.77 | 65 | 0 | 5 | 85 | 0.65 | 30 | 0 | 5 | 85 | 0.30 | 0.57 |
| 76 | -1 | 5 | 90 | 0.76 | 65 | 0 | 5 | 90 | 0.65 | 30 | 0 | 5 | 90 | 0.30 | 0.57 |
| 72 | -4 | 5 | 95 | 0.72 | 65 | 0 | 5 | 95 | 0.65 | 29 | -1 | 5 | 95 | 0.29 | 0.55 |
| 76 | 4 | 5 | 100 | 0.76 | 65 | 0 | 5 | 100 | 0.65 | 30 | 1 | 5 | 100 | 0.30 | 0.57 |
| | | | | | | | | | | | | | | | |
| | | Ksat (25min) mm/h | | 564.8778 | | | Ksat (25min) mm/h | | 528.931 | | | Ksat (25min) mm/h | | 256.7626 | |
| | | Total Volume ($cm^3$) | | 1995 | | | Total Volume ($cm^3$) | | 1992 | | | Total Volume ($cm^3$) | | 1014 | |

Surat Soil, TW Irrigation, Flux, 25 minute Hydraulic Conductivity Results & Total Drainage Water Volume for all Soil Cores

| STW1 | | | | | STW2 | | | | | STW3 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Discharge Q (cm³) | Difference per Interval (mL) | Time Period (min) | Elapsed Time (min) | Flux (cm/min) | Discharge Q (cm³) | Difference per Interval (mL) | Time Period (min) | Elapsed Time (min) | Flux (cm/min) | Discharge Q (cm³) | Difference per Interval (mL) | Time Period (min) | Elapsed Time (min) | Flux (cm/min) | Average Flux (cm/min) |
| 0 | 0 | 5 | 0 | 0.00 | 0 | 0 | 5 | 0 | 0.00 | 0 | 0 | 5 | 0 | 0.00 | 0.00 |
| 144 | 144 | 5 | 5 | 1.44 | 144 | 144 | 5 | 5 | 1.44 | 125 | 125 | 5 | 5 | 1.25 | 1.37 |
| 102 | -42 | 5 | 10 | 1.02 | 95 | -49 | 5 | 10 | 0.95 | 94 | -31 | 5 | 10 | 0.94 | 0.97 |
| 93 | -9 | 5 | 15 | 0.93 | 82 | -13 | 5 | 15 | 0.82 | 63 | -31 | 5 | 15 | 0.63 | 0.79 |
| 88 | -5 | 5 | 20 | 0.88 | 74 | -8 | 5 | 20 | 0.74 | 62 | -1 | 5 | 20 | 0.62 | 0.75 |
| 83 | -5 | 5 | 25 | 0.83 | 66 | -8 | 5 | 25 | 0.66 | 58 | -4 | 5 | 25 | 0.58 | 0.69 |
| 78 | -5 | 5 | 30 | 0.78 | 68 | 2 | 5 | 30 | 0.68 | 54 | -4 | 5 | 30 | 0.54 | 0.67 |
| 76 | -2 | 5 | 35 | 0.76 | 63 | -5 | 5 | 35 | 0.63 | 50 | -4 | 5 | 35 | 0.50 | 0.63 |
| 70 | -6 | 5 | 40 | 0.70 | 61 | -2 | 5 | 40 | 0.61 | 47 | -3 | 5 | 40 | 0.47 | 0.59 |
| 70 | 0 | 5 | 45 | 0.70 | 59 | -2 | 5 | 45 | 0.59 | 45 | -2 | 5 | 45 | 0.45 | 0.58 |
| 68 | -2 | 5 | 50 | 0.68 | 55 | -4 | 5 | 50 | 0.55 | 45 | 0 | 5 | 50 | 0.45 | 0.56 |
| 66 | -2 | 5 | 55 | 0.66 | 55 | 0 | 5 | 55 | 0.55 | 43 | -2 | 5 | 55 | 0.43 | 0.55 |
| 63 | -3 | 5 | 60 | 0.63 | 52 | -3 | 5 | 60 | 0.52 | 41 | -2 | 5 | 60 | 0.41 | 0.52 |
| 62 | -1 | 5 | 65 | 0.62 | 52 | 0 | 5 | 65 | 0.52 | 40 | -1 | 5 | 65 | 0.40 | 0.51 |
| 59 | -3 | 5 | 70 | 0.59 | 50 | -2 | 5 | 70 | 0.50 | 38 | -2 | 5 | 70 | 0.38 | 0.49 |
| 60 | 1 | 5 | 75 | 0.60 | 49 | -1 | 5 | 75 | 0.49 | 37 | -1 | 5 | 75 | 0.37 | 0.49 |
| 58 | -2 | 5 | 80 | 0.58 | 47 | -2 | 5 | 80 | 0.47 | 35 | -2 | 5 | 80 | 0.35 | 0.47 |
| 58 | 0 | 5 | 85 | 0.58 | 45 | -2 | 5 | 85 | 0.45 | 34 | -1 | 5 | 85 | 0.34 | 0.46 |
| 56 | -2 | 5 | 90 | 0.56 | 43 | -2 | 5 | 90 | 0.43 | 33 | -1 | 5 | 90 | 0.33 | 0.44 |
| 55 | -1 | 5 | 95 | 0.55 | 44 | 1 | 5 | 95 | 0.44 | 31 | -2 | 5 | 95 | 0.31 | 0.43 |
| 55 | 0 | 5 | 100 | 0.55 | 43 | -1 | 5 | 100 | 0.43 | 31 | 0 | 5 | 100 | 0.31 | 0.43 |
| 49 | -6 | 5 | 105 | 0.49 | 40 | -3 | 5 | 105 | 0.40 | 29 | -2 | 5 | 105 | 0.29 | 0.39 |
| 51 | 2 | 5 | 110 | 0.51 | 41 | 1 | 5 | 110 | 0.41 | 29 | 0 | 5 | 110 | 0.29 | 0.40 |
| 51 | 0 | 5 | 115 | 0.51 | 40 | -1 | 5 | 115 | 0.40 | 29 | 0 | 5 | 115 | 0.29 | 0.40 |
| | | | | | | | | | | | | | | | |
| | | Ksat (25min) mm/h | | 426.226 | | | Ksat (25min) mm/h | | 338.9267 | | | Ksat (25min) mm/h | | 297.8447 | |
| | | Total Volume (cm³) | | 1615 | | | Total Volume (cm³) | | 1368 | | | Total Volume (cm³) | | 1093 | |

Toowoomba Soil, PLD Irrigation, Flux, 25 minute Hydraulic Conductivity Results & Total Drainage Water Volume for all Soil Cores

| TLP1 | | | | | TLP2 | | | | | TLP3 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Discharge Q (cm³) | Difference per Interval (mL) | Time Period (min) | Elapsed Time (min) | Flux (cm/min) | Discharge Q (cm³) | Difference per Interval (mL) | Time Period (min) | Elapsed Time (min) | Flux (cm/min) | Discharge Q (cm³) | Difference per Interval (mL) | Time Period (min) | Elapsed Time (min) | Flux (cm/min) | Average Flux (cm/min) |
| 0 | 0 | 5 | 0 | 0.00 | 0 | 0 | 5 | 0 | 0.00 | 0 | 0 | 5 | 0 | 0.00 | 0.00 |
| 24 | 24 | 5 | 5 | 0.24 | 140 | 140 | 5 | 5 | 1.40 | 105 | 105 | 5 | 5 | 1.05 | 0.90 |
| 32 | 8 | 5 | 10 | 0.32 | 61 | -79 | 5 | 10 | 0.61 | 56 | -49 | 5 | 10 | 0.56 | 0.50 |
| 23 | -9 | 5 | 15 | 0.23 | 40 | -21 | 5 | 15 | 0.40 | 39 | -17 | 5 | 15 | 0.39 | 0.34 |
| 19 | -4 | 5 | 20 | 0.19 | 37 | -3 | 5 | 20 | 0.37 | 29 | -10 | 5 | 20 | 0.29 | 0.28 |
| 13 | -6 | 5 | 25 | 0.13 | 28 | -9 | 5 | 25 | 0.28 | 22 | -7 | 5 | 25 | 0.22 | 0.21 |
| 8 | -5 | 5 | 30 | 0.08 | 22 | -6 | 5 | 30 | 0.22 | 18 | -4 | 5 | 30 | 0.18 | 0.16 |
| 9 | 1 | 5 | 35 | 0.09 | 19 | -3 | 5 | 35 | 0.19 | 15 | -3 | 5 | 35 | 0.15 | 0.14 |
| 4 | -5 | 5 | 40 | 0.04 | 14 | -5 | 5 | 40 | 0.14 | 13 | -2 | 5 | 40 | 0.13 | 0.10 |
| 4 | 0 | 5 | 45 | 0.04 | 14 | 0 | 5 | 45 | 0.14 | 11 | -2 | 5 | 45 | 0.11 | 0.10 |
| 4 | 0 | 5 | 50 | 0.04 | 12 | -2 | 5 | 50 | 0.12 | 9 | -2 | 5 | 50 | 0.09 | 0.08 |
| 4 | 0 | 5 | 55 | 0.04 | 12 | 0 | 5 | 55 | 0.12 | 10 | 1 | 5 | 55 | 0.10 | 0.09 |
| 5 | 1 | 5 | 60 | 0.05 | 12 | 0 | 5 | 60 | 0.12 | 8 | -2 | 5 | 60 | 0.08 | 0.08 |
| 4 | -1 | 5 | 65 | 0.04 | 10 | -2 | 5 | 65 | 0.10 | 8 | 0 | 5 | 65 | 0.08 | 0.07 |
| 5 | 1 | 5 | 70 | 0.05 | 11 | 1 | 5 | 70 | 0.11 | 8 | 0 | 5 | 70 | 0.08 | 0.08 |
| 9 | 4 | 5 | 75 | 0.09 | 10 | -1 | 5 | 75 | 0.10 | 7 | -1 | 5 | 75 | 0.07 | 0.09 |
| 9 | 0 | 5 | 80 | 0.09 | 8 | -2 | 5 | 80 | 0.08 | 5 | -2 | 5 | 80 | 0.05 | 0.07 |
| 8 | -1 | 5 | 85 | 0.08 | 7 | -1 | 5 | 85 | 0.07 | 5 | 0 | 5 | 85 | 0.05 | 0.07 |
| 9 | 1 | 5 | 90 | 0.09 | 5 | -2 | 5 | 90 | 0.05 | 5 | 0 | 5 | 90 | 0.05 | 0.06 |
| 10 | 1 | 5 | 95 | 0.10 | 5 | 0 | 5 | 95 | 0.05 | 4 | -1 | 5 | 95 | 0.04 | 0.06 |
| 11 | 1 | 5 | 100 | 0.11 | 6 | 1 | 5 | 100 | 0.06 | 5 | 1 | 5 | 100 | 0.05 | 0.07 |
| | | | | | | | | | | | | | | | |
| | | Ksat (25min) mm/h | | 66.76 | | | Ksat (25min) mm/h | | 143.79 | | | Ksat (25min) mm/h | | 112.98 | |
| | | Total Volume ($cm^3$) | | 214 | | | Total Volume ($cm^3$) | | 473 | | | Total Volume ($cm^3$) | | 382 | |

Bundaberg Soil, PLD Irrigation, Flux, 25 minute Hydraulic Conductivity Results & Total Drainage Water Volume for all Soil Cores

| BLP1 | | | | | BLP2 | | | | | BLP3 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Discharge Q ($cm^3$) | Difference per Interval (mL) | Time Period (min) | Elapsed Time (min) | Flux (cm/min) | Discharge Q ($cm^3$) | Difference per Interval (mL) | Time Period (min) | Elapsed Time (min) | Flux (cm/min) | Discharge Q ($cm^3$) | Difference per Interval (mL) | Time Period (min) | Elapsed Time (min) | Flux (cm/min) | Average Flux (cm/min) |
| 0 | 0 | 5 | 0 | 0.00 | 0 | 0 | 5 | 0 | 0.00 | 0 | 0 | 5 | 0 | 0.00 | 0.00 |
| 215 | 215 | 5 | 5 | 2.15 | 105 | 105 | 5 | 5 | 1.05 | 280 | 280 | 5 | 5 | 2.80 | 2.00 |
| 14 | -201 | 5 | 10 | 0.14 | 17 | -88 | 5 | 10 | 0.17 | 13 | -267 | 5 | 10 | 0.13 | 0.15 |
| 5 | -9 | 5 | 15 | 0.05 | 8 | -9 | 5 | 15 | 0.08 | 3 | -10 | 5 | 15 | 0.03 | 0.05 |
| 3 | -2 | 5 | 20 | 0.03 | 7 | -1 | 5 | 20 | 0.07 | 3 | 0 | 5 | 20 | 0.03 | 0.04 |
| 3 | 0 | 5 | 25 | 0.03 | 5 | -2 | 5 | 25 | 0.05 | 2 | -1 | 5 | 25 | 0.02 | 0.03 |
| 2 | -1 | 5 | 30 | 0.02 | 4 | -1 | 5 | 30 | 0.04 | 2 | 0 | 5 | 30 | 0.02 | 0.03 |
| 3 | 1 | 5 | 35 | 0.03 | 3 | -1 | 5 | 35 | 0.03 | 2 | 0 | 5 | 35 | 0.02 | 0.03 |
| | | | | | | | | | | | | | | | |
| | | Ksat (25min) mm/h | | 15.41 | | | Ksat (25min) mm/h | | 25.68 | | | Ksat (25min) mm/h | | 10.27 | |
| | | Total Volume ($cm^3$) | | 245 | | | Total Volume ($cm^3$) | | 149 | | | Total Volume ($cm^3$) | | 305 | |

Surat Soil, PLD Irrigation, Flux, 25 minute Hydraulic Conductivity Results & Total Drainage Water Volume for all Soil Cores

| **SLP1** | | | | | **SLP2** | | | | | **SLP3** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Discharge Q (cm³) | Difference per Interval (mL) | Time Period (min) | Elapsed Time (min) | Flux (cm/min) | Discharge Q (cm³) | Difference per Interval (mL) | Time Period (min) | Elapsed Time (min) | Flux (cm/min) | Discharge Q (cm³) | Difference per Interval (mL) | Time Period (min) | Elapsed Time (min) | Flux (cm/min) | Average Flux (cm/min) |
| 0 | 0 | 5 | 0 | 0.00 | 0 | 0 | 5 | 0 | 0.00 | 0 | 0 | 5 | 0 | 0.00 | 0.00 |
| 62 | 62 | 5 | 5 | 0.62 | 68 | 68 | 5 | 5 | 0.68 | 47 | 47 | 5 | 5 | 0.47 | 0.59 |
| 21 | -41 | 5 | 10 | 0.21 | 109 | 41 | 5 | 10 | 1.09 | 22 | -25 | 5 | 10 | 0.22 | 0.51 |
| 13 | -8 | 5 | 15 | 0.13 | 366 | 257 | 5 | 15 | 3.65 | 13 | -9 | 5 | 15 | 0.13 | 1.30 |
| 10 | -3 | 5 | 20 | 0.10 | 245 | -121 | 5 | 20 | 2.45 | 10 | -3 | 5 | 20 | 0.10 | 0.88 |
| 12 | 2 | 10 | 30 | 0.06 | 260 | 15 | 10 | 30 | 1.30 | 12 | 2 | 10 | 30 | 0.06 | 0.47 |
| 11 | -1 | 15 | 45 | 0.04 | 81 | -179 | 15 | 45 | 0.27 | 10 | -2 | 15 | 45 | 0.03 | 0.11 |
| 13 | 2 | 30 | 75 | 0.02 | 176 | 95 | 30 | 75 | 0.29 | 10 | 0 | 30 | 75 | 0.02 | 0.11 |
| 11 | -2 | 70 | 145 | 0.01 | | | | | | 10 | 0 | 70 | 145 | 0.01 | 0.01 |
| | | | | | | | | | | | | | | | |
| | | Ksat (25min) mm/h | | 51.35 | | | Ksat (25min) mm/h | | 1258.14 | | | Ksat (25min) mm/h | | 51.35 | |
| | | Total Volume ($cm^3$) | | 153 | | | Total Volume ($cm^3$) | | 1305 | | | Total Volume ($cm^3$) | | 134 | |

Toowoomba Soil, LLD Irrigation, Flux, 25 minute Hydraulic Conductivity Results & Total Drainage Water Volume for all Soil Cores

| TLL1 | | | | | TLL2 | | | | | TLL3 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Discharge Q (cm³) | Difference per Interval (mL) | Time Period (min) | Elapsed Time (min) | Flux (cm/min) | Discharge Q (cm³) | Difference per Interval (mL) | Time Period (min) | Elapsed Time (min) | Flux (cm/min) | Discharge Q (cm³) | Difference per Interval (mL) | Time Period (min) | Elapsed Time (min) | Flux (cm/min) | Average Flux (cm/min) |
| 0 | 0 | 5 | 0 | 0.00 | 0 | 0 | 5 | 0 | 0.00 | 0 | 0 | 5 | 0 | 0.00 | 0.00 |
| 14 | 14 | 5 | 5 | 0.14 | 14 | 14 | 15 | 15 | 0.05 | 150 | 150 | 5 | 5 | 1.50 | 0.56 |
| 13 | -1 | 5 | 10 | 0.13 | 10 | -4 | 10 | 25 | 0.05 | 62 | -88 | 5 | 10 | 0.62 | 0.27 |
| 23 | 10 | 10 | 20 | 0.11 | 23 | 13 | 10 | 35 | 0.11 | 44 | -18 | 5 | 15 | 0.44 | 0.22 |
| 41 | 18 | 5 | 25 | 0.41 | 24 | 1 | 5 | 40 | 0.24 | 32 | -12 | 5 | 20 | 0.32 | 0.32 |
| 35 | -6 | 5 | 30 | 0.35 | 29 | 5 | 5 | 45 | 0.29 | 26 | -6 | 5 | 25 | 0.26 | 0.30 |
| 21 | -14 | 5 | 35 | 0.21 | 26 | -3 | 5 | 50 | 0.26 | 23 | -3 | 5 | 30 | 0.23 | 0.23 |
| 17 | -4 | 5 | 40 | 0.17 | 23 | -3 | 5 | 55 | 0.23 | 19 | -4 | 5 | 35 | 0.19 | 0.20 |
| 12 | -5 | 5 | 45 | 0.12 | 18 | -5 | 5 | 60 | 0.18 | 14 | -5 | 5 | 40 | 0.14 | 0.15 |
| 10 | -2 | 5 | 50 | 0.10 | 13 | -5 | 5 | 65 | 0.13 | 11 | -3 | 5 | 45 | 0.11 | 0.11 |
| 16 | 6 | 10 | 60 | 0.08 | 12 | -1 | 5 | 70 | 0.12 | 10 | -1 | 5 | 50 | 0.10 | 0.10 |
| 11 | -5 | 10 | 70 | 0.05 | 13 | 1 | 5 | 75 | 0.13 | 14 | 4 | 10 | 60 | 0.07 | 0.08 |
| 11 | 0 | 10 | 80 | 0.05 | 12 | -1 | 5 | 80 | 0.12 | 12 | -2 | 10 | 70 | 0.06 | 0.08 |
| | | | | | | | | | | 11 | -1 | 10 | 80 | 0.05 | 0.05 |
| | | | | | | | | | | | | | | | |
| | | Ksat (25min) mm/h | | 210.55 | | | Ksat (25min) mm/h | | 25.68 | | | Ksat (25min) mm/h | | 133.52 | |
| | | Total Volume ($cm^3$) | | 224 | | | Total Volume ($cm^3$) | | 217 | | | Total Volume ($cm^3$) | | 428 | |

Bundaberg Soil, LLD Irrigation, Flux, 25 minute Hydraulic Conductivity Results & Total Drainage Water Volume for all Soil Cores

| **BLL1** | | | | | **BLL2** | | | | | **BLL3** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Discharge Q ($cm^3$) | Difference per Interval (mL) | Time Period (min) | Elapsed Time (min) | Flux (cm/min) | Discharge Q ($cm^3$) | Difference per Interval (mL) | Time Period (min) | Elapsed Time (min) | Flux (cm/min) | Discharge Q ($cm^3$) | Difference per Interval (mL) | Time Period (min) | Elapsed Time (min) | Flux (cm/min) | Average Flux (cm/min) |
| 0 | 0 | 5 | 0 | 0.00 | 0 | 0 | 5 | 0 | 0.00 | 0 | 0 | 5 | 0 | 0.00 | 0.00 |
| 180 | 180 | 5 | 5 | 1.80 | 220 | 220 | 5 | 5 | 2.20 | 350 | 350 | 5 | 5 | 3.49 | 2.50 |
| 10 | -170 | 35 | 40 | 0.01 | 10 | -210 | 30 | 35 | 0.02 | 12 | -338 | 35 | 40 | 0.02 | 0.02 |
| 0 | -10 | 30 | 70 | 0.00 | 0 | -10 | 30 | 65 | 0.00 | 0 | -12 | 30 | 70 | 0.00 | 0.00 |
| | | | | | | | | | | | | | | | |
| | | Ksat (25min) mm/h | | 7.34 | | | Ksat (25min) mm/h | | 8.56 | | | Ksat (25min) mm/h | | 8.80 | |
| | | Total Volume ($cm^3$) | | 190 | | | Total Volume ($cm^3$) | | 230 | | | Total Volume ($cm^3$) | | 362 | |

Surat Soil, LLD Irrigation, Flux, 25 minute Hydraulic Conductivity Results & Total Drainage Water Volume for all Soil Cores

| SLL1 | | | | | SLL2 | | | | | SLL3 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Discharge Q (cm³) | Difference per Interval (mL) | Time Period (min) | Elapsed Time (min) | Flux (cm/min) | Discharge Q (cm³) | Difference per Interval (mL) | Time Period (min) | Elapsed Time (min) | Flux (cm/min) | Discharge Q (cm³) | Difference per Interval (mL) | Time Period (min) | Elapsed Time (min) | Flux (cm/min) | Average Flux (cm/min) |
| 0 | 0 | 5 | 0 | 0.00 | 0 | 0 | 5 | 0 | 0.00 | 0 | 0 | 5 | 0 | 0.00 | 0.00 |
| 60 | 60 | 5 | 5 | 0.60 | 130 | 130 | 5 | 5 | 1.30 | 70 | 70 | 5 | 5 | 0.70 | 0.87 |
| 33 | -27 | 5 | 10 | 0.33 | 87 | -43 | 5 | 10 | 0.87 | 42 | -28 | 5 | 10 | 0.42 | 0.54 |
| 24 | -9 | 5 | 15 | 0.24 | 82 | -5 | 5 | 15 | 0.82 | 23 | -19 | 5 | 15 | 0.23 | 0.43 |
| 19 | -5 | 5 | 20 | 0.19 | 67 | -15 | 5 | 20 | 0.67 | 20 | -3 | 5 | 20 | 0.20 | 0.35 |
| 17 | -2 | 5 | 25 | 0.17 | 45 | -22 | 5 | 25 | 0.45 | 14 | -6 | 5 | 25 | 0.14 | 0.25 |
| 13 | -4 | 5 | 30 | 0.13 | 10 | -35 | 5 | 30 | 0.10 | 11 | -3 | 5 | 30 | 0.11 | 0.11 |
| 12 | -1 | 5 | 35 | 0.12 | 12 | 2 | 5 | 35 | 0.12 | 10 | -1 | 5 | 35 | 0.10 | 0.11 |
| 10 | -2 | 5 | 40 | 0.10 | 18 | 6 | 5 | 40 | 0.18 | 13 | 3 | 10 | 45 | 0.06 | 0.11 |
| 10 | 0 | 5 | 45 | 0.10 | 42 | 24 | 5 | 45 | 0.42 | 10 | -3 | 10 | 55 | 0.05 | 0.19 |
| 14 | 4 | 10 | 55 | 0.07 | 67 | 25 | 5 | 50 | 0.67 | 10 | 0 | 10 | 65 | 0.05 | 0.26 |
| 11 | -3 | 10 | 65 | 0.05 | 72 | 5 | 5 | 55 | 0.72 | 10 | 0 | 10 | 75 | 0.05 | 0.27 |
| | | | | | 71 | -1 | 5 | 60 | 0.71 | | | | | | 0.71 |
| | | | | | 99 | 28 | 5 | 65 | 0.99 | | | | | | 0.99 |
| | | | | | 72 | -27 | 5 | 70 | 0.72 | | | | | | 0.72 |
| | | | | | 110 | 38 | 5 | 75 | 1.10 | | | | | | 1.10 |
| | | | | | 96 | -14 | 5 | 80 | 0.96 | | | | | | 0.96 |
| | | | | | 65 | -31 | 5 | 85 | 0.65 | | | | | | 0.65 |
| | | | | | 67 | 2 | 5 | 90 | 0.67 | | | | | | 0.67 |
| | | | | | | | | | | | | | | | |
| | | Ksat (25min) mm/h | | 87.30 | | | Ksat (25min) mm/h | | 231.09 | | | Ksat (25min) mm/h | | 71.89 | |
| | | Total Volume ($cm^3$) | | 223 | | | Total Volume ($cm^3$) | | 1212 | | | Total Volume ($cm^3$) | | 233 | |

Powder Laundry Detergent Colloids

**Filter Paper Colloid Calculations**

| Average Filter Paper Weight (g) | | | | | | 0.575 |
|---|---|---|---|---|---|---|
| **Filter** | **Dish** | **Dish + Lid (g)** | **Dish + Lid + Moist Filter (g)** | **Dish + Lid + Dry Filter (g)** | **Filter + Colloids (g)** | **Colloids (g)** |
| TLP1L | M31 | 41.5619 | 43.682 | 42.1771 | 1.5049 | 0.9299 |
| TLP2L | M25 | 41.0265 | 42.8719 | 41.6163 | 1.2556 | 0.6806 |
| TLP3L | M9 | 41.8704 | 43.9509 | 42.5128 | 1.4381 | 0.8631 |
| | | | | | | |

**Leachate Sample Colloid Concentration**

| **Sample** | **Dish** | **Dish + Lid (g)** | **Dish + Lid + Leachate (g)** | **Dish + Lid + Colloids (g)** | **Leachate Volume ($cm^3$)** | **Colloids (g)** | **Colloid Conc. ($g/cm^3$)** | **Total Volume of Leachate Collected ($cm^3$)** | **Total Colloids (g)** | **Total Colloids + Filter Colloids (g)** | **Total Conc. of Colloids ($g/cm^3$)** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| TLP1L | M77 | 38.3626 | 63.6674 | 38.4581 | 26 | 25.209 | 0.9696 | 214 | 207.4919 | 208.4218 | 0.9739 |
| TLP2L | M62 | 71.571 | 71.3245 | 39.6961 | 32 | 31.628 | 0.9884 | 473 | 467.5073 | 468.1879 | 0.9898 |
| TLP3L | M26 | 41.3056 | 70.2708 | 41.4413 | 29 | 28.83 | 0.9941 | 382 | 379.7541 | 380.6172 | 0.9964 |
| | | | | | | | | | | | |
| BLP1L | M6 | 41.2962 | 73.7659 | 41.4064 | 33 | 32.36 | 0.9806 | 245 | 240.2448 | | |
| BLP2L | M19 | 41.551 | 69.709 | 41.6316 | 29 | 28.077 | 0.9682 | 149 | 144.2597 | | |
| BLP3L | M45 | 41.1064 | 82.516 | 41.2178 | 42 | 41.298 | 0.9833 | 305 | 299.9036 | | |
| | | | | | | | | | | | |
| SLP1L | M69 | 39.9864 | 60.4061 | 39.9909 | 21 | 20.415 | 0.9722 | 153 | 148.7393 | | |
| SLP2L | M42 | 41.2718 | 66.2687 | 41.3916 | 24 | 24.877 | 1.0365 | 1305 | ####### | | |
| SLP3L | M14 | 41.9155 | 69.5251 | 41.9279 | 28 | 27.597 | 0.9856 | 134 | 132.0723 | | |

Tap Water Chemical Results

| | | $Na^+$ mmol $L^{-1}$ | $Ca^{2+}$ mmol $L^{-1}$ | $Mg^{2+}$ mmol $L^{-1}$ | $K^+$ mmol $L^{-1}$ | SAR | Mean SAR | SE SAR |
|---|---|---|---|---|---|---|---|---|
| Tap Water | TW1 | 1.828 | 1.098 | 1.070 | 0.102 | 1.756 | | |
| | TW2 | 1.784 | 1.098 | 1.070 | 0.077 | 1.714 | | |
| | TW3 | 1.697 | 1.098 | 0.987 | 0.102 | 1.662 | 1.711 | 0.0271 |
| | | | | | | | | |
| | TTW1L | 1.001 | 1.297 | 0.905 | 0.077 | 0.954 | | |
| | TTW2L | 1.523 | 1.048 | 0.823 | 0.077 | 1.575 | | |
| | TTW3L | 1.523 | 0.948 | 0.732 | 0.077 | 1.662 | 1.397 | 0.2229 |
| | | | | | | | | |
| | BTW1L | 1.480 | 1.048 | 0.642 | 0.102 | 1.610 | | |
| | BTW2L | 1.436 | 1.048 | 0.691 | 0.102 | 1.540 | | |
| | BTW3L | 1.393 | 0.998 | 0.642 | 0.128 | 1.538 | 1.563 | 0.0236 |
| | | | | | | | | |
| | STW1L | 1.697 | 1.248 | 0.708 | 0.153 | 1.717 | | |
| | STW2L | 1.697 | 1.248 | 0.732 | 0.128 | 1.706 | | |
| | STW3L | 1.697 | 1.248 | 0.782 | 0.128 | 1.685 | 1.702 | 0.0093 |

Powder Laundry Detergent Chemical Results

| | | $Na^+$ mmol $L^{-1}$ | $Ca^{2+}$ mmol $L^{-1}$ | $Mg^{2+}$ mmol $L^{-1}$ | $K^+$ mmol $L^{-1}$ | SAR | Mean SAR | SE SAR |
|---|---|---|---|---|---|---|---|---|
| Laundry Powder | LP1 | 17.406 | 0.050 | 0.082 | 0.026 | 67.711 | | |
| | LP2 | 17.842 | 0.050 | 0.082 | 0.026 | 69.403 | | |
| | LP3 | 17.842 | 0.050 | 0.082 | 0.563 | 69.403 | 68.839 | 0.5643 |
| | | | | | | | | |
| | TLP1L | 3.003 | 1.098 | 0.757 | 0.077 | 3.118 | | |
| | TLP2L | 6.527 | 0.798 | 0.683 | 0.102 | 7.585 | | |
| | TLP3L | 5.222 | 0.898 | 0.691 | 0.102 | 5.858 | 5.520 | 1.3004 |
| | | | | | | | | |
| | BLP1L | 10.879 | 0.898 | 1.070 | 0.153 | 10.968 | | |
| | BLP2L | 8.268 | 1.048 | 0.987 | 0.153 | 8.196 | | |
| | BLP3L | 12.185 | 0.798 | 0.905 | 0.102 | 13.203 | 10.789 | 1.4480 |
| | | | | | | | | |
| | SLP1L | 4.308 | 1.996 | 1.152 | 0.102 | 3.434 | | |
| | SLP2L | 15.231 | 0.749 | 0.905 | 0.102 | 16.751 | | |
| | SLP3L | 3.525 | 2.096 | 1.152 | 0.128 | 2.766 | 7.650 | 4.5543 |

Liquid Laundry Detergent Chemical Results

| | | $Na^{+}$ mmol $L^{-1}$ | $Ca^{2+}$ mmol $L^{-1}$ | $Mg^{2+}$ mmol $L^{-1}$ | $K^{+}$ mmol $L^{-1}$ | SAR | Mean SAR | SE SAR |
|---|---|---|---|---|---|---|---|---|
| Laundry Liquid | LL1 | 2.176 | 0.050 | 0.082 | 0.026 | 8.464 | | |
| | LL2 | 2.654 | 0.050 | 0.082 | 0.026 | 10.326 | | |
| | LL3 | 2.654 | 0.050 | 0.082 | 0.026 | 10.326 | 9.705 | 0.6207 |
| | | | | | | | | |
| | TLL1L | 0.522 | 0.599 | 0.428 | 0.077 | 0.729 | | |
| | TLL2L | 0.783 | 0.549 | 0.428 | 0.077 | 1.121 | | |
| | TLL3L | 0.914 | 0.399 | 0.370 | 0.077 | 1.473 | 1.108 | 0.2150 |
| | | | | | | | | |
| | BLL1L | 1.349 | 0.349 | 0.650 | 0.128 | 1.908 | | |
| | BLL2L | 1.871 | 0.449 | 0.675 | 0.179 | 2.496 | | |
| | BLL3L | 2.132 | 0.399 | 0.584 | 0.077 | 3.041 | 2.482 | 0.3270 |
| | | | | | | | | |
| | SLL1L | 0.914 | 0.499 | 0.658 | 0.102 | 1.201 | | |
| | SLL2L | 2.437 | 0.599 | 1.070 | 0.230 | 2.668 | | |
| | SLL3L | 0.957 | 0.549 | 0.765 | 0.153 | 1.181 | 1.684 | 0.4923 |