Phosphorus as a limiting factor on sustainable greywater irrigation

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Abstract

Water reuse through greywater irrigation has been adopted worldwide and has been proposed as a potential sustainable solution to increased water demands. Domestically, knowledge of greywater reuse is limited, furthermore the commercial drive to produce low-level phosphorus products is lacking. Additionally, current guidelines and legislation are inadequate due to the lack of long term data and practical relevance. Research clearly identifies phosphorus as a potential environmental risk to waterways from many forms of irrigation.

To assess the question of greywater irrigation sustainability, this study focused on four residential lots that had been irrigated with greywater for four years.
Adjacent non-irrigated lots were also assessed as controls. Each lot was monitored for irrigation volumes applied and various chemical and physical water quality parameters. Multiple soil chemistry profiles were analyzed for all the non-irrigated and irrigated sites. The non-irrigated profiles showed low levels of phosphorus and were used as baseline results. A Mechlich3 Phosphorus ratio (M3PSR) was used to determine environmental risk of phosphorus leaching from the irrigated soils. Further analyses using Colwell-P and phosphorus buffering index ratio (BPI) was used as additional evidence in identifying potential environmental risk of phosphorus leaching. Reported soil phosphorus results were also compared to theoretical greywater irrigation loadings. Both the reported phosphorus soil concentrations and the estimated greywater loadings were of the similar magnitude indicating that M3PSR and PBI ratios are useful surrogates for determining long term P loadings in irrigated soils. Sustainable greywater reuse is promising, however incorrect use or the lack of understanding about how household products impact the water quality of greywater, can result in significant risk of phosphorus impacting the natural environment.

**Introduction**

Water scarcity is increasingly becoming a problem worldwide (Jury, Vaux 2007, Godfrey, Labhasetwar & Wate 2009). Greywater irrigation has been adopted as one way to combat the scarcity of water (Eriksson, Donner 2009, Maimon et al. 2010, Winward et al. 2008) and to ensure the sustainability of this resource (Al-Jayyousi 2003). This type of water reuse has been demonstrated to be one of the potential solutions to increased water demands (Jury, Vaux 2007, Gross, Kaplan
& Baker 2007), however the sustainability of this practice has been questioned even though it may relieve water demands (Wiel-Shafran et al. 2006) as environmental pollution is probable if incorrectly utilised.

It is evident that there is a lack of consumer knowledge on the impacts and sustainability of greywater irrigation (Whitehead, Patterson 2007). Furthermore the commercial drive to produce low-level phosphorus cleaning products is not supported due to consumer habits and lack of legislation (Knud-Hansen 1994). This can lead to high levels of phosphorus being irrigated onto soil via the good intentions of recycling greywater (Patterson 2004). Guidelines and legislation on greywater irrigation tend to focus on human health (Maimon et al. 2010, Avvannavar, Mani 2007) and unfortunately they often do not address relevant issues on environmental impacts and sustainability. Furthermore guidelines are incomplete due to limited scientific data and have no measure of phosphorus loadings (Environment Protection and Heritage Council 2006, Department of State Development, Infrastructure and Planning 2007).

Research clearly identifies phosphorus as a potential risk with many forms of irrigation (Christova-Boal, Eden & McFarlane 1996). Increased inputs of phosphorus from anthropogenic runoff can accelerate freshwater eutrophication (Sharpley 1995, Sharpley, Robinson & Smith 1995) (Koopmans 2002). Typically phosphates are used as builders in detergents (Hammond 1971, Lanfax Labs 2009), and are often used as either sodium tripolyphosphate or potassium phosphates (ReVelle, ReVelle 1988, Jenkins et al. 1973). The primary role of builders is to reduce the hardness of the water. This is achieved by binding to
and neutralising calcium, magnesium, iron as well as manganese ions thus enabling the surfactant to work on the dirt and improving washing performance (Jenkins et al. 1973).

Typically the reuse of greywater is through irrigation (Wiel-Shafran et al. 2006, Howard et al. 2007, Travis et al. 2010b), although it is becoming more common to use this water to flush toilets (Godfrey, Labhasetwar & Wate 2009, March, Gual 2009, Jeppesen 1996). Recently guidelines have listed other uses for greywater including; washing of paths, wall, and vehicles and reuse in washing machines (Department of State Development, Infrastructure and Planning 2007). These types of reuse need to have clear guidelines as to the final quality of greywater (which they do not) as the water path to environmental waterways has no retention or remediation capacity (i.e. when washing down a path or driveways with greywater the runoff will go straight into the stormwater system which ends up in the local river system). The commercial economics of greywater reuse tends to drive the use of simple forms of irrigation and minimal treatment for the general public. These simple forms of irrigation; bucketing laundry water, diverting washing machine waste water or shower water with a hose and storing these water sources in converted wheelie bins can are just a few examples of simple irrigations which can be problematic. Due to a lack of understanding of greywater; minimal public education about the do’s and don’ts of greywater; and simple measures of greywater reuse, urban subdivisions are potentially faced with future environmental contamination.
When phosphate is irrigated onto soil, it can be adsorbed chemically, taken up by plants or leached through the soils profile (Barton et al. 2005). Generally phosphate is chemically absorbed to mineral surfaces in soils via ligand exchange. Phosphorus sorption is primarily a function of the concentration of iron and/or aluminum oxy-hydroxides (de Mesquita Filho, Torrent 1993, Lewis, Clarke & Hall 1981), as well as aluminosilicates minerals (Barton et al. 2005).

Once all the active sites in soil have been occupied by phosphorus, further irrigation results in unbound free phosphorus. This free phosphorus can then either move down the soil profile potentially being intercepted by groundwater or move across the surface by interacting with surface water runoff. Two processes generally explain the chemical availability of free phosphorus; desorption of phosphorus from sorption sites on iron and aluminium oxy-hydroxides, associated with clay mineral surfaces and organic matter; and dissolution of phosphorus compounds present as soil minerals and or fertiliser (Moody 2011). These movements of phosphorus can cause environmental contamination, and contribute to freshwater ecosystem eutrophication of water bodies (Sharpley et al 1996 & Gross et al. 2005) thus potential impacting sustainable greywater irrigation.

Two alternate approaches have been proposed to assess the sustainability of effluent irrigation on soils. Sims et al 2002 ((Sims et al. 2002)) suggested using a molar ratio of Mehlich3 extractable phosphorus to Mehlich3 extractable iron and Mehlich3 extractable aluminium (M3PSR_ICP-AES) as an indicator of the potential loss of phosphorus from soils to surface and groundwater. Subsequently Maguire
et al 2002 ([Maguire, Sims 2002]) defined environmental criteria for the leaching characteristics of phosphorus in soils; Mehlich3 saturation ratios less than 0.10 indicate, soil phosphorous saturations below environmental concern; ratios between 0.10-0.15 indicate, a range of soil phosphorous saturation where environmental concern might become an issue; and a ratio range greater than 0.2 is evident of significant soil phosphorous saturation that is of environmental concern.

Moody et al ([Moody 2011]) stated that using a Colwell-P and phosphorus buffering index ratio where a ratio greater than 2.0 would demonstrate a potential environmental hazard due to the loss of phosphorus from the soil. The magnitudes of such ratios of irrigated soils is heavily governed by the water quality of the irrigated greywater (Roesner et al. 2006) and the chemistry and physical properties of soil (Wiel-Shafran et al. 2006, Travis et al. 2010a).

In determining the sustainability of greywater irrigation two aspects should be considered. Firstly is there a benefit of greywater irrigation regarding water reuse? This has been demonstrated by many researchers (Al-Jayyousi 2003, Whitehead, Patterson 2007, Regelsberger et al. 2007, Khalil et al. 2004, Pinto, Maheshwari 2010). Secondly is there a benefit of greywater irrigation to the environment that is manageable and does not adversely impact the soil, waterways and groundwater?

Therefore in answering the research question “can greywater irrigation be sustainable”, it essential to ensure that irrigation of urban greywater does not
adversely impact the surrounding environment. Thus to forecast or predict the
impacts of any future greywater irrigation development within the urban
environment, phosphorus irrigation loadings should be introduced into
legislation. Furthermore irrigation (sub-surface) assessment models such as
MEDLI (Gardner, Vieritz & Atzeni 2002) need to be utilised and enhanced to
assess the suitability of the site. Greywater application guidelines need to be
updated to address phosphorus impacts along with education programs to
encourage residents to maintain the environmental sustainability of their land
(Patterson 2004). This paper assesses the potential environmental impacts as a
result of four years of greywater irrigation at four residential lots and evaluates
the long term sustainability of these sites from phosphorus loading.

**Methods**

**Study area**

The study area was a 22-lot residential subdivision with a total area of 3.8 ha,
located approximately 10 km west of Brisbane, Queensland, Australia (Figure 1).
Individual lots ranged in area between 800 and 1800 m². The majority of the
study area is steep with slopes less than 20 percent. Overland flow from the
subdivision flows into Enoggera Creek which is known to be of environmental
significance (Brisbane City Council 2010, Sinclair Knight Merz 2011). Each lot
has a 200m² transpiration zone for greywater irrigation. The water supply for
each household is captured rain water.
Four residential lots were chosen from the 22 for this study. These were selected based on the results of workplace health and safety and site access considerations and the demography of the household. The household of each selected lot was surveyed to determine what cleaning products were utilised in the laundry and kitchen. In addition, a member of each lot was interviewed for their knowledge and understanding of the importance and sustainability of greywater reuse as well as water efficiency. This gave insights into the residents’ consumer attitudes and belief in and knowledge of greywater reuse. In a related study but not discussed in this paper piezometer installations identified a perched water table approximately 3 meter below the surface behind lot D.
In summary the design of this research study required:

1) Collection of greywater and soil samples from four residential urban lots.
2) Collection of soil samples as non-irrigated controls from adjacent vacant lots.
3) Surveys to determine consumer household habits, on products used in the laundry and kitchen as well as frequency of washing and bathing.
4) Chemical analysis of greywater.
5) Chemical and physical analysis of soil depth profiles.
6) Soil profiles were then evaluated to ascertain phosphorus sustainability.
7) Actual phosphorus loading in the soil were compared to estimated phosphorus loadings from the greywater chemistry and the results were used to estimate future phosphorus soil loadings.

Greywater

All the greywater at the four selected lots was treated and stored in a vermiculture (Biolytix 2005) greywater treatment system. Greywater consisted of all water discharged from the bathrooms, laundry and kitchen apart from blackwater (toilet waste). The greywater is then subsurface drip irrigated into a 200 m² transpiration area, termed "transpiration zone". A moisture sensor is located in each transpiration zone to reduce over irrigation. If the soil was deemed to be saturated the greywater was automatically diverted to sewer.

Each household's water discharges were measured, allowing the total calculation of greywater sent to sewer or irrigation. The greywater from each lot was measured monthly by two water meters during the period of May 2005 to July 2009. One meter measured irrigation volumes and the other meter measured bypass volumes to sewer. Grab samples of greywater were taken over five

Average characteristics of the greywater samples taken during 2006 were presented by Beal et al. 2008. Each greywater sample was a composite 24-hour sample taken directly from the irrigation outlet. These were collected in a 2 L bottle, kept on ice and retrieved each day. Each sample was subsampled according to the Australian Standard (AS/NZS 5667.1:1998) (Standards Australia 1998) and sent to NATA accredited laboratories for chemical analysis (Kaus 2010). Greywater samples were analysed for the following parameters; total Kjeldahl nitrogen as N and total Kjeldahl phosphorus as P by Flow Injection Analysis (Eaton et al. 2005); calcium, potassium, magnesium and sodium by Inductively Coupled Plasma-Optical Emission Spectrometer simultaneous detection analysis (Eaton et al. 2005, Varian 2001); pH @ 25º C and electrical conductivity @ 25º C by electrode (Eaton et al. 2005).

Soil

Up to five individual soil cores were taken from the transpiration zones of each lot, using methods based on (Rayment, Lyons 2010, Peverill, Reuter & Sparrow 1999) and these soils were termed “irrigated soils”. Each core was augured to a depth of 1.5 m or until auger refusal. The soil depth profiles are only reported to 0.5 m depth as this allowed a uniform data set to permit consistent comparisons. Each soil core was sampled at hundred millimeter intervals to establish detailed depth profiles for each transpiration zone. A total of twelve soil cores were collected from adjacent vacant lots using the methods previously described. These were not directly irrigated with greywater and are referred to as “non-
irrigated soils”. Sampling occurred between 22nd of January 2009 to 5 February 2009. Soil chemistry profiles were analysed every hundred millimeters, averaged and reported for that transpiration zone.

Each soil sample was analysed for: air dry moisture content @ 105ºC ((Rayment, Lyons 2010); pH and electrical conductivity by 1:5 soil water extraction (Eaton et al. 2005) (Rayment, Lyons 2010) extractable phosphorus as P by Colwell 0.5M NaHCO₃ auto analyser (Rayment, Lyons 2010); aluminium, iron and phosphorous by elemental analysis Mehlich3 extraction on Inductively Coupled Plasma-Optical Emission Spectrometer simultaneous detection analysis (Rayment, Lyons 2010); phosphorus single point buffer index by Colwell Auto Analyser (Rayment, Lyons 2010); and particle size analysis for coarse sand (2.0 to 0.2 millimeters), fine sand (0.2 to 0.02 millimeters) silt (0.02 to 0.002 millimeters) and clay (less than 0.002 millimeters) (Thorburn, Shaw 1987, Standards Australia 2003)

Phosphorus irrigation sustainability

The sustainability of greywater irrigation can be assessed by looking at phosphorus concentrations in greywater and the ability of the soil to bind the phosphorus. Modeling programs such as MEDLI (Gardner, Vieritz & Atzeni 2002) have been designed to assess the suitability of irrigation areas. However the analysis required for the model is expensive and not routinely conducted in Australian laboratories. Two alternate approaches have been postulated (1) the
Mehlich3 phosphorus saturation ratio (Sims et al. 2002) Equation 1; and (2) the Colwell-P and phosphorus buffing index ratio (Moody 2011).

**Equation 1 Mehlich3 phosphorus saturation ratio**

\[ M3PSR = \frac{P_{M3}}{Al_{M3} + Fe_{M3}} \]

- M3PSR = Mehlich3 phosphorus saturation ratio
- \( P_{M3} \) = Mehlich3 extracted phosphorus expressed in mmol kg\(^{-1}\)
- \( Al_{M3} \) = Mehlich3 extracted aluminium expressed in mmol kg\(^{-1}\)
- \( Fe_{M3} \) = Mehlich3 extracted iron expressed in mmol kg\(^{-1}\)

**Equation 2 Colwell-P and phosphorus buffing index ratio**

\[ \beta = \frac{PBI}{C^p} \]

- \( \beta \) = Colwell-P and phosphorus buffing index ratio
- \( PBI \) = Phosphorus single point buffer index by Colwell Auto Analyser
- \( C^p \) = Extractable phosphorus as P by Colwell 0.5M NaHCO\(_3\) auto analyser mgL\(^{-1}\)

**Phosphorus loading comparison**

To compare phosphorus loadings in the soil to the estimated greywater irrigation loads we need to calculate the soil nutrient content. To calculate the soil nutrient content the sites soil bulk density had to be estimated for each 100 millimeter horizon for each lot, then the calculation of the soil mass for each irrigation zone and then calculate the soil nutrients content for the entire soil profile and irrigation zone. This was done by using Equation 5, Equation 3 and Equation (Johnson 2012).
\[ \phi = \Delta NF \]

Where

\[ \phi = \text{Soil phosphorus (Colwell-P) nutrient content in kilograms per hectare} \]
\[ \Delta = \text{Soil mass in kilograms per hectare} \]
\[ N = \text{phosphorus nutrient content in milligrams per kilogram} \]
\[ F = \text{conversion factor to convert concentration} \]

Equation 3 Soil mass

\[ \Delta = T \rho (1 - S)10^5 \]

Where

\[ \Delta = \text{Soil mass in kilograms per hectare} \]
\[ T = \text{thickness of soil horizon in centimeters} \]
\[ \rho = \text{Site soil bulk density in grams per centimeter cubed} \]
\[ S = \text{soil fraction greater than two millimeters in decimal percent} \]

Equation 5 Site soil bulk density

\[ \rho = ((S/100) 1.5) + ((I/100) 1.3) + ((C/100) 1.2) \]

Where

\[ \rho = \text{Soil bulk density in grams per centimeter cubed (was determined by calculating every 100mm horizon and obtaining an average “site soil bulk density”)} \]
\[ S = \text{Particle size analysis percent sand (Sand = 1.5 g/cm³)} \]
\[ I = \text{Particle size analysis percent silt (Silt = 1.3 g/cm³)} \]
\[ C = \text{Particle size analysis percent clay (Clay = 1.2 g/cm³)} \]
Results and Discussion

Study area

In understanding the transpiration zones characteristics insight can be obtained into the household dynamics, as well as adding relevance of irrigation exposure in volume and time to help assess the soil profile chemistry. These characteristics are shown in Table 1 and are a summary of data collected during May 2005 to July 2009. In reviewing Table 1 it is evident that lots A, C and D irrigated similar volumes of greywater to their transportation zones, whereas (due to the lower number of occupants) Lot B had markedly less irrigation. The large family in Lot C resulted in the greatest volume of greywater irrigated, however nearly fifty percent was sent to sewer. Lots A and D had similar daily volumes applied whereas lot B had significantly less irrigation than all three. The final column in Table 1 displays the average volume of irrigated greywater per person per day during the monitored period; it is interesting to note, that with the different lengths of irrigation exposure and the different volumes of greywater produced, that the greywater irrigated per person per day are very similar. The Department of State Development, Infrastructure and Planning 2007, estimates greywater generation in sewered areas at 95 litres per person per day and 120 litres per person per day for unsewered areas. Queensland Urban Utilities 2012, estimates 106 litres per person per day. In another approach Diaper et al 2008, published an average value of 230 litres per household per day; Table 1 shows a variable range of 134 to 388 litres per household per day. In comparing this data, an average value of "litres per household per day" will not capture the variability of greywater generation, as
volumes generated are driven by the number of occupants in each household.

This is evident in the narrow range of 71 to 65 litres per person per day. However the values in Table 1 for litres per person per day are markedly lower than the estimates greywater generation in sewered and unsewered areas.

Table 1 Greywater (GW) irrigation figures

<table>
<thead>
<tr>
<th>Lot</th>
<th>Days of potential irrigation</th>
<th>Number of occupants</th>
<th>Total GW produced (Litres)</th>
<th>GW Irrigated (Litres)</th>
<th>% GW Irrigated</th>
<th>Total GW Irrigated (Litres/day)</th>
<th>GW Irrigated (LITRES/cap/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1678</td>
<td>4</td>
<td>485784</td>
<td>478612</td>
<td>98.5</td>
<td>285</td>
<td>71.33</td>
</tr>
<tr>
<td>B</td>
<td>1284</td>
<td>2</td>
<td>172486</td>
<td>172087</td>
<td>99.8</td>
<td>134</td>
<td>67.05</td>
</tr>
<tr>
<td>C</td>
<td>1255</td>
<td>6</td>
<td>940820</td>
<td>486887</td>
<td>51.8</td>
<td>388</td>
<td>64.68</td>
</tr>
<tr>
<td>D</td>
<td>1561</td>
<td>4</td>
<td>445858</td>
<td>433188</td>
<td>97.2</td>
<td>277</td>
<td>69.38</td>
</tr>
</tbody>
</table>

Surveyed results of each lots average weekly habits’ are presented in Table 2. The larger number of occupants residing in lot C (Table 1) is reflected in Table 2 by the highest number of showers. This is consistent with lot C having the most generated volume of greywater, which is a result of the bathroom/shower being one of the highest water use sections in any household, utilising greater than a quarter of all household water use (Christova-Boal, Eden & McFarlane 1996, Roesner et al. 2006, Widiastuti et al. 2008). Furthermore, Lot C has a higher frequency of using the dishwasher and washing dishes manually and it has been reported that laundry waste water carries some of the highest levels of pollutants (Stevens et al. 2011, Lanfax Labs 2009, Misra, Sivongxay 2009).

Table 2 Summary of average weekly house activities that can impact greywater quantity and composition.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Monday</th>
<th>Tuesday</th>
<th>Wednesday</th>
<th>Thursday</th>
<th>Friday</th>
<th>Saturday</th>
<th>Sunday</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lot A (4 Occupants)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clothes washing (number of loads)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Dishwasher</td>
<td>0</td>
<td>Yes</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>Yes</td>
<td>0</td>
</tr>
<tr>
<td>Washing up dishes (manually)</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Shower (number of showers)</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Lot B (2 Occupants)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clothes washing (number of loads)</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Dishwasher</td>
<td>0</td>
<td>0</td>
<td>Yes</td>
<td>0</td>
<td>0</td>
<td>Yes</td>
<td>0</td>
</tr>
</tbody>
</table>
A diverse range of household products are used by the studied households, when we observe the products for clothes washing (Table 3). Both lots A and B used a low phosphorus product with approximately one to two milligrams per liter, lot C utilise a product which has phosphorus concentrations of approximately 45-55 milligrams per liter and Lot D has the highest phosphorus concentrated laundry detergent of all four, with approximately 75 milligrams per liter (Lanfax Labs 2009). Reviewing these results with the phosphorus soil concentrations will be essential, as these product and soil concentrations should be of similar proportions.

Residents of each lot were questioned about their knowledge of water efficiency and their understanding of greywater sustainability is summarised in Table 3. As this interview was conducted during a prolonged drought in Queensland, each resident was keenly aware of water efficiency concepts and measures. However, due to the nature of lot C’s household demographic, implementing water efficiency was difficult and this was acknowledged by the resident. When the residents were interviewed about greywater sustainability each lot identified knowledge in the area. Lot A’s occupants had recently moved in (approximately
4 months prior) and the previous resident was not able to be interviewed. Lot B showed the most understanding of greywater sustainability and the impacts of the irrigation. Lot C had knowledge of greywater sustainability, but due to the household demographic they were not able to or did not want to apply any of that knowledge towards greywater irrigation. Lot D had knowledge of greywater sustainability but did not know the full impacts of each of the products they used in their household.

Table 3 Household product use

<table>
<thead>
<tr>
<th>Activity</th>
<th>Lot A product name</th>
<th>Lot B product name</th>
<th>Lot C product name</th>
<th>Lot D product name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clothes washing liquid or powder</td>
<td>Green Care</td>
<td>Biozet</td>
<td>Surf &amp; Bus-matic</td>
<td>Cold Power Liquid</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(frontloader)</td>
<td>Advanced (lemon)</td>
</tr>
<tr>
<td>Clothes washing fabric softener</td>
<td>Cuddly</td>
<td>Fluffy</td>
<td>Fluffy Ultra</td>
<td>Nil</td>
</tr>
<tr>
<td>Clothes washing prewash treatment</td>
<td>Oxy Advanced</td>
<td>Sard Oxy Plus Spray &amp;</td>
<td>Napisan</td>
<td>Napisan</td>
</tr>
<tr>
<td>(bleach, enzyme, brightener)</td>
<td>Powder</td>
<td>Powder</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dishwasher liquid, powder, tablet</td>
<td>Finish</td>
<td>Coles dishwashing powder</td>
<td>Finish Powerball</td>
<td>Finish Powerball</td>
</tr>
<tr>
<td>Dishwasher clearing agent (sparkle)</td>
<td>Finish</td>
<td>Unknown</td>
<td>Nil</td>
<td>Nil</td>
</tr>
<tr>
<td>Dishwashing liquid</td>
<td>Earth Choice</td>
<td>Earth Choice</td>
<td>Sunlight &amp; Trx</td>
<td>Palmolive - antibacterial</td>
</tr>
<tr>
<td>Water efficiency*</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Greywater sustainability~</td>
<td>Unknown</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

In summary, the study area has a diverse range of factors which will impact on the quantity and quality of the greywater. Some of the important influences are; lot A's use of low phosphorus products; lot B's low water use, use of low phosphorus products as well as their knowledge of greywater sustainability; Lot C's high water use and high phosphorus containing product use; Lot D's comparatively average water use but having the highest phosphorus containing product.

Greywater quality

Between 11 and 15 individual samples of each lots greywater were analysed for pH, electrical conductivity, sodium adsorption ratio, calcium, magnesium, sodium, potassium, total nitrogen and total phosphorous, with a total of 51
samples analysed for the study site. Results are shown in Table 4 for lot A, Table 5 for lot B, Table 6 for lot C and Table 7 for lot D, and a summary of all samples in Table 8.

The pH of the greywater for each of the four lots ranges between 5.7 and 10.3 (Table 8) with the average pH for lot A, B and D between 7.3 and 7.6 whereas lot C has an average pH of 8.7 a marked difference. The electrical conductivity (EC) of the greywater has a similar pattern as the pH, lot A, B and D have an average between 378 and 451 μS cm$^{-1}$ whereas lot C was significantly higher with an average EC of 1239 μS cm$^{-1}$. Lot C also had the maximum EC of 2511 μS cm$^{-1}$. Lot C’s high EC could be attributed to the use of a front loader washer as this type of washing machine will generate higher concentrated greywater, it’s interesting to note that even though Lot C utilised the most water the EC still remains high as one would assume there would be obvious dilution. The high EC is most probably a result in the high number of washing cycles due to the household demographic. It must be noted that as the source water for each household is captured rain water (conductivity averaging 10 μS cm$^{-1}$), thus the conductivity of the greywater is a true representation of products added from each household. This situation gives us insights into the true nature of the household products added to the greywater. The pattern of Sodium Adsorption Ratio (SAR) between the lots is slightly different. Lots A and B had averages of 11 and 12, respectively and lot D had the lowest average of 6.2; while lot C still had the highest average SAR of 36 as well as the maximum SAR value of 79. The likelihood of this will be due to the cations (Ca, Mg, Na and K) contained in the household products. Yet again this is most probably a result in the high number of washing cycles. It must
be noted that when we irrigate soil with high SAR (Misra, Sivongxay 2009, Dawes, Goonetilleke 2006, Dawes, Goonetilleke & Cox 2005) the soil structure starts to degrade, resulting in reduced permeability. Furthermore if the degradation results in transformation to sodic soils, this can lead to increased accumulation of greywater compounds, reduced infiltration through the soil profile and an increase possibility of surface soils erosion (Dawes, Goonetilleke & Cox 2005). This erosion could further increase the availability of phosphorus to surface water runoff, amplified by the steep nature of the site and its relative location to Enoggera Creek. Potential water eutrophication could occur demonstrating non sustainable greywater irrigation.

### Table 4 Greywater quality lot A

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Median</th>
<th>Mean</th>
<th>Lower bound on mean (95%)</th>
<th>Upper bound on mean (95%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>6.4</td>
<td>7.6</td>
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<td>320.0</td>
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### Table 5 Greywater quality lot B

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<th>Parameter</th>
<th>Minimum</th>
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<th>Median</th>
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<td>1043</td>
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<td>Calcium (soluble) as Ca mg/L</td>
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<td>315</td>
<td>315</td>
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<td>320.0</td>
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### Table 6 Greywater quality lot C

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<td>5.9</td>
<td>9.0</td>
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<td>11</td>
<td>11</td>
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<td>11</td>
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<tr>
<td>Calcium (soluble) as Ca mg/L</td>
<td>24.0</td>
<td>63.0</td>
<td>30.0</td>
<td>30.0</td>
<td>30.0</td>
<td>30.0</td>
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<tr>
<td>Magnesium (soluble) as Mg mg/L</td>
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<td>8.0</td>
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<tr>
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<td>1.0</td>
<td>1.0</td>
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<tr>
<td>Potassium (soluble) as K mg/L</td>
<td>11.0</td>
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<td>15.9</td>
<td>15.9</td>
<td>15.9</td>
<td>15.9</td>
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<tr>
<td>Total Nitrogen mg/L</td>
<td>3.4</td>
<td>49.0</td>
<td>28.0</td>
<td>28.0</td>
<td>28.0</td>
<td>28.0</td>
</tr>
<tr>
<td>Total Phosphorous mg/L</td>
<td>3.4</td>
<td>49.0</td>
<td>28.0</td>
<td>28.0</td>
<td>28.0</td>
<td>28.0</td>
</tr>
</tbody>
</table>
The comparison of total phosphorus in the greywater of the four lots (Table 4 to Table 7) demonstrates a similar pattern to the products used in each household. In quick review; Lot A and B had low phosphorus products whereas lot C and D had high levels phosphorus products. The average phosphorus concentration in greywater increased from Lot B, to lot A, to lot D and finally lot C with values of 4.1 mgL⁻¹, 12.1 mgL⁻¹, 16.7 mgL⁻¹ and 25.4 mgL⁻¹, respectively and this is of a similar proportion to the noted household products described in Table 3. Furthermore Lot D had the highest phosphorus containing product which would produce water from the laundry of approximately 75 mgL⁻¹ and the maximum recorded phosphorus levels is from lot D was 65 mgL⁻¹. In reviewing the
greywater phosphorus results for lot C (Table 6) and noting the irrigation
volumes and irrigation duration (Table 1); lot C's transportation zone has been
irrigated with the highest average phosphorus concentration, the maximum
irrigation volumes and established the shortest amount in time. This can only
lead to this lots transpiration zone having the highest levels of phosphorus in the
soil. Therefore lot C's potential environmental impacts as a result of greywater
irrigation has no long term sustainability from phosphorus loading.

In reviewing the “Queensland Plumbing and Wastewater Code 2007”, in relation
to greywater statutory requirements under the Plumbing and Drainage Act 2002;
lot C has adhered to all aspects; lot C has twice the recommended irrigation area,
(200m² as opposed to the recommended 108m²) uses less than 95 liters per
person per day (65 liters per person per day) and yet the potential phosphorus
loading is extreme (no legislative guidelines). There is a high risk of
environmental impacts and there is limited long term irrigation sustainability.
Yet again this illustrates that legislation is lacking on greywater irrigation, as
they tend to focus on human health and unfortunately do not address relevant
issues on environmental impacts and sustainability from greywater irrigation.

The pH, electrical conductivity, Sodium Adsorption Ratio (SAR), Total Kjeldahl
Nitrogen as N (TKN) and Total Phosphorus as P (TP) of the greywater were
compared to; the Australian Guidelines for Water Recycling (AGWR)
(Environment Protection and Heritage Council 2006); Christova-Boal (Christova-
Boal, Eden & McFarlane 1996); CSIRO (Diaper, Toifl & Storey 2008), Beal et al
(Beal et al. 2008) and Stevens (Stevens et al. 2011) (Table 9).
Table 9 Greywater comparisons to other research

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
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<td>6.4—10</td>
<td>5.0—10.0</td>
<td>5.4—10.3</td>
<td>6.5—8.0*</td>
<td>10.4—11.1</td>
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<td>Conductivity (µS/cm)</td>
<td>53—640</td>
<td>82—1400</td>
<td>80—1300</td>
<td>280—2500</td>
<td>300—400</td>
<td>950—6700</td>
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<td>Sodium Adsorption Ratio</td>
<td>4—12</td>
<td>0.9—32</td>
<td>0.79—32</td>
<td>2—79</td>
<td>NR</td>
<td>55—379</td>
</tr>
<tr>
<td>Total Kjeldahl Nitrogen as N (mg/L)</td>
<td>1.2—16</td>
<td>1.0—40</td>
<td>0.06—50</td>
<td>0.1—43</td>
<td>3.0—5.0</td>
<td>NR</td>
</tr>
<tr>
<td>Total Phosphorus as P (mg/L)</td>
<td>0.3—5.1</td>
<td>0.06—42</td>
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<td>1.8—65</td>
<td>10—20</td>
<td>&lt;1—245</td>
</tr>
</tbody>
</table>

1 Combination of bathroom and laundry water sources
2 Water source is laundry only and range is 5th to 95th percentile
3 Synthetic Greywater
4 Calculated not published

Need to provide a short summary of what all this means.
Eg The values from the present study are largely consistent with the data from previous reported Australian studies except SAR is markedly lower. This means .... (results are able to be applied)
Soil profiles

To understand the soil conditions in each lot and to permit comparisons of the chemical and physical nature of the soils between each lot as well as comparisons to the non-irrigated control soils, detailed soil depth profile graphs have been created and are shown in Figure 2 to Figure 5 for pH, EC, Colwell P and PBI.

![Depth Profile pH](image)

**Figure 2** Depth profile for pH for each lot and non-irrigated control sites (the averaged concentration data has been plotted for each 100mm horizon at a depth value of 0.05m i.e. horizon 0.2—0.3m is plotted at 0.25m).

All lots are more alkaline compared to the control, non-irrigated soils (Figure 2), except for lot C at depths greater than 0.2 m. This is most likely to be due to the presence of detergents and other household products in greywater. The alkaline greywater in this instance is theoretically improving the soil (from an acidic range of 5.4-5.8), as the pH of soil should be around 6.0 to 7.5 pH units for optimal soil fertility. The increase of pH is due to the cations (K⁺, Ca⁺, Mg⁺ and Na⁺) binding to the soil solids through cation exchange. The greywater cation results shown in Table 4 to Table 8 are generally low when compared to *National guidelines for water recycling 2006*, thus the irrigation cation loadings will be
lower, helping lengthen the sustainability of the transportation zone in terms of pH and potentially EC irrigation. Generally, in Figure 2, each lot's soil pH decreased and approached the non-irrigated control values with increasing depth, confirming that the cation additions through cation exchange are increasing the soils pH. In this instance with the more acidic nature of the non-irrigated soil, the addition of greywater seems to be of a sustainable nature; as the pH has moved to above 6 pH units (optimal for soil fertility). As long as future irrigation do not elevate the pH towards alkaline conditions (greater than 7.5 pH units) resulting in potential sodic soils. The current levels of greywater irrigation should have minimal impacts and be considered sustainable.

**Figure 3** Depth profile for; electrical conductivity (EC, dScm⁻¹) for each lot and non-irrigated control sites (the averaged concentration data has been plotted for each 100mm horizon at a depth value of 0.25m i.e. horizon 0.2—0.3m is plotted at 0.25m).

The electrical conductivity of lot C is higher than the other three lots at all depths, which can be linked to the markedly high levels of sodium salts in their greywater (Table 6). Generally, with increasing depth the electrical conductivity decreased and approached the values of the non-irrigated control sites. This data is generally not consistent with other literature as they tend to show high conductivity levels in soils irrigated with greywater. (Howard et al. 2007,
The overriding reason is the fact that the source water for these lots is rain water (low starting conductivity as previously stated), furthermore the addition of salts from greywater irrigation is lower ($K^+$, $Ca^+$, $Mg^+$ and $Na^+$) as seen in Table 4 to Table 8. The soil conductivity confirms that with all lots there is minimal impact from greywater irrigated salts.

![Graph](image)

**Figure 4** Depth profile for Colwell extractable phosphorus (mg kg$^{-1}$) for each lot and non-irrigated control sites (The averaged concentration data has been plotted for each 100mm horizon at a depth value of 0.25m i.e. horizon 0.2—0.3m is plotted at 0.25m).

The concentration of Colwell extractable P in the soil surface (0.0 to 0.1 m) decreased in the following order Lot A, C, D and B. Lot B’s Colwell extractable P levels are very low, even lower than the non-irrigated soils. This could be a result of the location of the lot (Figure 1) being on a slightly different ridge to the other three lots, and having the lowest concentration of phosphorus in the greywater (Table 5). The concentrations of lots A, C and D all were greater than for the non-irrigated soils, while that for lot B was marginally less than the non-irrigated soils. In general, the Colwell extractable concentration decreased with increasing depth, apart from lot B which remained essentially unchanged. At a depth of 0.3 to 0.4 m the Colwell P values for all lots, except lot C, converged to the same
concentration as the non-irrigated soils, demonstrating that the movement of the irrigated phosphorus is being bound by the soil. Irrespective of depth the Colwell P concentration of lot C remained greater than that of the non-irrigated soils. Figure 4 confirms the values seen in Table 4 to Table 7, with lots, A, B and D having markedly lower median total phosphorus concentrations in greywater than lot C. With excessive phosphorus concentration plant growth can be inhibited. With soils having a pH less than 7 (as seen in Figure 2), excessive phosphorus can lead to Iron deficiency (Moody, Bolland 1999). Furthermore the Queensland Department of Primary Industries and Fisheries states that Colwell P levels should not exceed 150mgkg\(^{-1}\) because of the risk of offsite phosphorus movement (Pattison, Moody & Bagshaw 2010). In light of these findings, it is evident that the current levels of irrigated phosphorus in the greywater (with an average range of 5—65mgL\(^{-1}\)), the high Colwell P concentration already in the soil (with an average range of 2—620mgkg\(^{-1}\)), questions over the long term sustainability of the whole development must be explored. To explore this sustainability it is important to investigate if the current transpiration zones still have a capacity to adsorb more irrigated phosphorus in the future. To assess this, details of the soil’s Phosphorus Buffering Index (PBI) for each lot as well as the non-irrigated control sites are shown in Figure 5.
Figure 5 Depth profile for Phosphorus Buffering Index (PBI) for each lot and non-irrigated control sites. (The averaged concentration data has been plotted for each 100mm horizon at a depth value of 0.25m i.e. horizon 0.2—0.3m is plotted at 0.25m)

In Figure 5, the PBI of all lots has decreased in comparison to the non-irrigated soils. The current PBI capacity of lots A, B and D are less than 110. It is fortuitous that lot C has the highest PBI capacity (of the irrigated lots) as it also has the highest average phosphorus irrigated greywater (Table 6) This could support the adsorption of the high levels of phosphorus in the future, potentially lengthening the transpiration zones sustainability. As the PBI of all the studied soils are not high (i.e. a PBI value greater than 840 which would have significant phosphorus sorption capacity (Peverill, Reuter & Sparrow 1999)) further sustainability is required and needs to be achieved by all lots using or continuing to use low or no phosphorus containing household products, especially lots C and D.

Phosphorus irrigation sustainability

To evaluate the sustainability of the transpiration zone and the potential environmental impact we need to review Table 10 and Table 11. The two tables
evaluate each 100 millimeter horizon in relation to potential phosphorus loss to the environment and thus the phosphorous irrigation sustainability.

Table 10 Phosphorus irrigation sustainability using the Mehlich3 phosphorus saturation ratio (M3PSR); values with a × indicate significant phosphorus leaching risks; values with a † indicate environmental concern with regards to phosphorus leaching; values with a ✓ indicate no environmental concern due to phosphorus leaching.

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Lot A</th>
<th>Lot B</th>
<th>Lot C</th>
<th>Lot D</th>
<th>Average</th>
<th>Non irrigated</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>0.71</td>
<td>0.03</td>
<td>0.47</td>
<td>0.14</td>
<td>0.32</td>
<td>0.07</td>
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<td>0.2</td>
<td>0.37</td>
<td>0.02</td>
<td>0.28</td>
<td>0.05</td>
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At the surface (0—0.1 m) the M3PSR values (Table 10) for lots A and C displayed significant phosphorus leaching risks to the surrounding environment (M3PSR values greater than 0.2). Lot D had M3PSR values that indicated that leaching was of environmental concern (M3PSR 0.10—0.15) whereas Lot B displayed similar results to the non-irrigated soils (0.03 and 0.07 respectively). As the soil depth approached 0.5 m the M3PSR values converged with the non-irrigated soil values. Irrigating greywater onto the surface soil (Table 11) in lots A and C poses a significant environmental phosphorus risk (i.e., Colwell-P and phosphorus buffing index ratio greater than 2.0 could lead to loss of phosphorus to the environment). Lot D showed ratios that were of intermediate environmental risk (i.e., ratios less than 2.0), whereas Lot B posed a similar risk to that for the non-irrigated soils (0.30 and 0.73 respectively). Is it therefore not sustainable to continue irrigating greywater to the transpiration zones at lots A, C and D. As it is no longer sustainable the question should be asked, is the perched groundwater contaminated? It also appears that in Table 10 and Table 11 the saturated surface layers could cause preferential movement of phosphorus into both
surface water and through the soil profile, thus potentially intercepting the

Table 11 Colwell-P and PBI ratio values, down to 0.5m depth for each lot and non-irrigated control sites (Colwell-P and phosphorus buffing index ratio greater than 2.00 could lead to loss of phosphorus to the environment, whereas ratios less than 2.0 pose an intermediate environmental risk).

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Lot A</th>
<th>Lot B</th>
<th>Lot C</th>
<th>Lot D</th>
<th>Average</th>
<th>Non irrigated</th>
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<tr>
<td>0.1</td>
<td>3.42</td>
<td>0.30</td>
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<td>0.2</td>
<td>2.02</td>
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<td>1.00</td>
<td>1.56</td>
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<td>0.3</td>
<td>0.74</td>
<td>0.28</td>
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<td>0.56</td>
<td>0.82</td>
<td>0.32</td>
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<td>0.4</td>
<td>0.45</td>
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<td>1.08</td>
<td>0.29</td>
<td>0.60</td>
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<td>0.12</td>
<td>0.95</td>
<td>0.26</td>
<td>0.49</td>
<td>0.10</td>
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Phosphorus loading comparison

Beal et al. (2008) hypothesized that irrigating (on Lot A to D) with greywater was sustainable despite the high concentrations of phosphorus. Beal et al 2008 research showed the average loading range of phosphorus irrigated to the transpiration zones areas, was between 54 to 127 kg.ha⁻¹ yr⁻¹. With a further two years of irrigation and further greywater analysis this study has been able to update Beal et al 2008 data and is shown in Table 12.

Table 12 Theoretical Phosphorus (P) loading rates to irrigation area

<table>
<thead>
<tr>
<th>Lot</th>
<th>No. days of irrigation</th>
<th>Years of irrigation</th>
<th>Mean P Load (kg/Ha/yr)</th>
<th>Lower 95% CI for P load (kg/Ha/yr)</th>
<th>Upper 95% CI for P load (kg/Ha/yr)</th>
<th>Maximum P load (kg/Ha/yr)</th>
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<td>A</td>
<td>1678</td>
<td>4.60</td>
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<tr>
<td>B</td>
<td>1284</td>
<td>3.52</td>
<td>10</td>
<td>4</td>
<td>16</td>
<td>32</td>
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<tr>
<td>C</td>
<td>1255</td>
<td>3.44</td>
<td>180</td>
<td>93</td>
<td>268</td>
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<td>D</td>
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<td>4.28</td>
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<td>142</td>
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</table>

With further and more comprehensive research, the phosphorus loading range became more dynamic and varied; this revised phosphorus loading of 10 to 180 kg.ha⁻¹ yr⁻¹ for the four lots was observed with the potential maximum
application of phosphorus of 350 kg ha\(^{-1}\) yr\(^{-1}\). Crush and Rowarth 2007, stated that commonly commercial pasture fertilisation practice applies about 30 kg P ha\(^{-1}\) yr\(^{-1}\), which is exceeded by the mean of lot A, C and D, whereas (Vieritz et al. 2003) demonstrated an optimal uptake of 100 kg P ha\(^{-1}\) yr\(^{-1}\) from grass, which is only exceeded by lot C. The potential maximum phosphorus load exceeds the 30 kg ha\(^{-1}\) yr\(^{-1}\) application of phosphorus by commercial pasture practices, tenfold and also exceed the 100 kg P ha\(^{-1}\) yr\(^{-1}\) stated for grass uptake by three fold demonstrating that significant phosphorus is being irrigated and can't be used by plant uptake nor sustained by this transpiration zone. It is likely that phosphorus could be transported to nearby waterways. Lot B upper 95 percent confidence interval for phosphorus loading is 16 kg ha\(^{-1}\) yr\(^{-1}\), which is well under the commercial pasture application rates. As most of the transpirations zones are turfed there is potential for excessive phosphorus loading on the soil from lots A, C and D. To enhance the sustainability of these transpiration zones simple steps could be taken (e.g. changes of washing products and through education) to protect any long term environmental impact.

The theoretical loads of phosphorus from the irrigation water were compared to the actual Colwell-P phosphorus concentrations in the soil samples to a depth of 0.4m. In general, below 0.4m the non-irrigated soils were equal to or slightly exceeded the different lots. The loading rates from Table 12 were compared to the soil nutrient content of added horizons down to 0.4m this comparison can be seen in Table 13.
Table 13 Phosphorus (P) loading comparison (Soil Colwell P kgHa$^{-1}$ = Total Colwell P – non-irrigated Colwell P per 100 millimeter horizon totaling 0.0 to 0.4m, estimated GW loads (P) are calculated from actual greywater irrigation concentrations)

<table>
<thead>
<tr>
<th>Lot</th>
<th>Soil Colwell P kgHa$^{-1}$</th>
<th>Estimated GW load P kgHa$^{-1}$ for the irrigation period (CI 5% — x — CI 5%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>425</td>
<td>91—269—448</td>
</tr>
<tr>
<td>B</td>
<td>&lt;1</td>
<td>14—32—49</td>
</tr>
<tr>
<td>C</td>
<td>769</td>
<td>288—560—831</td>
</tr>
<tr>
<td>D</td>
<td>105</td>
<td>110—334—558</td>
</tr>
</tbody>
</table>

The Colwell-P in each soil profile is clearly of the portions of irrigated phosphorous. Yet again lot C displays higher results for phosphorus, with lots A and D being comparable to each other. Lot B had significantly lower concentrations. Future sustainability can also be assessed by doubling the exposure time (irrigation volumes “GW Load P kgHa$^{-1}$”) approximately another four years of irrigation to estimate potential “Soil Colwell P kgHa$^{-1}$” concentrations. Lot A is estimated to have Colwell-P levels of 539 kgHa$^{-1}$; Lot B 63 kgHa$^{-1}$, Lot C 1119 kgHa$^{-1}$, Lot A 669 kgHa$^{-1}$. At these current rates of irrigation there is limited sustainability of Lot’s A, C and D based on the M3PSR and PBI ratios, and potential utilization by plants. This would cause substantial impacts from phosphorus to the surrounding environment.

Conclusions

In assessing the sustainability of greywater irrigation, the data clearly shows benefits regarding water reuse, as the four lots collectively saved 1.6 million litres of potable water over four years. However in assessing greywater irrigation with respect to phosphorus as a limiting factor in sustainability, and
looking at the transpiration zones soil and adverse environmental impacts the
results are varied. It is clear that two lots (A and C) displayed a significant
phosphorus leaching risk to the surrounding environment and therefore have
limited sustainability. It was demonstrated that one lot (D) showed levels of
phosphorus that was of environmental concern but with careful management it
could be considered sustainable. Whereas another lot (B) displayed similar
phosphorus leaching risk results to the non-irrigated control soils and
demonstrates sustainable greywater irrigation. These varied results emphasize
that there is limited knowledge of domestic greywater reuse. It shows there is a
lack of understanding in the residents' ability to connect how the household
products are associated with the water quality of greywater and its impact on
the irrigation zones soil. This lack of understanding is not helped by the fact
there is still no holistic desire to produce or use low-level phosphorus products.
Additionally, if current guidelines and legislation were adequate and contained
guidelines on phosphorus irrigation loadings the situation with lot A and C could
be avoided and lot D successfully managed. To assist the enhanced legislation,
education programs could encourage residents to understand the impact of
household products on greywater and be active in maintaining their
environmental footprint. This would assist in the sustainable outcomes for
greywater irrigation.

The reported phosphorus soil concentrations and the estimated greywater
loadings were of the similar magnitude, indicating that M3PSR and PBI ratios are
useful surrogates for determining long term P loadings in irrigated soils.
Furthermore irrigation (sub-surface) assessment models such as MEDLI could be
enhanced by including this data, which in turn would help model future residential developments.

It is important to conclude by remarking that the results from lot B do demonstrate that with knowledge, appropriate household product use and responsible use of greywater; that is, being a good citizen, sustainable greywater irrigation can significantly reduce the phosphorus load thus significantly reducing environmental risk. Greywater irrigation can be practiced sustainably.

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