ENVIRONMENTALLY FRIENDLY USE OF GREYWATER THROUGH SELECTING GREYSMART HOUSEHOLD PRODUCTS

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ABSTRACT

An environnmental risk assessment tool was developed using the approach in the Australian Guidelines for Water Recycling (NRMMC and EPHC 2006) to assess if household laundry products were greywater friendly or GreySmart. A preliminary risk assessment was then completed on 142 different clothes washing detergents (most currently available in Australia). Data from the literature (60 to 70% of data required for the GreySmart assessment was available) was used to determine if the household products were greywater friendly (GreySmart). Only 16% (23) of the detergents assessed were considered environmentally safe for use of the greywater from the clothes wash-only cycle to irrigate the household garden. This assessment has helped focus which detergents could still be ranked as very low to low risk (i.e. GreySmart or GreySmart with Care) if missing data is obtained through additional analysis.

This paper also shows that there are a large number of clothes washing detergents currently on the market (120) that could have a deterimental impact on household gardens and plants. These observations highlight the need for the GreySmart project to assist the public with making informed choices when selecting household cleaning and personal care products that may end up in the greywater they use for irrigation around the house.

INTRODUCTION

Through the recent drought approximately 60% of Melbourne households have used greywater to some extent. In Victoria, grey water was the most common source of water for the garden (42.7%) (ABS 2007). An assessment of current household cleaning and personal care products indicates that this is not sustainable in the long term (>20 years), and may in some cases be detrimental to plant and soil health in the short-term (1-19 years). Recent studies have highlighted the impacts on soils and importance of using greywater friendly products if using greywater (Landloch Pty Ltd 2005; Meehan and Maxey 2009; Namdarian 2007).

The aim of this GreySmart project is to provide a website with sufficient information for consumers to make informed choices on selection of products (or source control as defined in the Australian Guidelines for Water Recycling). Source control is the best control measure if long-term greywater irrigation is practiced. GreySmart will rank greywater friendliness of household products (i.e. GreySmart) based on impacts on the environment where they are used (the garden). Impacts on plants, soils, microbes and nearby waterbodies will be assessed.

A detailed environmental risk assessment underpins GreySmart and enables the development of a definition for 'greywater friendliness' or 'GreySmart' for urban irrigation in Melbourne and across Australia. The resulting definition extends beyond nitrogen, phosphorus and sodium concentration to include boron, sodium absorption ratio, pH, salinity, residual sodium carbonate, cadmium, biodegradability and potentially other parameters in the future, allowing for more accurate assessments of 'greywater friendly products' and calculations of acceptable loads on garden plants and soil textures. In turn, this enables assessment of household products for their greywater friendliness based on typical usages and concentration of resulting hazards in greywater. It also identifies additional control measures that can be used in the garden.

GreySmart's approach allows providers, installers and users of greywater to access this information in an easy to understand practical format. The research undertaken as part of this ongoing project has been combined with data from across Melbourne (funding is being sought to include Australia) and synthesised into a user friendly website, promoted through a strategic communications and marketing plan that utilises existing water authority networks. The website also incorporates an interactive web calculator (H_2Ome*Calc*) for setting up greywater and rainwater systems, and acts as a focused knowledge bank for greywater use in Victoria and across Australia (www.greysmart.com.au).

This paper reports on the science behind developing the GreySmart ranking system for greywater friendly household products and the features of the GreySmart website.

METHODOLOGY

Review of hazards

A comprehensive review identified hazards found in household personal use and cleaning products (e.g. from clothes washing detergent to sunscreens) that were likely to enter the greywater. The review also assessed greywater quality reported in national and international literature to determine the concentration of potential hazards and the risk they may pose (Stevens and Wilson 2009). This review identified 10 hazards that should be considered for the use of greywater on household gardens:

1. Acidity/alkalinity (pH)
2. Electrical conductivity (EC)
3. Boron (B)
4. Cadmium (Cd)
5. Phosphorus total (P_{total})
6. Nitrogen total (N_{total})
7. Sodium adsorption ratio - surface structure ($SAR_{surface}$)
8. Sodium adsorption ratio - soil stability ($SAR_{stability}$)
9. Residual sodium carbonate (RSC)
10. Degradability (organic chemicals)

Zinc was also identified for specific cases where sunscreen or certain antidandruff shampoos were used. These should be avoided if using shower water for irrigation of household gardens.

Organic hazards measured in greywater for this report were taken primarily from two studies with a limited number of samples (Eriksson et al. 2003; Almqvist and Hanaeus 2006). Data on the measurement of organic hazards present in greywater are currently limited and represents a significant gap in the data required to assess the environmental risk posed by irrigation of greywater on household gardens.

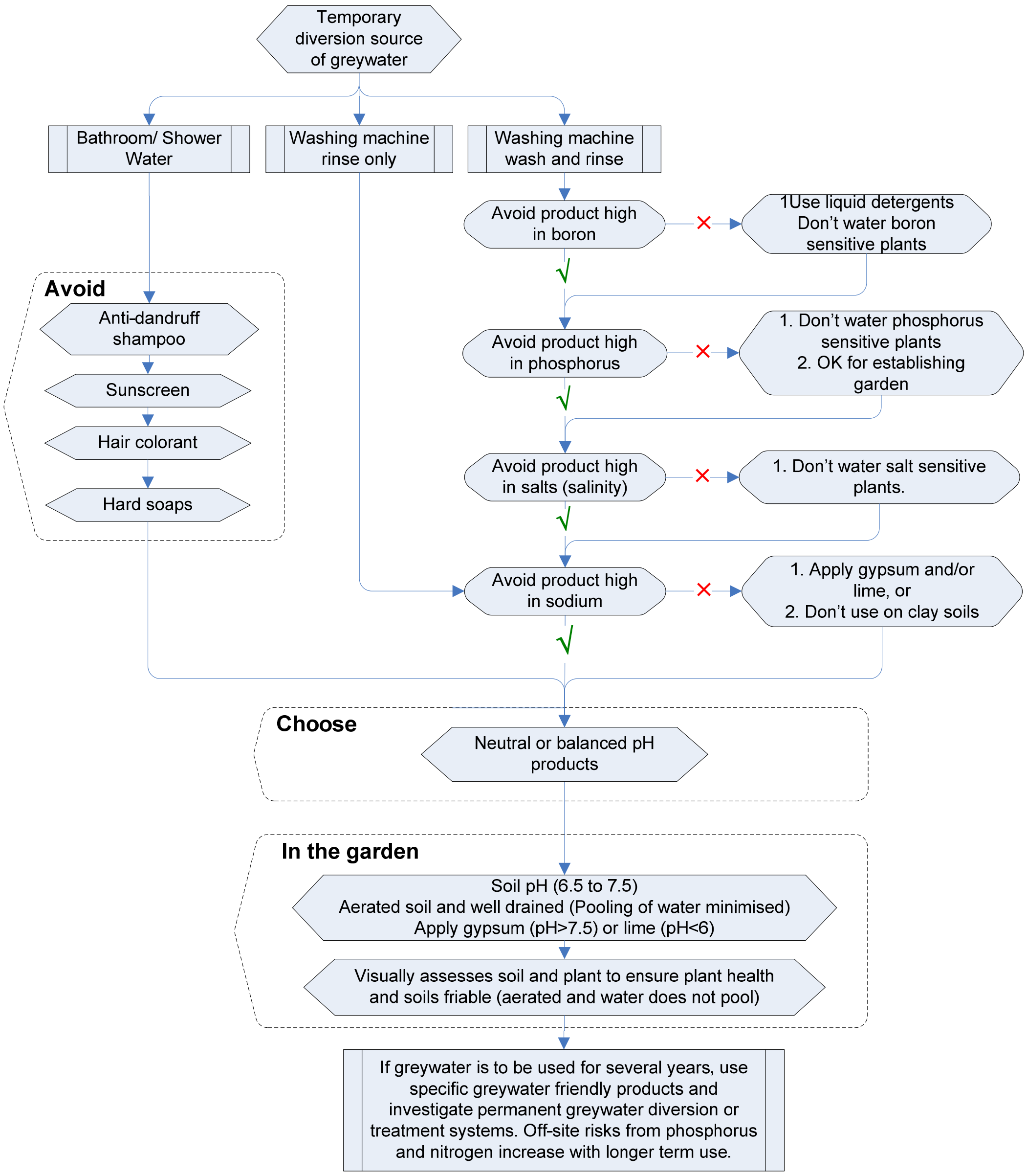

Figure 1: Simplified decision tree for temporary use of greywater sources (Stevens and Wilson 2009).

The detailed risk assessment by Stevens and Wilson (2009) defined linear alkylbenzene sulphonate (LAS) to be of moderate risk, requiring ongoing monitoring and assessment. There were limited terrestrial toxicity data available for other organic chemicals commonly found in household cleaning and personal care products and this is an area requiring further research.

Given the hazards found in recycled water, Stevens and Wilson summarised a method for greywater management that would minimise the householders' risk when irrigating with greywater (Figure 1). However, to maximise the greywater available for reuse, the householder must choose appropriate products to use in the home and/or onsite management in the garden is required.

The variability of greywater quality is highlighted by Figure 2, which indicates measured pH concentration in greywater when all sources are mixed or if the greywater is taken from the clothes washing machine only. Again, this data indicates that the source of the greywater and the cleaning products used in specific parts of the house are important factors when managing the risks posed by using greywater for irrigation around the home.

To give householders this choice, the aim of the GreySmart ranking system was to develop a comprehensive risk assessment tool to determine the greywater friendliness of products that could eventually end up in greywater used for irrigation around the house.

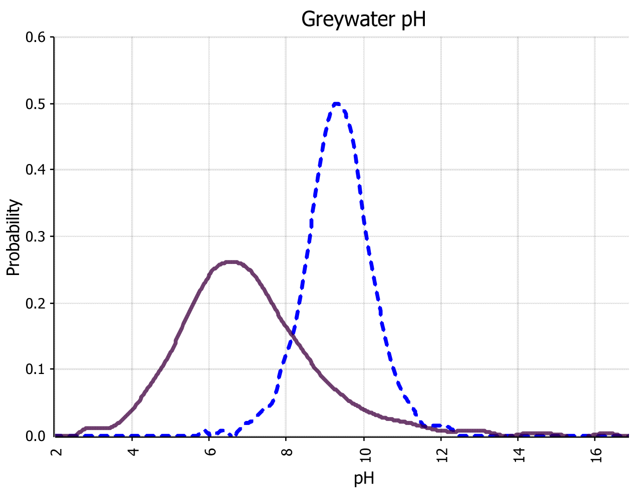

Figure 2: Comparison of greywater pH modelled from all greywater sources combined (solid) and washing machine greywater only (dashed) (Landloch Pty Ltd. 2005).

GreySmart ranking system

The GreySmart ranking system was developed utilising the Australia Guidelines for Water Recycling (AGWR) (NRMMC and EPHC 2006) as a foundation. The risk assessment was completed using a semi-quantitative method where risk was determined by:

likelihood + impact = risk

Other inputs required for the risk assessment were:

1. Top soil texture (light clay assumed)
2. Top soil depth (mm)
3. Irrigation demand (600 mm assumed)

The risks posed by SAR are modified as soil texture varies. This is becasue clay is required for sodicity to affect soil structure (ANZECC and ARMCANZ 2000; NRMMC and EPHC 2006).

Likelihood

Likelihood for greywater use was assumed to be likely to almost certain (i.e. will occur once or multiple times within a year; NRMMC and EPHC 2006). If the likelihood varies from possible to almost certain, the likelihood definitions in the AGWR does not affect the risk determined by the risk matrix (Table 2.7 of the AGWR; NRMMC & EPHC 2006). Therefore the major variance in the risk determined will be influenced predominantly from the impact of specific hazards.

Impact

Impact was assessed using data from a variety of sources to develop probability distribution functions (PDFs) if sufficient data was available, or trigger values were used if data was limited. Data for household lawn and garden plants were also used in preference to agricultural crop plants (Table 1).

Table 1: Data used to determine PDFs and trigger values for assessment of impact from a hazard.

Parameter	Abbrev.	References
Acidity/alkalinity	pH	(USDA 1998; Anderson et al. 2007; Handreck and Black 2002)
Electrical conductivity	EC	(ANZECC and ARMCANZ 2000; Cresswell and Weir 1997; DofA WA 2005; Kotuby-Amacher et al.; Maas 1987, 2005; Marcum 1999; QDNR 1997; Tanji et al. 2007)
Boron	B	(Tanji et al. 2007; Maas 2005)
Cadmium	Cd	(ANZECC and ARMCANZ 2000)
Phosphorus total	P	(ANZECC and ARMCANZ 2000; NRMMC and EPHC 2006)
Nitrogen total	N	
Sodium adsorption ratio	SAR	(ANZECC and ARMCANZ 2000)
RSC	RSC	(Carrow and Duncan 1998; Handreck and Black 2002)
Degradability		Not data (SA 1996)

Abbrev. = abbreviation

Melbourne water quality (maximum concentrations) was used as the water that detergents were added to (Melbourne Water 2009) for the preliminary risk assesment discussed in this paper. However, the final GreySmart ranking will use base water quality data from all water authorities across Victoria to assess the sensitivity of the base water quality on the GreySmart assessment.

The PDF was used to identify the hazard concentration that would protect a specified portion of the population from a specific hazard and the identified endpoints (Table 2).

Table 2: Percentiles of the population used to determined impact rating for specific hazards.

Portion of population protected (percentile) for all[A] hazards with PDFs except pH	Impact	Percentile to the median[B] for pH
95%	Insignificant	90%
90%	Minor	80%
33%	Moderate	70%
50%	Major	50%
67%	Catastrophic	30%

[A]excludes pH
[B]pH is a double sided impact where if the pH increase or decreases from the median there is a potential impact and therefore required a different logic for trigger values.

Trigger values for pH were extracted from a PDF (Figure 3) developed from optimised pH values identified for a range of impacts that pH may exhibit to plants (Handreck and Black 2002). These were similar to those proposed by United States Department of Agriculture (USDA 1998).

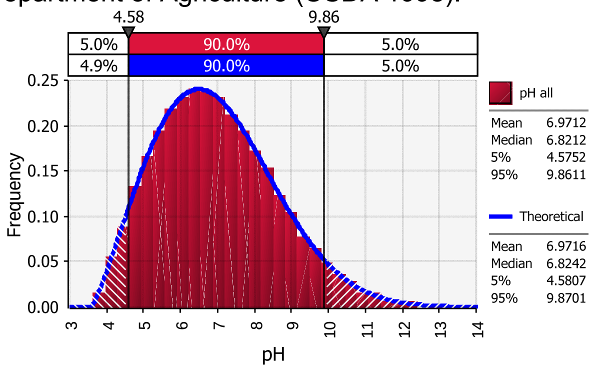

Figure 3: PDF for optimal pH values used to determine trigger values for impacts from pH (Table 3).

Trigger values for electrical conductivity (EC) were extracted from a PDF for garden plants only (n = 935, this was then compared to all plants (including agricultural crops – n = 1081) (Figure 4). There was little difference between the trigger values determined for garden plants and all plants (Figure 4). The garden plants PDF was used to determine trigger values (Table 4).

Table 3: Summary of trigger values for assessment of impact from greywater pH on household garden plants.

Percentile to median	pH trigger values	Impact
30%	≤4.9	Catastrophic
50%	4.9 to <5.5	Major
70%	5.5 to <6.0	Minor
90%	6.0 to <6.4	Moderate
100%	6.4 to 7.5	Insignificant
90%	>7.5 to 8.0	Moderate
70%	>8.0 to 8.6	Minor
50%	>8.6 to 9.1	Major
30%	>9.1	Catastrophic

Table 4: Summary of trigger values for assessment of the impact from greywater electrical conductivity (EC) on household garden plants.

Percentile	EC (dS/m) trigger values	Impact	Ref [A] (dS/m)
95%	<1.1	Insignificant	0.65
90%	1.1 to <1.4	Minor	1.3
67%	1.4 to <2.8	Moderate	2.9
50%	2.8 to <3.9	Major	5.2
	≥3.9	Catastrophic	

[A]Source: (ANZECC and ARMCANZ 2000)

Trigger values determined using PDFs varied slightly from generally accepted tolerance levels (Table 4 and 5). For example, a slighly higher salinity level 1.1 dS/m) was identified for the protection of 95% of the garden plant population, compared to 0.65 dS/m for sensitive crops (or a very low salinity rating). The definition of the values compared varied slightly. However, they have been defined using similar rationale yet different data sets, with a focus in this paper on garden plants not crop plants.

Table 5: Summary of trigger values for boron concentration in greywater irrigated on household garden plants.

Impact	%ile	B (mg/L)	Ref [A] (dS/m)
Insignificant	5%	<0.49	0.5
Minor	10%	0.49 to <0.51	1
Moderate	33%	0.51 to <0.63	2
Major	50%	0.63 to <0.79	4
Catastrophic		≥0.79	

%ile = Percentage of the population where boron toxicity threshold exceeded
[A](ANZECC and ARMCANZ 2000)

Interestingly, boron trigger values determined from PDF were much lower than the high levels identified in the literature (ANZECC and ARMCANZ 2000) (Table 5). As discussed above, the definition of the values is based on plant sensitivity not protection of a percentile of the household garden's plant populations.

Similar to pH and EC above, PDFs of toxicity theshold were also detemined for boron (Table 5) and nitrogen/phosphorus (Table 6).

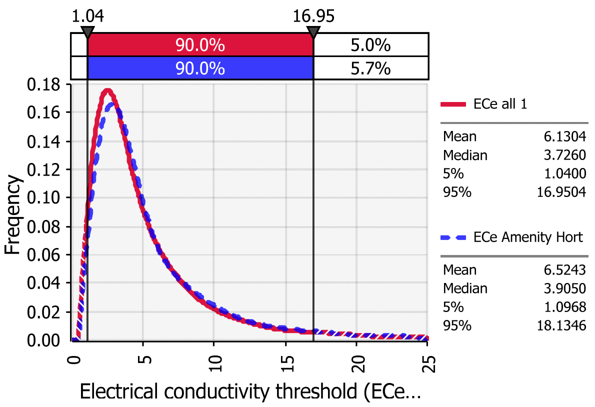

Figure 4: Distribution of toxicity theshold for irrigation water electrical conductivity values used to determine impact trigger values (Table 4). change to garden vs crop DPS.

Table 6: Summary of trigger values for assessment of the over supply of nitrogen and phosphorus in greywater through irrigation of garden plants.

Impact	%ile	Nitrogen		Phosphorus	
		kg/ha	mg/L	kg/ha	mg/L
Insignificant	5%	10.5	<1.8	1.7	<0.3
Moderate	10%	16.9	1.8 to <2.8	2.8	0.3 to <0.5
Minor	33%	43.1	2.8 to <7.2	7.4	0.5 to <1.2
Major	50%	67.0	7.2 to <11	11.5	1.2 to <1.9
Catastrophic			≥11		≥1.9

%ile = Percentage of the population over supplied with nitrogen or phosphorus. Not trigger levels change with irrigation rate (600 mm/year was assumed in this preliminary risk assessment)

Trigger values for impact from cadmium, SAR and RSC were taken directly from Australian Guidelines (ANZECC and ARMCANZ 2000). The trigger levels for SAR were linked to electrical conductivity and soil texture. For SAR, assessment of the impact on soil structural stability was also modified by:

- SAR < 3, impact = insignificant
- top soil texture = sand or sandy loam, and depth > 40 mm, impact = insignificant.

Forty mm depth was selected as this is what is required for a sand to hold approximately 2 days supply of readily plant-available water during 2 days of extreme heat in Melbourne (Tanji et al. 2007).

Minor and moderate triggers for cadmium were set by ensuring cadmium addition to soil would not exceed the 2 kg/ha in a 50 (minor) or 75 year (moderate) period. Major impact was exceedance of the long term trigger values and Catastrophic was considered exceedance of the short term impact (modified from ANZECC and ARMCANZ 2000).

Residual sodium carbonate (RSC) trigger values were taken from Carrow and Duncan (1998). Biodegradability is currently set at 70 to 80% (GECA 2006a, b; SA 1996) and values were set to give 2 $\log_{10}$ removal as insignificant (Table 7). These may be revised in the future as more data becomes available.

Table 7: Impacts trigger values biodegradability

Impact	Biodegradability[A]
Insignificant	99%
Minor	95%
Moderate	90%
Major	70%
Catastrophic	50%

[A]Measured as per SA (1996)

Risk assessment

The risk rating was determined by adding the corresponding number from 1 to 5 for the likelihood and impact. For example, if the likelihood was almost certain (5); bottom row of Table 8 and impact minor (2) the risk would be 7-Mod (moderate) for the almost certain row on the bottom of Table 8.

Table 8: Risk matrix from assessment of risk from likelihood and impact.

Likelihood	Consequences or impact: 1 - Insignificant	2 - Minor	3 - Moderate	4 - Major	5 - Catastrophic
1 - Rare	2-Low	3-Low	4-Low	5-Low	6-High
2 - Unlikely	3-Low	4-Low	5-Mod.	6-High	7-VH
3 - Possible	4-Low	5-Mod.	6-High	7- VH	8-VH
4 - Likely	5-Low	6-Mod.	7-High	8- VH	9- VH
5 - Almost certain	6-Low	7-Mod.	8-High	9- VH	10- VH

Mod. = moderate, VH = Very high

RESULTS AND DISCUSSION

To determine the sensitivity of the GreySmart ranking, hazard concentrations in laundry washing water (wash only) were sourced from the literature (Choice Magazine 2005, 2009; Patterson 2009; Tjandraatmadja et al. 2008; van der Kooij 2009) and the risk to the garden environment assessed, as discussed above. Fourteen detergents were considered very low risk (GreySmart) (Table 9) out of the 142 assessed. Nine detergents were ranked as low risk (GreySmart with care). All other detergents were of moderate to very high risks and not considered safe for the garden, even if greywater from the wash clothes washing cycle was used only (i.e. 84% of laundry detergents tested). There was insufficient data to fully establish the GreySmart ranking (risk) due to the absence of RSC, nitrogen, cadmium and biodegradability data (Table 10).

There was insufficient data to determine how these risks changed if the wash and rinse cycle from the clothes washing machine were combined. However, for many detergents, a straight one third dilution (i.e. 1 wash cycle with 2 rinse cycles) would not modify the overall risk ratings significantly. For example, in some cases the concentration of hazards is so far above the high trigger level (Table 9) that a third dilution would still exceed the highest trigger level. In other cases if the SAR is reduced, so is the salinity and in some cases this can lead to an increased risk to surface instability as salinity suppresses the dispersive effects of sodicity (SAR).

Table 9: Number of detergents in each risk category and GreySmart (Interim) ranking.

Level of risk[A]	No of detergents	GreySmart ranking
Very low[B]	14	Grey Smart Greywater friendly GreySmart
Low	9	Grey Smart with Care Greywater friendly use with care GreySmart
Moderate	26	Not considered greywater friendly
High	53	Not considered greywater friendly
Very high	41	Not considered greywater friendly
Total number of detergents assessed	143	

[A]Determined from Table 8.
[B]Very low has been added as a level of risk to inidicate a low risk with no Major or catastrophic impacts from specific hazards.

All detergents ranked as GreySmart or GreySmart with Care (Table 9) were liquid detergents (Figure 5). There was a significantly lower ($P<0.001$) risk ranking for liquid detergents compared with ultra concentrates and powder detergents (Figure 5). There was also a trend for top loaders to be lower risk than front loaders (probably due to dilution ratios). However, this is complicated by the factors discussed above regarding wash water versus wash and rinse water combined.

It should be noted that of the 10 hazards (Table 1) to be assessed as part of GreySmart, only data for 6 (liquids) and 7 (detergents and ultra concentrates) data points on average could be identified in the literature sourced. Therefore the GreySmart rankings above are not definitive. However, they will allow the GreySmart project funded by the Smart Water Fund to focus resources on 23 liquid detergents to fill these data gaps and finalise the GreySmart ranking for clothes washing detergents.

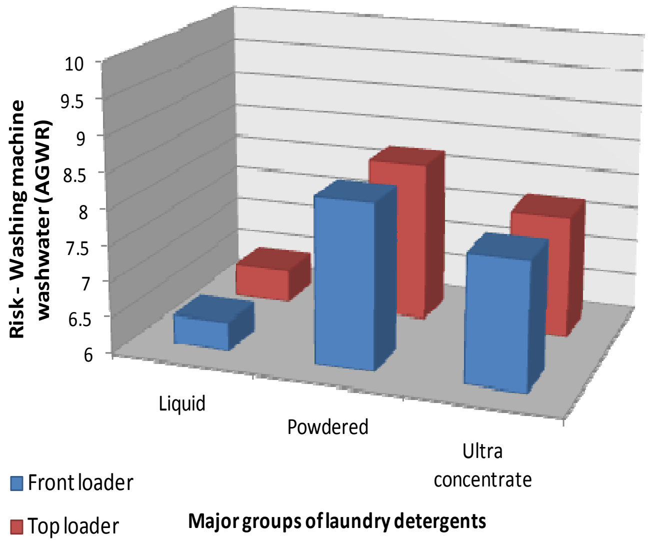

Figure 5: GreySmart risk assessment for wash water from clothes washing machines using liquid, powdered and ultra concentrates. Least significant difference = 0.4, n = 142. See Table 1 for hazards assessed. Where likelihood = almost certain and 6 = low risk, 7 = moderate risk, 8 = high risk and 9 to 10 = very high risk (Table 2).

GreySmart

The GreySmart website will allow the user to insert soil types to assess specific risks on-site. The risk assessment above has used a light clay soil type as a worse case scenario to determine if the detergent will pose a risk or not. This type of assessment determines if a household product will always be low risk no matter how or where the greywater is irrigated in the garden. When all data is available for a product all very low risk products will be ranked as GreySmart (Table 9).

Additional assessment for products will be undertaken with the full data set and a number of scenarios to determine if a low risk can be obtained by modifying the soil type or with minimal onsite controls. If this is determined to be the case, then the household product tested will be ranked as 'GreySmart with Care'.

Table 10: *Summary statistics of parameters for main types of clothes washing detergents ranked by GreySmart (mg/L unless stated otherwise).*

Parameter	Ultra		Liquid		Powder	
	med	stdev	med	stdev	med	stdev
Acidity	10.6	0.2	7.4	1.7	10.7	0.2
Sodium	287.3	233.7	21.6	7.5	574.0	369.7
Alkalinity (as $CaCO_3$)	Id	id	id	id	16026	22820
Electrical conductivity (dS/m)	0.6	0.3	0.2	0.1	0.9	0.4
Boron	0.0	0.0	id	id	id	id
Cadmium	id	id	id	id	id	id
Phosphorus total	1.9	7.7	0.0	0.0	0.3	2.0
Nitrogen total	Id	id	id	id	id	id
Total dissolved salts	403.3	168.9	118.5	55.7	579.3	236.3
Sodium adsorption ratio	18.6	15.1	1.4	0.5	37.2	24.0
RSC	Id	id	id	id	479.7	682.5
Number of observations	16		43		80	

id = insufficient data. med = median. stdev = standard deviation from the median. Data source (Choice Magazine 2005, 2009; Patterson 2009; Tjandraatmadja et al. 2008; van der Kooij 2009)

Clothes washing detergents have been the first detergents assessed due to the high use of washing machine water for irrigation. The GreySmart project aim is to assess a range of household cleaning and personal care products during 2010 that have been identified through this GreySmart ranking tool (risk assessment), to be ranked as potentially GreySmart or GreySmart with Care. Once completed, GreySmart products will be listed on the GreySmart website to help greywater users make informed choices when selecting household cleaning and personal care products for use in the house while greywater irrigation is being practiced.

Some of the main components of the GreySmart website are:

1. H_2Ome*Calc* - A calculation tool to determine what volumes/mix of greywater/rainwater/borewater/mains are needed to supplement house and garden water requirements;
2. Purple pages - Greywater friendly supplies;
3. Household product information (GreySmart ranking); and
4. Greywater information and systems.

See www.greysmart.com.au for more information.

CONCLUSION

The key conclusions of this paper are:

- Product selection is critical;
- GreySmart provides a more developed classification of greywater friendliness than existing frameworks and complies with the Australian Guidelines for Water Recycling ; and
- The interim risk assessment suggests that there are a good number of commercial clothes washing detergents that can achieve the GreySmart ranking.

Assessment of a range of household cleaning and personal care products will be the next phase of the project. GreySmart also encourages manufacturers to submit products for assessment.

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