The Greysmart ranking system for assessing houshold cleaning and personal care products that enter greywater used for irrigating gardens.

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Contents

1 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 cleaning and personal care products posed a detrimental risk to the garden if greywater was used for irrigation (i.e. were they garden friendly or ‘GreySmart’). A risk assessment was completed on 143 different clothes washing detergents (most currently available in Australia) using data publicly available from the literature (50 to 60% of data required for the hazards assessed in the GreySmart assessment were generally available). Using this data, only 16% (23) of the detergents assessed were considered potentially environmentally safe for use of the greywater from the clothes wash-only cycle to irrigate the household garden (i.e GreySmart). Additional analysis is now required to confirm if these detergents will be GreySmart when all data is assessed. 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 the missing data is obtained through additional analysis.

This report 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.

2 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). Several recent studies have highlighted the impacts on soils and importance of using garden 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. The GreySmart Assessment Tool will rank household products based on impacts on the environment where they are used (the garden). Impacts considered will be to plants, soils, microbes and nearby waterbodies.

A detailed environmental risk assessment underpins GreySmart and enables the development of a definition for ‘garden friendly’ or ‘GreySmart’ for urban irrigation in Melbourne and across Australia. The GreySmart Assessment Tool extends beyond nitrogen (N), phosphorus (P) and sodium concentration to include boron (B), sodium absorption ratio (SAR), pH, salinity (measured as electrical conductivity (EC) or total dissolved salts (TDS)), residual sodium carbonate (RSC), cadmium (Cd), biodegradability and potentially other parameters in the future, allowing for more accurate assessments of ‘garden friendly products’ and calculations of acceptable loads on garden plants and soil textures. This enables assessment of household products for their greywater garden friendliness based on the typical usages and concentration of resulting hazards in the 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 report details the science behind the GreySmart Assessment Tool, a tool which determines if greywater produced from household cleaning and personal care products poses a low risk to gardens watered (i.e. is friendly or GreySmart).

3 METHODOLOGY

3.1 Review of hazards

A comprehensive review identified hazards found in household personal use and cleaning products (e.g. from clothes washing detergents to sunscreens) that were likely to enter 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 when assessing the use of greywater on household gardens:

- Acidity/alkalinity (pH)
- Electrical conductivity (EC)
- Boron (B)
- Cadmium (Cd)
- Phosphorus total (P_{total})
- Nitrogen total (N_{total})
- Sodium adsorption ratio - surface structure ($SAR_{surface}$)
- Sodium adsorption ratio - soil stability ($SAR_{stability}$)
- Residual sodium carbonate (RSC)
- 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. These hazards are similar to the key hazards identified in the Australian Guidelines for Water Recycling (NRMMC and EPHC 2006), with the addition of pH, carbonate (RSC) and degradability, and with the exception of chlorine residual (as greywater is generally not chlorinated but may contain bleach) and hydraulic loading (as this can only be managed at the site of irrigation, not by the product manufacturer).

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 gap in the data required to assess the environmental risk posed by irrigation of greywater on household gardens.

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 (2009) 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.

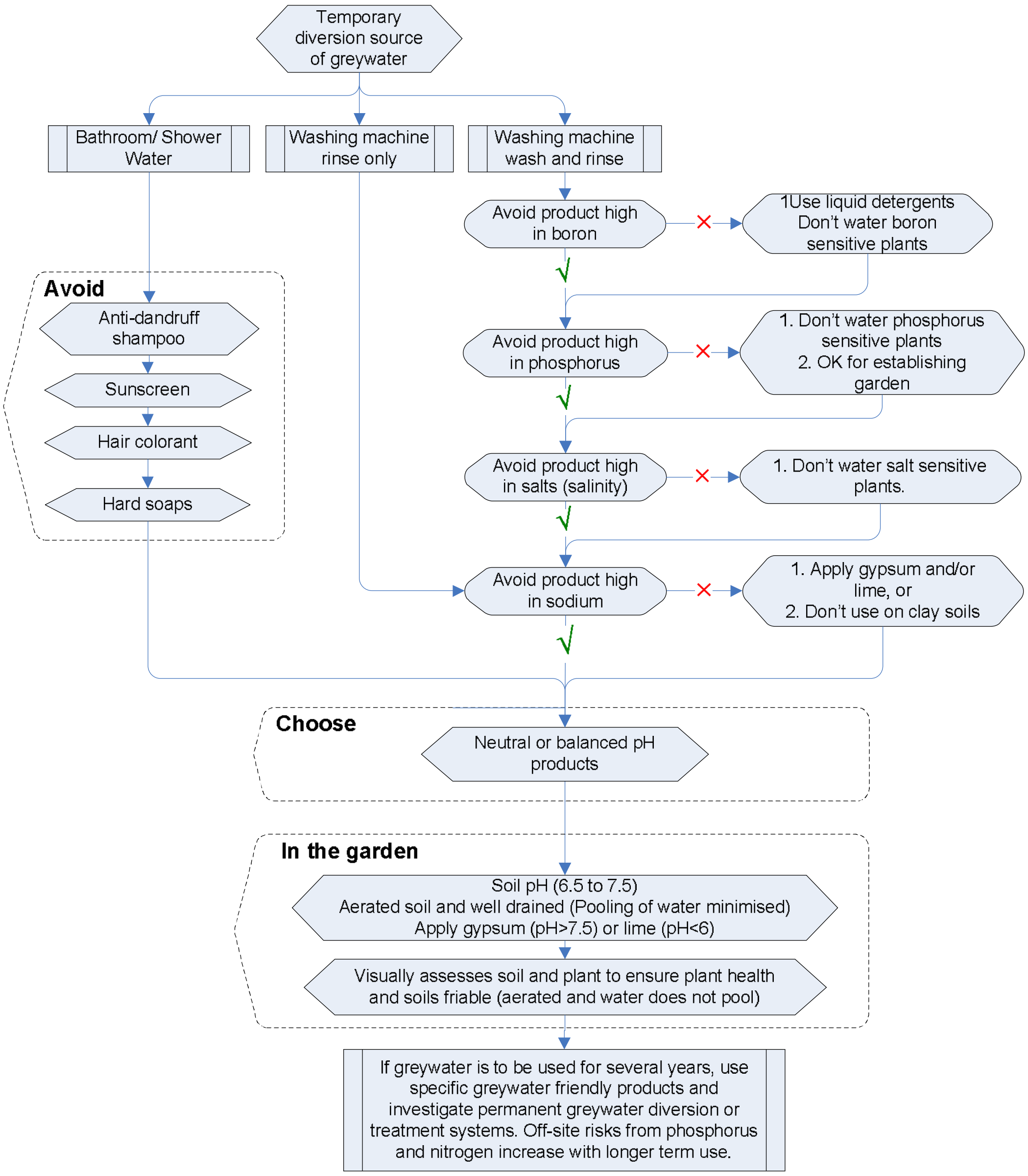

Figure 1 Simplified decision tree for temporary use of greywater sources (Stevens and Wilson 2009).

Greywater quality is highly variable. For example, the pH measured in greywater when all sources are mixed compared to when the greywater is taken from the clothes washing machine only (Figure 2) can vary from 3 to 12. Again, this data indicates that the source of the greywater and the choice of 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 household garden irrigation.

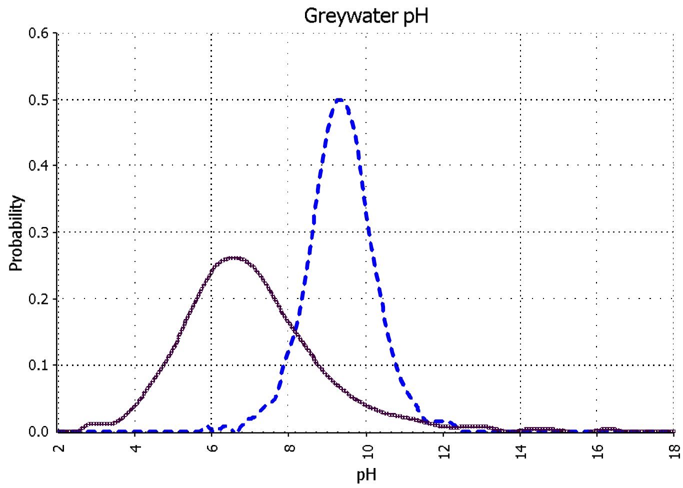

Figure 2 Comparison of greywater pH modelled from all greywater sources combined (solid) and washing machine greywater only (dashed) (Modified from Landloch Pty Ltd. 2005).

3.2 GreySmart assessment tool

The GreySmart assessment tool was developed utilising the Australian 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

For true qualitative analysis, risk is considered a product of likelihood and impact (i.e. likelihood x impact). However, in this case the assessment used a qualitative assessment matrix, where impact was converted to a qualitative description using quantitative data (e.g. semi quantitative) and an additive combination has been used to simplify and not over emphasise the level of risk determined. This is possible in this case as the scores given for likelihood and impact are used primarily as identifiers in the risk matrix to determine the risk. This method still complies with the basic understanding that risk is defined as combination of the likelihood of an occurrence of a hazardous event or exposure(s) and the severity of injury or impact that can be caused by the event or exposure(s).

Other inputs required for the risk assessment were:

- Top soil texture (light clay assumed as worse case for most gardens where soils have not been improved in the topsoil)

- Top soil depth (mm)
- Irrigation demand (600 mm assumed)

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

3.3 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 (likelihood definitions in the AGWR) this 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 from the household products.

3.4 Impact assessment

Impact was assessed using data from a variety of sources to develop probability distribution functions (PDFs). For hazards where there was limited data, trigger values were taken directly from Australian Guidelines (ANZECC and ARMCANZ 2000)..Data for household lawn and garden plants were also used in preference to agricultural crop plants (Table 1).

Table 1 Sources of 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; Tanji et al. 2007)
Biodegradability[A]		No data

Abbrev. = abbreviation. [A] (SA 1996)

When analysing household products in the course of this study, Melbourne water quality (maximum concentrations (Melbourne Water 2009)) was used as the dilution water. This represents the worse case scenario as this water has one of the lowest total dissolved salts in Victoria and impacts will be predominantly from the household products used. For example, RSC and SAR will improve with higher calcium concentration in the water, so using a low calcium concentration is the worst case..This also represents the largest number of gardens in Victoria also. The sensitivity of base water quality on risks will be assessed across Victoria when product analysis is completed.. Probability distribution functions (PDF) were used to identify the hazard concentration that would protect a specified portion of the specific population (soil, plant) from a specific hazard (Table 2). A range of trigger values were developed which correlate to these different portions of biota protected.

Table 2 Percentiles of the specific biota protected (e.g. plant species) used to determine impact rating for hazards.

Portion of biota protected (percentile) for all[A] hazards with PDFs except pH	Impact
95%	Insignificant
90%	Minor
67%	Moderate
50%	Major
>50%	Catastrophic

[A]excludes pH see Table 3

3.4.1 Greywater pH

Trigger values for pH were extracted from a PDF (Figure 3 and Table 3) that was 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) (Table 3).

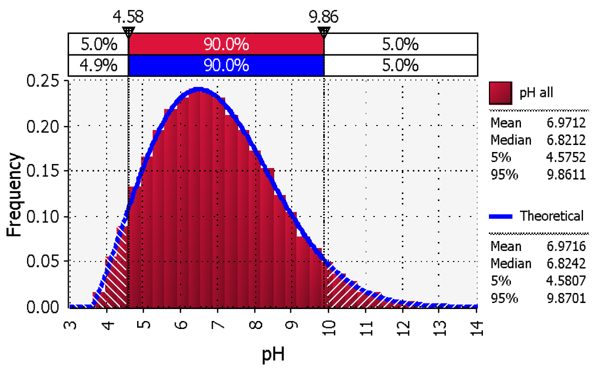

Figure 3 PDF for optimal pH values used to determine trigger values for impacts from pH (Table 3).

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

Percentile of values used to estimate ideal pH	Generated from PDFs		Described in literature[A]	
	pH trigger values	Impact	pH trigger values	Description
			3.5 to 4.4	Extremely acid
15	<4.9	Catastrophic	4.5 to 5.0	Very strongly acid
25	4.9 to <5.5	Major	5.1 to 5.5	Strongly acid
35	5.5 to <6.0	Moderate	5.6 to 6.0	Moderately acid
45	6.0 to <6.4	Minor	6.1 to 6.5	Slightly acid
50	6.4 to <7.5	Insignificant	6.6 to 7.3	Neutral
55	7.5 to <8.0	Minor	7.4 to 7.8	Slightly alkaline
65	8.0 to <8.6	Moderate	7.9 ato 8.4	Moderately alkaline
75	8.6 to <9.1	Major	8.5 to 9.0	Strongly alkaline
85	≥9.1	Catastrophic	>9.0	Extremely alkaline

[A](USDA 1998). For 90 % of the time the pH value should be within the ideal range (6.4 to 7.5)

3.4.2 Greywater salinity or electrical conductivity

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).

Trigger values determined using PDFs varied slightly from generally accepted tolerance levels (Table 4). For example, a slightly 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) from the reference value (Table 4). It is important to note that the definition of the values from the PDF are in fact different to those in the literature. 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 4 Summary of trigger values for assessment of the impact from greywater electrical conductivity (EC) on household garden plants.

Calculated from PDF			Literature[A] equivalent		
Percentile of plants protected	EC (dS/m) TV from garden plant PDF	Impact level for PDF	Reference TV (dS/m)	Water salinity rating	Plant tolerance
99%	<0.7		<0.65	Very low	Sensitive
95%	0.7 to <1.0	Insignificant	0.65 to 1.3	Low	Moderately sensitive
90%	1.0 to <1.4	Minor			
67%	1.4 to <2.7	Moderate	1.3 to 2.9	Medium	Moderately tolerant
50%	2.7 to <3.9	Major	2.9 to 5.2	High	Tolerant
	≥3.9	Catastrophic			
No ratings			5.2 to 8.1	Very High	Very tolerant
			>8.1	Extreme	Generally too saline

[A]Source: (ANZECC and ARMCANZ 2000), PDF = probability distribution function, TV = trigger values.

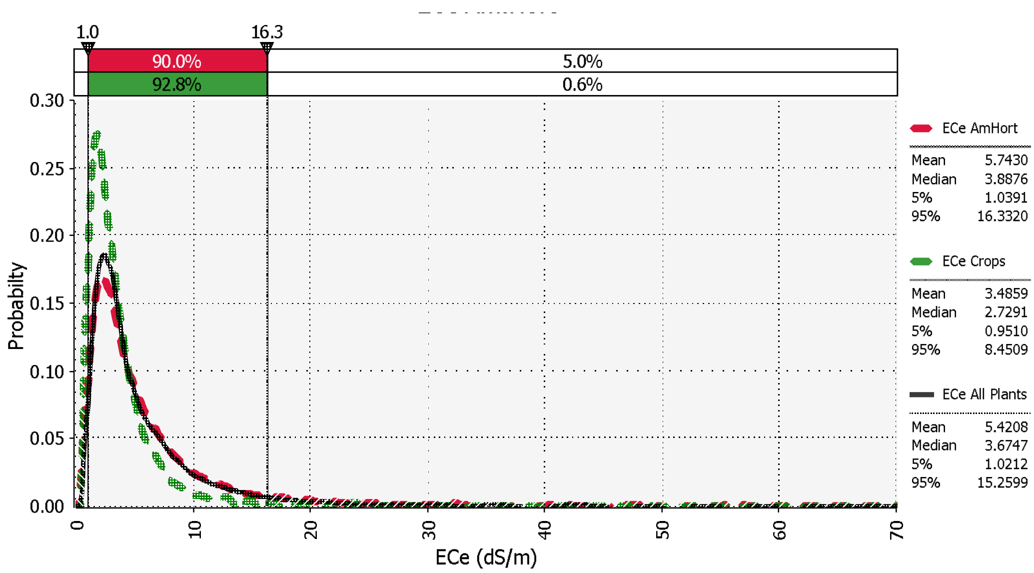

Figure 4 Distribution of toxicity theshold for irrigation water electrical conductivity values used to determine impact trigger values (Table 4).

3.4.3 Greywater boron

Interestingly, boron trigger values determined from PDF were much lower than the high levels identified in the literature (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. There were only 164 data points for B (compared to approximately 1000 for EC) and data ranges were often quoted rather than a specific trigger level. If ranges were identified then the mid point was used for determining the PDF. Due to the limited data available for amenity horticultural plants (n=53) and the associated coarse trigger value ranges, data for all plants was used to determine the PDF for calculating trigger values (Table 5).

Table 5 Summary of trigger values for boron concentration in greywater irrigated on all plants.

Calculated from PDF			Literature[A] equivalent	
Impact	%ile of plants protected	B (mg/L)	Reference TV (dS/m)	Tolerance
Insignificant	95%	<0.49	<0.5	Very sensitive
Minor	90%	0.49 to <0.55	0.5 to 1.0	Sensitive
Moderate	67%	0.55 to <0.74		
Major	50%	0.74 to <1.00		
Catastrophic		≥1.00		
No ratings			1.0 to 2.0	Moderately sensitive
			2.0 to 4.0	Moderately tolerant
			4.0 to 6.0	Tolerant
			6.0 to 15	Very tolerant

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

3.4.4 Greywater nitrogen and phosphorus

Similar to pH, EC and B above, PDFs of toxicity threshold were also determined for nitrogen and phosphorus (Figure 5, Table 7). Data used to determine the PDFs was predominantly from crop plants (ANZECC and ARMCANZ 2000), some of which would be grown with greywater. Specific data for landscape plant nutrient requirements are rare and usually general (e.g. Table 6) as requirements depend on the age of the plant, soil type, density of planting, growth rate and look required (Handreck and Black 2002). For setting of trigger values (i.e. converting kg/ha to mg/L in greywater) an irrigation rate of 600 mm/year was assummed to represent a typical irrigation requirement for many household gardens in Victoria (assumes a crop factor of 0.7, rainfall efficiency of 0.9 and irrigation efficiency of 0.8 (Handreck and Black 2002; Raine 1999; UCCE and CDWR 2000)).

When compared to plant requirements, trigger values defined for N and P from the PDF (Table 7 and Table 8) were generally considered lower than many garden plant requirements. However, these values would be more representative of plants with low N and P requirements; protecting the worst case scenario of nutrient excess to requirements being applied to garden soils. If N and P requirements for the garden are known to be high, then the N and P trigger values could be modified.

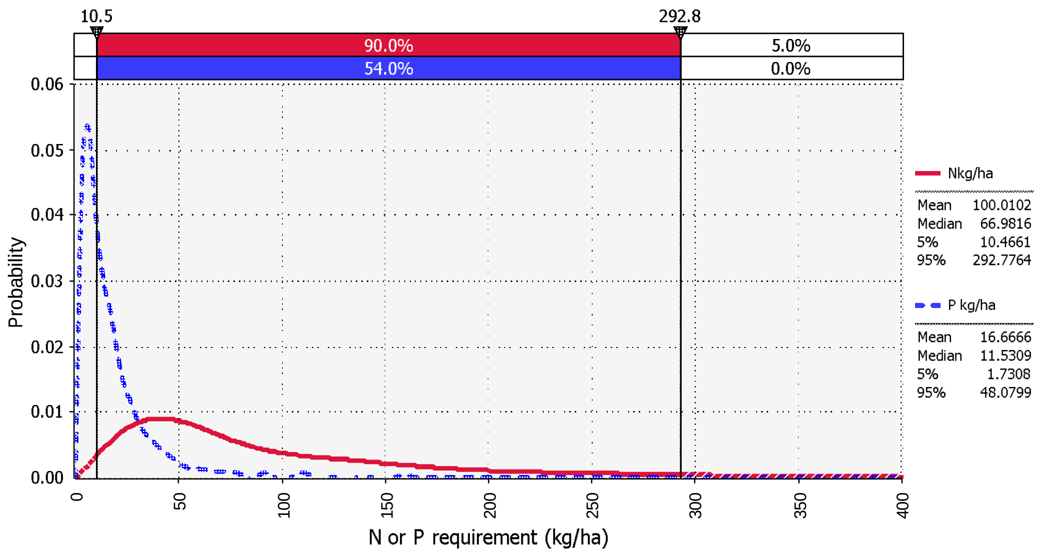

Figure 5 **PDFs for N and P requirements of plants (data sourced from ANZECC and ARMCANZ (2000)).**

Table 6 **Typical annual nutrient demands of turf plants and removal with clippings**

	N[C]		P		K	
Component	(g/m^2)	(kg/ha)	(g/m^2)	(kg/ha)	(g/m^2)	(kg/ha)
Annual application	6-40[A]	60-400[D]	3.6-12.4	36-124[B]	6-48	40-267[E]
Removed with clippings	24	240	6	60	13	130
Home lawn	12-20	120-200	2.5-10.5	25-105	8-13	80-130

[A]Handreck and Black 2001, p 287
[B]Depending on the P fixing capacity of the soil.
[C]note the 20 to 50% of the nitrogen applied can be lost through volatilisation and denitrification (Handreck and Black 2001,Asano *et al.* 2007)
[D]depending on turf species, what the turf is being grown for, growth requirements and N losses.
[E]approximately a 3:2 ratio N:K (Handreck and Black 2001, p 294).

Table 7 **Summary of trigger values for assessment of the over supply of nitrogen in greywater through irrigation of garden plants.**

Impact	%ile of plant not over supplied	Nitrogen		Tanji et al. (2007)		Turf requirements (Table 6)
		kg/ha	mg/L	NH_3 and NO_3 mg/L as N	Degree of restriction	kg/ha
Insignificant	95%	10.5	<1.8			60-400
Moderate	90%	16.9	1.8 to <2.8			
Minor	67%	43.1	2.8 to <7.2	<5	None	
Major	50%	67.0	7.2 to <11			
Catastrophic			≥11	5-30	Slight to moderate	
				>30	Severe	

%ile = Percentage of the population over supplied with nitrogen or phosphorus. Note trigger values change with irrigation rate (600 mm/year was assumed in this preliminary risk assessment).

Table 8 Summary of trigger values for assessment of the over supply of phosphorus in greywater through irrigation of garden plants.

Impact	%ile of plant species not over supplied with phosphorus	Phosphorus		Turf requirements (Table 6)
		kg/ha	mg/L	kg/ha
Insignificant	95%	1.7	<0.3	
Moderate	90%	2.8	0.3 to <0.5	
Minor	67%	7.4	0.5 to <1.2	36-124
Major	50%	11.5	1.2 to <1.9	
Catastrophic			≥1.9	

%ile = Percentage of the population over supplied with nitrogen or phosphorus. Note trigger values change with irrigation rate (600 mm/year was assumed in this preliminary risk assessment)

3.4.5 Greywater sodium adsorption ratio (SAR)

Trigger values for impacts from SAR were taken directly from Australian Guidelines (ANZECC and ARMCANZ 2000). The trigger values 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.

For soil surface stability the impact of SAR on a light clay soil was assumed for setting the trigger values (Table 9). The relationship between irrigation water SAR and EC to assess soil structural stability was modified from ANZECC and ARMCANZ (2000) with an additional line between the impacts minor and moderate (Figure 6). Structural stability was assessed by determining the point where the greywater SAR and EC intersects. For example, if the EC was 2 and SAR 40 the impact would be catastrophic (Figure 6). Equations used to define the border lines in Figure 6 were:

- $SAR = 1.3832EC^2 + 10.512EC$, for the moderate to catastrophic border
- $SAR = 0.6916EC^2 + 7.301EC$, for the minor to moderate border
- $SAR = 4.092EC$, for the insignificant to minor border.

Table 9 Changes in impact on soil surface stability as irrigation water Sodium Adsorption Ratio changes.

Sand and Sandy loam	Loam	Clay loam	Light clay	Impact
SAR values related to impact				
<20	<8.0	<5.0	<5.0	Insignificant
≥20	8.0 to <10	5 to <8	Not set	Minor
	10 to <11	8 to <11	5 to <8	Moderate
	11 to 20	11 to 13	8 to 11	Major
	≥20	>13	>11	Catastrophic

Modified from (ANZECC and ARMCANZ 2000; Carrow and Duncan 1998)

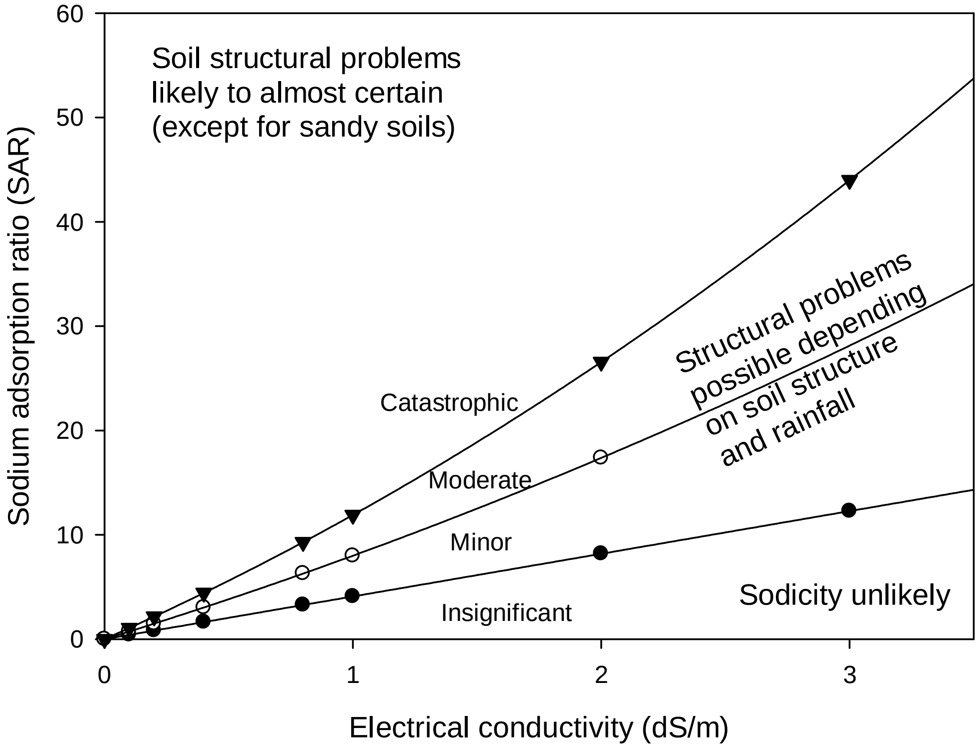

Figure 6 **Relationship between EC and SAR used to determine the risk from the SAR of greywater impacts household soils. (Impacts defined in centre of graph.) Note major impacts were at the same concentration as catastrophic and default to this.**

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).

3.4.6 Greywater cadmium

Trigger values for impacts from cadmium were taken directly from Australian Guidelines (ANZECC and ARMCANZ 2000). 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 impacts were defined as exceedance of the long term trigger values and Catastrophic impact was considered as exceedance of the short term impact (modified from ANZECC and ARMCANZ 2000). Temporal variability is important for cadmium as it it accumulates over time to concentrations that could cause detrimental impacts.

Table 10 **Summary of cadmium concentration and impact rating for greywater quality**

Modification during Round1 and 2 product assessment	Originally proposed Cadmium concentration in greywater (mg/L)	Impact
<0.01	0 to < 0.004	Insignificant
	0.004 to <0.007	Minor
	0.007 to <0.01	Moderate
0.01 to <0.05	0.01 to <0.05	Major
0.05	0.05	Catastrophic

Modification due to detection limit and additional cost not essential

3.4.7 Greywater residual sodium carbonate (RSC)

Residual sodium carbonate (RSC) trigger values were taken from predominantly from Carrow and Duncan (1998).

Table 11 Residual sodium carbonate (RSC) concentrations and associated impact for assessing greywater risk.

RSC (meq/L)	Impact	Comment
<0	Insignificant	Ca and Mg will not precipitate as carbonates from irrigation water
0-1.25	Minor	Some removal of Ca and Mg from irrigation water
1.25-2.5	Moderate	Appreciable removal of Ca and Mg from irrigation water
>2.5	Major	All or most of Ca and Mg removed as carbonate precipitates, leaving Na to accumulate.

Source: (Carrow and Duncan 1998; Tanji et al. 2007)

3.4.8 Greywater biodegradability

Biodegradability is currently set at 70 to 80% (GECA 2006a, b; SA 1996) and trigger values were developed to give insignificant impacts as 99% removal (or 2 $\log_{10}$ removal) (Table 12). These may be revised in the future as more data becomes available. This Standard specifies a method for the evaluation of the 'ready' biodegradability of organic compounds at a given concentration by aerobic microorganisms. It tests for dissolved organic carbon in solution and its removal over a 28 day period.

Table 12 Impacts trigger values biodegradability

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

[A]Measured as per SA (1996) under aerobic conditions similar to soil conditions in the garden.

Please note that biodegradeability will not be used in the GreySmart assessment tool when analysis begins in 2010 as there are limited laboratories offering this test and the method development will probably be costly. Predictive tools such as EPI Suite are being assessed for future improvement in GreySmart.

3.5 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 13 and impact minor (2) the risk would be 7-Mod (moderate) for the almost certain row on the bottom of Table 13. The assessment tool assumes that likelihood of greywater use on the garden is almost certain, as this risk assessment is undertaken to assess the environmental impacts of using greywater on the household garden. There were 14 individual parameters measured which aided in the assessment of 9 key hazards:

1. Acidity/alkalinity
2. Electrical conductivity (Salinity)
3. Boron
4. Cadmium
5. Phosphorus
6. Nitrogen
7. Sodium adsorption ratio (SAR) – Surface stability
8. Sodium adsorption raio (SAR) – Soil stability
9. Residual sodium carbonate (RSC)
10. Biodegradability

If the likelihood is assumed as almost certain, then each hazard will score between 6 and 10 (Table 13). There were no analytical data to statistically determine trigger values for GreySmart assessment. Logical consideration of scenarios was used instead.

Logically, to be considered GreySmart (very low risk - Table 14) there should be no catastrophic impacts from the use of greywater. Therefore, the highest average score possible without a catastrophic impact would be 6.3 i.e. (((9x6)+9)/10) which is 9 lows and one catastrophic, this also equates to 3 moderate and 7 low impacts where average risk = ((3x7)+(7x6))/10 = 6.3).

Table 13 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-Very high
3 - Possible	4-Low	5-Mod.	6-High	7- Very high	8-Very high
4 – Likely	5-Low	6-Mod.	7-High	8- Very high	9- Very high
5 - Almost certain	6-Low	7-Mod.	8-High	9- Very high	10- Very high

Mod. = moderate. Source (NRMMC and EPHC 2006)

The low risk average score (Table 14) or 'GreySmart with Care' was set at 6.5 by logically considering half the hazards were low impact and half moderate impact (i.e. ((5x6)+(5x7))/10=6.5). Moderate, high and very high levels were set by giving a fairly even distribution of the remaining average score between 6.5 and 9.5, considering that 10 for all 10 hazards would be a rare event (Table 14).

Table 14 Summary of average scores, risk and GreySmart assessment

Average risk score	Risk	GreySmart assessment
≤6.3	very low	GreySmart
>6.3 to 6.5	low	GreySmart with care
>6.5 to 7.5	moderate	Fail
>7.5 to 8.5	high	Fail
>8.5 to 10	very high	Fail

4 Results and discussion

4.1 Verification that GreySmart is achievable

4.1.1 Wash water only

To determine the sensitivity of the GreySmart ranking and determine if GreySmart status is achieveable, 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, for the 10 hazards discussed above (Section 3). For many products there was insufficient data to fully establish the GreySmart status (risk) due to the absence of cadmium, nitrogen and biodegradability data (Table 16) in most cases, and B and RSC in some cases (Table 15). A summary of hazard concentrations highlight the relatively low concentration, on average, in liquid detergents (Table 16).

Table 15 Summary of available data for assessment of GreySmart status

Hazard	Symbol	Data assessed	
		Number of data	Percent assessed with GreySmart
Acidity/alkalinity	pH	142	99%
Electrical conductivity	EC	142	99%
Boron	B	17	12%
Cadmium	Cd	1	1%
Phosphorus total	P	143	100%
Nitrogen total	N	1	1%
Sodium adsorption ratio - Surface structure	SARsurf	141	99%
Sodium adsorption ratio - soil stability	SARsoil	142	99%
Residual sodium carbonate	RSC	84	59%
Biodegradability	BioDg	1	1%

Note: total products assessed 143 (Choice Magazine 2005, 2009; Patterson 2009; Tjandraatmadja et al. 2008; van der Kooij 2009)

Table 16 Summary statistics of hazards concentrations assessed for main types of clothes washing detergents (wash water only) ranked by GreySmart (mg/L unless stated otherwise).

Hazards	Liquid		Ultra concentrated powder		Powder	
	median	stdev	median	stdev	median	stdev
pH (unitless)	7.4	1.7	10.6	0.2	10.7	0.2
Sodium	15.1	7.4	281.6	233.7	508.3	380.5
Alkalinity (as $CaCO_3$)	Id	id	Id	id	661.1	485.3
Electrical conductivity (EC) (dS/m)	0.1	0.1	1.5	0.8	2.3	1.1
Boron	Id	id	0.0	0.0	id	id
Cadmium	Id	id	id	id	id	id
Phosphorus total	0.0	0.9	28.0	30.1	6.1	62.9
Nitrogen total	Id	id	Id	id	id	id
Total dissolved salts (TDS)	82.5	39.3	939.5	506.7	1467.5	708.9
Sodium adsorption ratio (SAR) $(mmolc/L)^{0.5}$	1.4	0.7	26.0	21.6	46.9	35.1
Residual sodium carbonate (RSC)	Id	id	Id	id	19.0	14.6
Number of observations	43		16		84	

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). Assume 25L for frontloader and 60L for top loader clothes washing machine.

Due to the limited data the GreySmart assessments in the paper are not definitive. However, they allow the GreySmart project funded by the Smart Water Fund to identify hazards that could potentially be assessed as low or very low risk (i.e. potentially GreySmart). This allows the GreySmart project to focus on these hazards to fill data gaps and finalise the GreySmart ranking for clothes washing detergents.

Fourteen detergents were considered very low risk (GreySmart) (Table 17) out of the 142 assessed. Seven 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 and rinse cycle was used (i.e. 85% of laundry detergents tested). The biggest impact on the greysmart rating from combining wash and rinse water was the reduction in number of detergents ranked as very high risk to high risk (Table 17).

The hazards that posed the higher risk for powder detergents were alkalinity, pH, sodium, carbonate and salinity (EC or TDS).

Table 17 Number of detergents in each risk category and their potential GreySmart assessment.

Level of risk[A]	No. of detergents		Potential GreySmart assessment
	Wash only	Wash and rinse	
Very low[B]	14	15	Grey Smart
Low	7	7	Grey Smart with Care
Moderate	22	26	Fail
High	13	43	Fail
Very high	87	52	Fail
Total number of detergents assessed	143	143	

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

All detergents ranked as potential GreySmart or GreySmart with Care (Table 17) were liquid detergents (Figure 7). There was a significantly lower (P<0.001) risk ranking for liquid detergents compared with ultra concentrates and powder detergents (Figure 7 and Table 18). There was also a trend for top loader detergents to be of lower risk than those for front loaders (probably due to dilution ratios where front loader volumes of water are 25 L and top loaders 60 L).

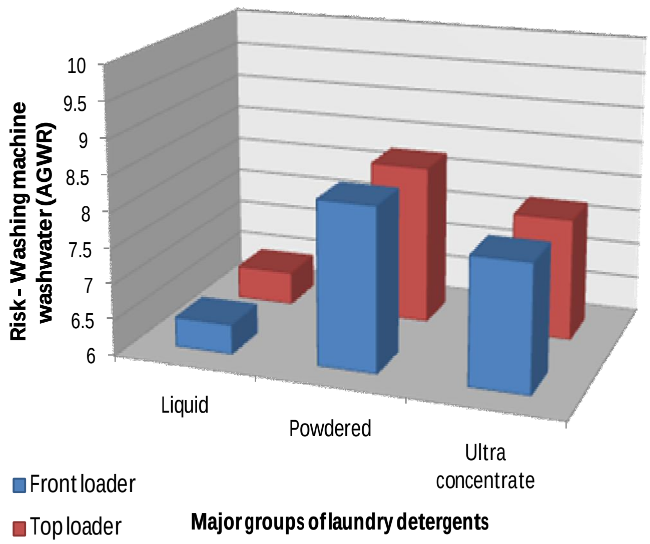

Figure 7 GreySmart average risk assessment for wash water from clothes washing machines using liquid, powdered and ultra concentrates. Least significant difference = 0.4, n = 142. See Table 1 for hazards assessed. Where likelihood = almost certain and 6 = low risk, 7 = moderate risk, 8 = high risk and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

Table 18 Average risk assessment score for all hazards grouped by laundry detergent type.

Hazard	Ultra concentrate		Liquid		Powder	
	Median	stdev	Median	stdev	Median	stdev
Acidity/alkalinity	10.0	0.0	8.0	1.4	10.0	0.0
Electrical conductivity	7.5	0.9	6.0	0.0	8.0	1.0
Boron	6.0	0.0	6.0	id	id	id
Cadmium	id	id	6.0	id	id	id
Phosphorus total	10.0	1.6	6.0	0.9	10.0	1.8
Nitrogen total	id	id	6.0	id	id	id
Sodium adsorption ratio - Surface structure	10.0	0.0	6.0	0.0	10.0	0.4
Sodium adsorption ratio - soil stability	10.0	0.5	6.0	0.7	10.0	0.8
RSC	id	id	6.0	id	9.0	0.0
Biodegradability	id	id	6.0	id	id	id
Overall	8.8	0.3	6.6	0.4	9.5	0.6

Risk values are Table 13 bottom row; 6 = low, 7= moderate, 8 = high, 9 and 10 = very high risk

4.1.2 Wash and rinse cycles (dilution)

For most detergents that were not potentially GreySmart when assessed as wash-only water,. dilution with a second volume of water equal to twice the wash volume increased the number of potential GreySmart detergents, or low and very low risk detergents, by 1 (Table 17). The number of very high risk detergents was also reduced by approximately 40%, with the ranking of high risk detergents. It was assumed that it was difficult for users of greywater to use just the rinse, and the most likely option practiced would be wash and rinse cycle and the rinse oly option was not assessed.

4.2 GreySmart

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. This will help confirm the risk value defining GreySmart with Care and if determined to be the case, then the household product tested will be ranked as 'GreySmart with Care'.

Clothes washing detergents have been the first detergents assessed due to the high use of washing machine grey 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.

5 Conclusion

There are two key conclusions from this paper. Firstly, this risk assessment suggests that there are a good number of commercial clothes washing detergents that have potential to achieve GreySmart ranking. In fact, from the data provided for one detergent where all data was available it would be considered GreySmart. The concencentation of hazards will be validated by an independent laboratory in 2010. Secondly, the use of the Australian Guidelines for Water Recycling provides a robust risk assessment framework to assess greywater quality.

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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8 APPENDIX

8.1 Analysis required and methods

Table 19 Analysis required of greywater/sewage water

Parameter	Abbreviation	Unit	Method[A]	Expected range of analysis	Cost per sample to for analysis
Acidity/alkalinity	pH		pH	4 to 11	
Electrical conductivity	EC	dS/m	conductivity	0.01 to 5	
Boron	B	mg/L	Total – ICP-OES	0.1 to 20	
Cadmium	Cd	mg/L	Total – ICP-OES	0.001 to 0.1	
Phosphorus total	P	mg/L	Total – ICP-OES	0.1 to 40	
Sodium total	Na	mg/L	Total – ICP-OES	0.1 to 1600	
Calcium total	Ca	mg/L	Total – ICP-OES	0.1 to 100	
Magnesium total	Mg	mg/L	Total – ICP-OES	0.1 to 100	
Nitrogen total	N	mg N/L	Total – Kjeldahl nitrogen	0.1 to 100	
Nitrate	N as NO_3	mg N/L	Please indicate!	0.1 to 100	
Carbonate	HCO_3	mg/L	Please indicate!	0.1 to 100	
Bicarbonate	H_2CO_3	mg/L	Please indicate!	0.1 to 100	
Biodegradation	BioDg	%	Biodegradability (SA 1996)[A]		
Internal standards for each analysis run should be reported marked against expected concentrations					

[A]Or equivalent NATA accredited method.