A Scoping Study to Evaluate the Fitness-for-Use of Greywater in Urban and Peri-Urban Agriculture

Report to

the Water Research Commission

By

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Executive Summary

Background

In many urban and peri-urban areas of South Africa, there is a growing need to use alternative sources of water for irrigating household gardens due to increasing costs of municipal water supplies. Greywater (used household water that is not toilet water) presents a potentially suitable water resource that can be used for irrigating certain crops in home gardens.

Greywater is often used for the watering of gardens in times of drought or restrictions on water use. However, as the quality of the different household sources can differ significantly, there is considerable uncertainty about the risks associated with, and the acceptability of, the practice. It is thus uncertain whether greywater use should be promoted or discouraged as a source of water for urban and peri-urban agriculture.

The Water Research Commission therefore decided to fund a scoping investigation in order to obtain a balanced evaluation of the opportunities and threats presented by the use of greywater in urban and peri-urban agriculture, and to identify further relevant research needs. The scoping study therefore needed to determine and synthesize available knowledge; to assess quantities and qualities of greywater being produced in South Africa; to assess the potential demand for greywater by different user groups; to identify the potential positive and negative impacts of greywater irrigation; to investigate policy implications and potentially suitable guidelines and to propose priorities for further research.

Approach followed

There is a limited amount of local data on the chemical and microbiological composition of household greywater, especially regarding low income households. For semi-arid, water-stressed countries, greywater produced by residences in upper and middle income group areas should have similar characteristics in terms of quality and per-capita volumes produced, taking into account the relative costs of water supplies. Thus where local data on greywater quality and per-capita volumes for upper and middle income areas may be lacking, substitute data from overseas sources could be used without adding a significant degree of error to the results. Seeing that greywater quality depends very much on the relative quantity of water used for washing and food preparation (i.e. the dilution factor), and on whether greywater is reused in the home prior to disposal, greywater quality data available for western-style houses could be used to obtain approximate quality data for poor communities by assuming that lower volumes of greywater from poor households would contain proportionally higher concentrations of microbes, dissolved salts and suspended particles. Thus for poor households without water-borne sanitation, a knowledge of the quantity of fresh water used per capita and per household should be sufficient to obtain a preliminary estimate of the characteristics and volumes of greywater produced per household.

Greywater production volume assessments

Greywater production volumes are dependent on the volume of supply water consumed by members of a household, and this in turn depends on the scarcity/ costs of supply water and on the water conservation measures being taken within the household, amongst other factors.

In the scoping study, greywater production was estimated from Census 2001 data, with some knowledge on average water consumption figures for different socio-economic groups in South Africa. Annual water consumption figures were estimated for dwellings, categorised according to water supply service categories presented in the Census 2001 data base, but excluding the Census 2001 categories where water is supplied from rainwater tanks, boreholes and springs (as these were assumed to be outside of municipal areas). The water consumption estimates were used to give a preliminary estimate of annual greywater production volumes per water supply service category. In the report, these are grouped into two categories: dwellings with piped water supplies directly to the house, and dwellings where water has to be obtained from piped supplies to a tap in the yard or further away. A preliminary estimate of the total greywater production from households that obtain their water from municipal water supply systems in South Africa in the year 2000 is 858 Mm^3 . A preliminary greywater production estimate of 1224 Mm^3 for the year 2000 was then made from municipal water consumption data presented in the National Water Resources Strategy (Department of Water Affairs and Forestry, 2004). Taking the average of the two preliminary greywater production estimates gives a revised estimate of 1040 Mm^3 for greywater produced in urban and peri-urban areas in South Africa in the year 2000.

Preliminary irrigation requirements

Preliminary irrigation requirements for irrigating vegetable crops on a daily basis during summer are presented in order to obtain an estimate of the land area required for two greywater producer categories. The following information serves as an approximate estimate only, and may be used for preliminary planning purposes for this study:

Based on the average greywater volume produced per dwelling, and assuming that sufficient greywater is produced to satisfy the peak monthly crop irrigation requirements of summer vegetables, then:

- For communities required to get their water from a community stand or a tap in the yard, a minimum area of about 17 m^2 per dwelling (for areas experiencing dry summers), and a maximum area of about 56 m^2 (for areas normally experiencing high rainfall in summer) are required.
- For communities with piped water directly to their homes, a minimum area of about 35 m^2 per dwelling (for areas experiencing dry summers), and a maximum area of about 116 m^2 (for areas normally experiencing high rainfall in summer) are required.

From the different seasonal requirements for crop irrigation, the use of greywater, a relatively constant supply source, requires either:

- that crops will be over-irrigated for part of the season or that some greywater will need to be diverted elsewhere, or
- that supplementary water will be needed for part of the season,

dependant on crop growth and seasonal climate characteristics. For this study, irrigation area calculations were based on the assumption that crops are over-irrigated for part of the season.

The following assumptions were made regarding the estimates:

- Although household greywater contains plant nutrients, the limiting constraint to irrigation application is assumed to be moisture rather than nutrients such as nitrogen (e.g.: nitrate-N) and phosphorus;
- irrigation with untreated greywater assumes the use of simple irrigation methods;
- irrigation volume estimates allow for excess irrigation for effective leaching purposes towards the beginning and end of the crop growth season. (note that effective drainage of cropland is required to promote leaching of accumulated salts in the topsoil);

- ☐ All the available greywater produced each day, including kitchen greywater, is used for irrigation. (If kitchen greywater is to be excluded, then for preliminary assessments, reduce the irrigated area by about 10 %).

Greywater quality assessments

Water conservation measures and greywater reuse in the home can be expected to increase the concentrations of dissolved chemicals in greywater significantly, thus impacting on its potential suitability for reuse for irrigation unless measures are taken to reduce the quantity and types of chemicals used in detergents and soaps for washing and cleaning. Greywater quality is also very much dependent on the source, with highest quality coming from the bathroom, the second highest from clothes washing, and the poorest quality coming from dishwashing activities (the kitchen).

The quality of greywater therefore varies depending on the volume of fresh water used per person in a household, on the chemical quality of this water, on the greywater source (bathroom, kitchen, laundry), on chemicals used in the washing/bathing process, and on the amount of greywater reuse carried out in the home before the final greywater is disposed.

The health risk associated with greywater is related to the microbial quality of greywater at the point of irrigation, on how irrigation is carried out, and the type of crops being irrigated. The microbial quality of kitchen greywater is generally poorest of the greywater sources (at the point of irrigation). In terms of chemical quality, the least suitable greywater for irrigating sensitive crops and soils is laundry greywater, especially greywater from the first wash, due mostly to the high sodium concentrations and the high pH of laundry greywater. Greywater from the first laundry wash is also usually too hot for direct irrigation.

This report includes the results of a preliminary greywater quality evaluation to compare the quality of different greywaters from different residential locations in the Cape peninsula area and with greywater quality as found in the literature. The results show that there are significant differences in quality between the different types of greywater as well as between the different locations where greywater is produced. The concentrations of greywater constituents reported on in the literature are compared with the results from this study. Except for nitrogen, constituent concentrations of greywater found in the local study were higher than for those reported on in other studies. Faecal bacterial concentrations in kitchen greywater were significantly higher than in greywater from the laundry or the bathroom, in agreement with studies done in Arizona.

It is obvious that the quality of greywater, in relation to the South African Water Quality Guidelines, Volume 4 Agricultural Use (SAWQG4) of the Department of Water Affairs and Forestry, is such that greywater from the bathroom and laundry could be used for restricted crop irrigation. It is recommended from the current study that greywater from the kitchen (excluding rinse water) should not be used for irrigating plants.

Potential demand for greywater for irrigating crops

For residences with gardens, during periods of water shortage or in areas where there is a chronic water shortage, there will be a greater demand for supplementary sources of irrigation water, such as greywater. At the same time due to water conservation measures, the per-capita production of greywater becomes less and the greywater quality is proportionately poorer. Thus although there is an increased demand for supplementary irrigation water, the poorer quality of greywater will make it less suitable for irrigation purposes, and the increase in potential demand for its use would therefore not be as great. Factors affecting this relate to implications for human health and quality of life, and the potential impact on plants and soils. User-friendly guidelines and educational drives should help to stimulate successful greywater irrigation however, and thus help to stimulate demand.

Not all plants and soils are suitable for irrigation with greywater, so careful identification of suitable crops and soils and appropriate irrigation management guidelines will be needed by householders intending to use greywater for irrigation purposes. Preliminary guidelines are presented in this report.

Demand for greywater reuse for irrigation will be less during cooler, rainy seasons and in the more humid areas of the country. Higher demand for supplementary irrigation water such as greywater is likely to occur during periods of drought, during the dry season, in the more arid areas of the country, and in expanding municipal areas with limited access to water resources, especially those that do not have an assured long-term water supply. For low-income communities, the demand for greywater irrigation would very likely be for subsistence crops such as tomatoes and cabbages (these are fairly tolerant of sodium and salinity in irrigation water), as well as for multi-purpose plants that provide shade, privacy, security, firewood, poles, fodder, and herbal remedies. For more affluent communities, uses and demand for greywater would most likely be for irrigation of flowers, shrubs, vines and lawns. Availability of suitable land for greywater irrigation is a factor in creating demand.

Demand will be greater where households have access to suitable land at a low elevation adjacent to the bathroom or washing area. Poor residential areas without waterborne sanitation are unlikely to be constrained by inappropriate plumbing fixtures or land elevation problems, as irrigation of plants is most likely to be by bucket or hand-basin. Residential properties with access to groundwater resources are unlikely to be constrained as much by the cost of municipal water supplies as other properties, so demand for greywater for irrigation purposes will be low except possibly for cases where groundwater quality causes it to be less suitable for irrigating garden plants than greywater would be.

Legal implications

Greywater reuse is referenced under the South African National Water Act (NWA) under "the use of water containing waste for irrigation purposes", a "controlled activity" requiring a wastewater irrigator to obtain a licence. Greywater is also categorised as domestic wastewater under the general authorizations (GA) regulatory requirements (Department of Water Affairs and Forestry, 2004).

A recent revision of the applicability of general authorizations (GA) to certain controlled activities (Department of Water Affairs and Forestry, 2004), does not require a domestic wastewater irrigator to apply for a licence provided that irrigation complies with a relevant set of limits and conditions in the applicable authorisation (Section 2.7 of the revision). Greywater irrigation is unlikely to benefit from the most relevant requirement (Section 2.7 (iii) of the revision), seeing that average greywater microbial quality is outside the limits specified. A strong case can be made for a relaxation of the limits and conditions for a general authorization on greywater irrigation, however, seeing that the average volumes of greywater produced are much smaller than the limit on the volume specified in the requirement. Alternatively, regulations for greywater irrigation and disposal could be excluded from the NWA legislation, and included instead under existing national health legislation for wastewater irrigation (Department of National Health and Population Development, 1978), or possibly under provincial ordinances and municipal bye-laws.

Greywater reuse by unsewered communities

This report includes a preliminary assessment of greywater reuse by unsewered poor communities in some villages of the Eastern Cape Province. The assessment was based on data obtained from a social survey done by the University of Cape Town in 2004. Survey participants reported that their households use, on average, between 20 to 150 L per day of water. In nearly all cases, greywater is thrown outside the house onto the ground, into a gulley, or into a pit latrine. The problems most survey participants associate with discarded stagnant greywater are smells, muck, mosquitoes and poor health, and are the major motivating factors for not practising greywater reuse. Other reasons for not practising greywater reuse relate to lack of knowledge on safe ways to reuse greywater beneficially and to the fact that greywater is of very poor quality.

Eleven percent of the survey participants reported re-using their greywater in the home, most using high-quality greywater (e.g. rinse water) for further washing purposes, and some also use greywater to wash floors. Five percent reported using greywater for watering their grass. It is not clear whether greywater reuse is on a regular basis or only when water supplies are severely restricted.

Potential positive and negative impacts of irrigating with greywater

Greywater generation, along with other forms of wastewater generation, can have a potential environmental impact at local and regional/national levels and can have both short term and long term consequences. Positive and negative impacts are considered from regional, municipal and household levels.

Potential positive impacts

- *Regional level:*

  Greywater irrigation in home gardens is seen as a way to reduce regional demand for fresh water. This lines up with the government policy on water demand management.

  Irrigation with greywater instead of with municipal supplies in areas close to the coast should increase the net quantity of water available to the country, in cases where the greywater would otherwise be lost to the sea.

  Although modern wastewater treatment plants are able to remove nutrients, pathogens, suspended solids, most organic contaminants and most trace elements, they are generally not able to remove highly soluble salts such as sodium and chlorides that present problems relating to soils, crops and water resources, especially over the longer term. It is therefore hypothesized that the greatest negative impact of discharge of treated wastewater on water resources at a regional level and over the longer term is presented by salinity. This should also be true of greywater where it forms a component of sewage. The removal of the greywater component from sewage therefore represents a positive, albeit small, impact in this regard.

- ☐ *Municipal level:*

  At a municipal level, the overriding positive environmental impact of greywater reuse is the reduction in municipal demand for fresh water. There is a growing argument against the use of high quality potable water for purposes that do not require such water, especially if the high-quality water could then be made available for other more suitable uses.

  Other positive impacts include the saving on costs of municipal supply water treatment and wastewater (sewage) treatment, and a reduction in the urgency of sourcing new raw water supplies and of building new storage and water abstraction facilities.

- ☐ *Local (household) level:*

  Greywater used in place of municipal tap water to irrigate garden plants saves on household water costs and can also save on fertiliser use (greywater contains plant nutrients). Greywater serves as a dependable source of water that can be used in times of water shortage to irrigate vegetables and fruit trees, and so provide a measure of food security for poor households.

  Greywater with a sufficient concentration of certain types of soap is believed to kill or weaken certain garden pests and to help prevent damage to vegetables caused by specific plant diseases.

Potential negative impacts

- ☐ *Regional level:*

  The most significant potential negative impact of greywater irrigation at regional level over the long term is believed to be an increase in salinisation of soils and salinisation of high-quality aquifers. Specifically, in the case of the high sodium content of greywater, sodification of soils would most likely represent the greatest long-term potential threat.

The magnitude of the longer-term salinity impact on high quality aquifers needs to be considered in the light of the small volumes of greywater likely to be used for irrigation, when compared with the high volumes of water from other sources currently used for irrigation. The total salt load contributed to high-quality aquifers by the latter could be orders of magnitude larger than that contributed by future greywater irrigation.

Other potential negative impacts of greywater irrigation on a regional level include the aquifer contamination threat posed principally by nitrates and pathogens and the surface water contamination threat posed principally by phosphates, organic particles and pathogens.

- ☐ *Municipal level:*

  For a municipality overlying an aquifer from which it abstracts water, greywater irrigation of household gardens can have a negative impact in terms of an increase in salinity, contamination by nitrates and contamination by pathogens. However, the significance of a potential impact depends on many factors, including the type of aquifer, the type of overlying soils, the depth to groundwater, the volumes and quality of greywater applied (amongst others). Also, the contamination threat to the aquifer from other sources, such as the municipal sewerage system, is likely to be far more significant for nitrates and pathogens than the threat from greywater irrigation.

  Removing the greywater component from sewage will result in a reduction of sewage flow volumes by up to 40%. This sewage flow would carry the same load of sewage solids, and so cause more frequent blockages of sewerage systems and in longer times for sewage to reach treatment works. A reduction of less than 5% (or even 10%) of total sewage volume as the result of greywater reuse is highly unlikely to have a significant negative affect on municipal or septic tank sewerage systems, unless for municipal systems this volume reduction occurs during times of very low sewage flows.

- ☐ *Local (household) level:*

  Potentially major negative environmental impacts of greywater irrigation at the household level are related to the relatively high concentration of sodium ions in relation to other chemical ions in greywater from clothes washing activities; to the pathogen, organic solids, and fat content of greywater from dishwashing and food preparation activities (kitchen greywater); and to bathing water containing pathogens from sick individuals (bathroom greywater).

The negative impact on health of greywater irrigation of vegetables for private household use may be potentially significant if irrigation is not carefully controlled, where hygiene standards relating to irrigation management, vegetable harvesting and food preparation are not upheld.

If improperly managed, greywater irrigation areas can become sources of public nuisance, with the development of nuisance conditions such as insect breeding, odours, unsightly discolouration, etc. For example, if greywater is stored or allowed to pond for longer than 24 hours, it can represent an increased health risk, and become a source of public nuisance in terms of insect breeding and odour generation.

The negative effects of high pH, high sodium, and to some extent raised chloride and boron concentrations in greywater used for irrigation, on crop growth / yields and on soils may be determined from the following statements derived from the South African Water Quality irrigation guidelines:

- ☐ High sodium, chloride and boron concentrations are toxic to plants on uptake through leaves (especially) and roots (to a lesser extent);
- ☐ High salinity (high concentrations of total dissolved salts such as sodium, chlorides and sulphates) reduces crop yield, and can have a negative effect on the quality of harvested fruit (e.g. grapes);
- ☐ Alkaline greywater (from detergents) increases the pH of soil: High soil pH has a potential negative effect on growth/health of many plants and can have a negative effect on the quality of harvested fruit;
- ☐ High sodium concentrations can cause a reduction in soil infiltration rate, in soil hydraulic conductivity and can cause hard-setting when the soil dries out. (Depends on SAR / EC ratio of irrigation water/ soil water). Thus the soil tends to prevent fresh water and air from reaching plant roots, resulting in root die-off.

Basic guide for irrigating crops with greywater

☐ Greywater availability

What sources of greywater (kitchen, laundry, bath, wash basin, shower) are available? For each source, estimate the volume of greywater produced on a daily or weekly basis.

☐ Land area suitable for irrigating garden plants

Calculate the area of land that can be irrigated using each greywater source. Determine whether the land required is available and accessible for irrigating with greywater from each source, and whether the soil is suitable for greywater irrigation.

☐ Identification of suitable crops/plants

Select crops/ plants that can be grown in the area and that are not sensitive to medium to high pH soils, or to the concentration levels of sodium and dissolved salts in the greywater from the source used for irrigation.

☐ Identification of suitable treatment / management measures

In order of preference, use

1. bathroom greywater;
2. laundry greywater (preferably use only rinse-wash water);
3. kitchen greywater (rinse water only).

☐ Management measures

Determine what management measures may be applicable for greywater irrigation from the source in question.

☐ Regulations

Determine what regulations (e.g. municipal bye-laws) may be applicable for greywater irrigation.

Other, more detailed guidelines and constraints are presented in the main body of this report.

General Conclusion

A fair amount of information exists in the literature and other sources on greywater production and its use for irrigation of household gardens. This information relates mostly to middle-income Western-style households. There is still a significant lack of local knowledge relating to low-income households. Knowledge gaps relate to:

- ❑ Where greywater reuse for irrigating garden plants is an established practice, and where historically it was practised but is not any more, and the reasons for this.
- ❑ The proportion of household supply water used to irrigate garden plants (i) in normal times and when water restrictions are applied and (ii) in areas where water is expensive versus areas where water is relatively cheap.
- ❑ To what extent greywater can be used to supplement plant nutrient needs with, and without, contribution from organic mulches, and what the risk is of nitrogen overload.
- ❑ To what extent greywater acts as a pest deterrent for crops, dependent on greywater source and on types of detergents and soaps used.
- ❑ To what extent the soil pore clogging effects of organic particles (including grease) affect infiltration.
- ❑ The chemical and microbial characteristics of greywater from poor households.
- ❑ What percentage of supply water becomes greywater for households (sewered and unsewered) in poor communities.
- ❑ To what extent the perceptions of poor greywater quality, effort and cost factors, and other factors hinder greywater reuse for irrigation purposes amongst different communities, and to what extent other perceptions may promote greywater reuse.

Although significant knowledge gaps exist regarding greywater reuse especially amongst unsewered poor communities in South Africa, enough information is available to prepare preliminary greywater irrigation guidelines. Basic (draft) guidelines for greywater irrigation of household gardens are presented in this report. These need to be tested, modified, incorporated into a protocol and a home found for them in terms of existing legislation.

The following are some suggestions for further research, given a high priority ranking.

- ❑ Test the basic (draft) guidelines for greywater irrigation of household gardens presented in this report, and modify them to account for South African conditions. Prepare a preliminary protocol to complement these guidelines and test (in consultation with authorities), with suitable institutions and with communities under different climatic and socio-economic conditions. Modify the guidelines so that they are contextualised to target different user groups (e.g. contextualise guidelines in terms of sewered vs. unsewered communities; urban versus semi-rural communities; inland versus coastal areas, winter versus summer rainfall areas, arid versus humid areas, etc.).

- In conjunction with relevant authorities, review the current institutional and legal framework for use of greywater. Investigate where the protocol and guidelines (see previous item in this list of proposed research items) could find a home in terms of the legislation, and how the protocol/ guidelines could be organised into phases or components for application at national, regional and local levels. Investigate what existing legislation/ guidelines could be modified to facilitate controlled greywater irrigation, and how such changes could be implemented/ institutionalised.

- (i) Investigate biocompatible detergents and soaps in terms of chemical content, detergent function and potential impact on the environment, and determine the likely improvement in greywater quality as a result of using such detergents and soaps in South Africa,
  (ii) draw up a list of biocompatible detergents suitable for use in South Africa and
  (iii) identify potentially suitable ways of promoting the availability and use of such detergents.

- It is generally believed that domestic wastewater (including greywater) use for agricultural purposes will benefit a nation by freeing up higher quality water resources (Ludwig, 2004a; Center for the Study of the Built Environment, 2003), but at least one literature source indicates that it won’t necessarily make an improvement to a nation’s net water balance (Pettigrove et. al, 1984). Investigate this, taking into account water availability and suitability for use (volume and quality aspects, - the latter also addressing chemical and microbial risks) and taking into account the potential impact / mitigating effect of using biocompatible detergents.

- Obtain detailed chemical and microbial analyses of greywater from poor communities, and interpret the results in terms of risk to community health and suitability for irrigating specific garden crops, and identify relevant measures to reduce risk and promote sustainability.

Modify the data obtained from overseas studies to take into account low volumes of available supply water resulting in lower volumes of greywater containing proportionally higher concentrations of microbes, dissolved salts and suspended particles. Compare these results with the results of the sample analyses of greywater produced by low income households. Discuss the relevance of using this approach.

☐ Research what percentage of supply water becomes greywater for households in poor communities, both sewered and unsewered, for different categories of water supply service, during summer and winter, and in times of water shortage.

☐ Research the extent that perceptions of poor greywater quality, effort required, cost factors and other factors hinder greywater reuse for irrigation purposes amongst different communities, and identify what beliefs or perceptions could promote greywater reuse. Investigate the proportion of household supply water used to irrigate garden plants (i) in normal times and when water restrictions are applied and (ii) in areas where water is expensive versus areas where water is relatively cheap. Identify where greywater reuse for irrigating garden plants is an established practice, and where historically it was practised but is not any more, identify the reasons for this.

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Ms B Genthe; Council for Scientific and Industrial Research
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CHAPTER 1

1 Introduction

1.1 Problem Statement

The White Paper on Agriculture emphasises food security. Household gardens and urban food gardens can contribute to food security and are, therefore, supported by government. One of the factors that limit the application potential of these systems is a shortage of water to supplement rainfall. Greywater (used household water that is not toilet water) may help to overcome this limitation by providing a dependable source of water that is under the control of the household gardener (NSW Dept. of Health, 1999).

1.2 Background

Over the last few decades there has been an increasing need to use alternative sources of water, such as treated sewage wastewater, for crop irrigation due to increased demand for limited resources of freshwater. Population growth along with increasing demands from industry and agriculture are putting greater stress on existing water resources. Treated sewage wastewater presents a potential resource that can and is being put to beneficial use for irrigating crops (Pettigrove et al., 1984). However, the high cost of treating sewage wastewater to strict microbiological standards required for crop irrigation often means that use of untreated sewage wastewater is allowed to occur unregulated (Blumenthal et al, 2000). Greywater from residences forms a component of sewage once it enters the sewerage system. Greywater from certain household sources may not require treatment for irrigation if suitably managed, so this greywater could be diverted before joining the sewerage system, and beneficially used for agricultural purposes at the household level. For example, greywater from the bathroom and from clothes washing has significantly lower levels of pathogens than does sewage, and should not need treatment if it’s use for irrigation is properly managed (Ludwig, 2004a; Water Conservation Alliance of Southern Arizona, 2001).

Greywater is the untreated household effluent that is produced from baths; showers, kitchen and hand wash basins as well as washing machines. About half of the indoor household water use is normally used for these purposes and can thus potentially be intercepted by the householder for additional uses. Greywater is often used for the watering of gardens in times of drought or restrictions on water use. However, as the quality of the different household sources can differ significantly, there is considerable uncertainty about the risks associated with, and the acceptability of, the practice. For example, high levels of boron in greywater from some detergents used in washing machines can cause damage to certain types of crop (Ayers and Westcott, 1985) and there could be significant risk to human health of using wash water for irrigating vegetables, if the water is from a household where a child has diarrhoea.

A further issue that needs to be resolved is that whether the use of greywater for irrigation does free up high-quality water resources for alternative use. Greywater would normally be returned to a water source such as a river as part of a treated municipal wastewater return flow, so that it can be used by downstream users. Should greywater be removed from the municipal wastewater system as a result of its use for home garden irrigation, there will not be less water for downstream users if greywater is used in place of municipal water supplies for garden irrigation, so the net quantity of water available to the nation would essentially be left unchanged. However, if greywater for irrigation is a new use that does not free up municipal water supplies for alternative (non-consumptive) uses, then there will be less water available for downstream users, thus the net quantity of water available to the nation will be reduced. The exception to this is where the greywater would otherwise be lost to the atmosphere or the sea (e.g. if greywater irrigation is at the coast, where the alternative destination for the greywater is the sea.), then in such cases the net quantity of water available to the nation will remain essentially unchanged. It is thus uncertain whether greywater use should be promoted or discouraged as a source of water for urban and peri-urban agriculture, especially in inland areas (Wood, Uchronska and Valashiya, 2001).

Potential risks associated with the use of greywater include the following:

- ☐ Health risks such as transmission of infectious diseases (Blumenthal *et al*, 2000; Jagals and Steyn, 2002; Asano and Sakaji, 1990) and bioaccumulation of potentially toxic elements in plants (Murphy, 2000).
- ☐ Reduced crop yield as a result of salinity, nitrogen overload, specific ion effects (e.g. boron, sodium and chlorides) and soil pore clogging effects of grease, phosphates and sodium. (Ayers and Westcot, 1985).
- ☐ Soil degradation because of high sodium, salinity or other substances (Hanson *et al*, 1993).
- ☐ Groundwater contamination (Broadbent and Reisenauer, 1984; Foster *et al*, 1994; Sililo *et, al*, 1999).
- ☐ Reduced flow and higher solid content may cause blockages in sewerage systems and treatment problems in waste water treatment works.

Potential benefits that can be derived from the use of greywater in urban and peri-urban agriculture, are:

- ☐ Reduced (or no) cost of water for gardening in urban and peri-urban areas (Shuval *et. al*., 1986).
- ☐ Reduced demand for high quality potable water and thus new treatment facilities and water supply schemes (Shuval *et al*, 1986).
- ☐ Reduced agricultural requirement for application of plant nutrients (Pettygrove et al, 1984).
- ☐ Reduced flow to septic tanks and water treatment facilities, that results in reduced pumping / treatment costs.
- ☐ Reduced flow from wastewater treatment works; which are closer to natural environmental flows, especially in winter rainfall areas.
- ☐ Soil, as a natural treatment medium, presents a low-cost treatment alternative for greywater (Bouwer, 1985).

In view of the opportunity that the use of greywater presents for household agriculture in urban and peri-urban areas and the risks this may hold, it was deemed necessary to conduct a scoping investigation that will present a balanced evaluation of the opportunities and threats presented by greywater use in urban/ peri-urban agriculture and the research needs that will have to be addressed in a research project to address the problem. This leads directly to the overall objective of the study, and to the more detailed objectives following this, specified in the following section.

1.3 Objectives of the study

1.3.1 Overall objective

- ☐ Conduct a scoping investigation to obtain a balanced evaluation of the opportunities and threats presented by the use of greywater in urban and peri-urban agriculture and identify the research needs that have to be addressed to resolve them.

1.3.2 Intermediate objectives

- ☐ Determine and synthesize the available knowledge (including completed research and existing local expertise) on greywater;
- ☐ Determine the quantities and qualities of greywater available for different user groups at different locations/areas based on secondary data and sources of expertise such as city engineers;

- Determine the range and extent of potential end users and the beneficial uses of greywater (national coverage);
- Determine the existing as well as the potential demand for greywater for different user groups at different locations/areas;
- Supplement available secondary data where appropriate with tests/ samples/ etc.
- Determine the potential positive and negative impacts of the use of greywater.
- Determine availability of suitable guidelines/criteria used in SA and internationally for acceptable and sustainable use of greywater. Identify (in conjunction with the Department of Water Affairs and Forestry) possible policy implications and needs for policy formulation and implementation.
- Propose priorities for further research.
- Test the provisional findings and priorities through two separate workshops with, firstly, a broader group of scientists and, secondly, end user representatives and stakeholders.
- Formulate the Terms of Reference for a follow-on research project.

1.4 Approach

In this report, irrigation refers to supplying the water needs of plants by bucket, by pipe to individual plants or by sophisticated drip irrigation systems, where plants include subsistence crops, vegetables, herbs, fruit trees, multi-purpose plants and grass. Urban and peri-urban areas refer to residential areas near city centres, in suburbs, informal areas and low density areas at city boundaries. In this report, greywater irrigation is restricted to that which occurs in the vicinity of the dwelling where the greywater is produced. Although greywater accumulated from several households and greywater from institutions is not excluded, it is not the focus of the report. The words “irrigation” and “watering”, and the words “crops” and “plants” are used interchangeably in the report.

The approach to this project has been to review and interpret currently available information relating to research, management and decision support (e.g. best-practice guidelines) relating to the field of greywater irrigation in urban and peri-urban agriculture, in the following categories (Chapter 2):

- greywater characteristics relating to human health risk and impact on plants, soils and groundwater;
- other positive and negative aspects of greywater use in household agriculture;
- greywater characteristics and discharge volume estimations in terms of source types (kitchen, bathroom, other) and producer groups;

- the existing and potential demand for greywater use for agricultural (and possibly horticultural) purposes;
- potential for greywater to water plants of households in urban and peri-urban settings;
- design and management guidelines for greywater irrigation;
- potential mitigation measures;
- suitable crops and soil types for irrigation by greywater, and associated applicable management/design measures;
- potential contamination risk to soils and to water resources;
- protocols, regulations and associated guidelines.

Information sources include the internet, printed publications and relevant experts. Literature and knowledge on agricultural irrigation with treated wastewater and brackish water was interpreted in light of characteristics common to greywater. Potentially-relevant guidelines were identified and then assessed for potential applicability to greywater use for agricultural purposes in South Africa.

Information on greywater generation was sought from government, municipal and local authorities, as well as from other sources. Information on greywater production and use in other countries was also sourced, and interpreted in light of its potential applicability for augmentation of, and comparison purposes with, information gathered locally. (Chapter 3)

Attempts have been made to characterise greywater from sources such as bathwater and shower water, from clothes washing /washing machines, and from dishwashing activities. Ranges in quality of greywater were considered, taking into account ease of access to source water (i.e.: municipal supplies). (Chapter 3)

Existing and potential demand for greywater use in agriculture was assessed by obtaining water consumption data for different user groups, and estimating greywater production from this data. Assessments were then made of the likely demand for greywater for irrigation by different user groups. (Chapter 3)

The potential use of greywater was considered for growing crops, taking into account crop and soil sensitivity to chemicals in greywater and potentially suitable mitigation measures such as using supplemental irrigation of higher quality water for flushing/leaching purposes. (Chapter 3)

Pilot studies and a social survey were conducted in typical South African settings, and results from these studies were used to contextualise and validate existing figures. (Chapter 4)

> The aim of the pilot study was to gather information first-hand on greywater production and disposal / reuse in the Stellenbosch and Kuilsrivier area in the Western Cape. A second aim was to evaluate the fitness for use of greywater by establishing the greywater quality with a limited sampling and analysis investigation. Greywater samples from 18 residences were analysed for potassium, sodium, boron, calcium, magnesium, ammonia, sulphate, chloride, alkalinity, nitrate, nitrite, ortho-phosphate, conductivity, pH, sodium absorption ratio, dissolved organic carbon, chemical oxygen demand, Kjeldahl nitrogen, total phosphorus, suspended solids, total dissolved solids, fats and oils, heterotrophic plate count, faecal coliform bacteria and *Escherichia coli.*
>
> A social survey was conducted of individuals in nine towns and villages in the Eastern Cape and one town in KwaZulu-Natal by researchers from the University of Cape Town. The questions asked relate to various aspects of water supply and greywater disposal and reuse, at household level. For this study, selected data from the survey has been used to help identify perceived benefits and threats of re-using greywater by poor communities, some of whom do not have ready access to reticulated fresh water and who are not serviced by a sewer system. The responses were compared to results of a greywater reuse survey conducted in residential areas in various counties around Tucson, Arizona.
>
> A pilot investigation into the use of treated sewage wastewater in the Western Cape was initiated. The main objective of this investigation was to gauge the level of wastewater use for agricultural purposes in the Western Cape in addition to helping municipalities to use their treated wastewater more efficiently while conserving fresh water supplies.

Potential positive and negative impacts of greywater were identified in terms of major greywater categories, and in terms of potential use. (Chapter 5)

Potentially enabling and restrictive legislation for greywater reuse for agriculture was identified and assessed in consultation with representatives of the Department of Water Affairs and Forestry, as well as with some Local Authorities. Potentially suitable legislation and guidelines have been explored with the aim of promoting and managing beneficial (and sustainable) utilisation of greywater for irrigating plants in urban and peri-urban environments. (Chapter 5).

CHAPTER 2

2 Literature survey

2.1 Greywater use in irrigation

2.1.1 Locally

Alcock (2002) has conducted the most comprehensive review on greywater use for irrigation in South Africa to date. He reports that greywater has been used for irrigating lawns and crops to a limited extent in South Africa. Eight informal and communal cases of greywater reuse for agriculture and horticulture are reported on, as well as twenty cases involving private middle-income households, mostly in KwaZulu-Natal and some in the Eastern Cape, Western Cape and Johannesburg areas. Four historical cases are also reported on. Most of the case reports are based on the results of discussions held with responsible authorities at the institutions, or with occupants of the properties, concerned.

Alcock reports that prior to 2002 virtually no scientific research work on greywater irrigation in respect of crops and the soil had been undertaken in South Africa. One known exception is a study conducted at Infruitec, Nietvoorbij, Stellenbosch (Alcock, 2002; Beukes, 2001). The results of this study, conducted on potted tomato plants and bean plants in a greenhouse, indicate that greywater had a beneficial effect on the growth of beans and tomatoes over the short term in composted soil. However, sodium values showed an increase in all three types of soil used in the study (sandy, loamy and clayey soils) (Beukes, 2001).

The source of the greywater was from a household in Stellenbosch, and consisted of a mixture of water from the kitchen, laundry and bathroom. The results of the study indicate that greywater could be used to irrigate coarse textured soils with a good permeability if leaching is carried out (Beukes, 2001) This means that this greywater would have to be applied in excess of crop moisture needs assuming there is sufficient drainage, and that the application of gypsum and/or compost would be required for longer term applications on finer textured soils (Department of Water Affairs and Forestry, 1996). The assumption is that leaching does not occur from rainfall or from supplemental irrigation with fresh water. Should moisture from other sources (e.g. rainfall, municipal water) be applied, then excess application of greywater may not be required to leach out accumulated salts from the soil. (Beukes, 2001)

In South Africa, greywater irrigation is being practiced amongst both poor and rich communities. Affluent users of greywater for irrigation seek to reduce municipal water bills. Users, who have to carry water home from a distant tap or water source, save water by re-using greywater either in the home or on subsistence crops. (Alcock, 2002)

Although greywater use for crop irrigation is not extensively practiced in South Africa, treated sewage wastewater is fairly extensively used for crop irrigation: many wastewater irrigation schemes are active, examples being the irrigation of golf courses and the irrigation of municipal-owned land for growing saplings and pasture grass, with treated sewage wastewater (Murphy, 2000).

2.1.2 Other countries

Kingdom of Jordan

Of all the literature reviewed to date, the greywater use study by the Center for the Study of the Built Environment (2003) reflects one of the most recent, comprehensive reviews on greywater use for irrigation outside South Africa. The investigation was based in the Kingdom of Jordan, a water-stressed, mostly arid, country. The investigation included:

- ☐ A review of greywater reuse (including irrigation of plants) in countries outside Jordan;
- ☐ a study into existing greywater reuse cases and projects (most involve irrigation of garden plants) in Jordan, and
- ☐ an assessment of viability of greywater reuse in Jordan.

United States of America

Ludwig (Ludwig, 2004a, b) is the most quoted reference as the source of published practical greywater expertise, and has had a significant influence on the formulation and adoption of the most recently enacted greywater irrigation legislation of states in the south-western U.S.A. and some other countries. Ludwig has conducted the earliest and most comprehensive practical studies on greywater irrigation that have yet been recorded, concentrating his efforts mostly on the South-western states of the U.S.A.

In the U.S.A. numerous studies and assessments have been carried out, mostly through Universities (New Mexico State University, 1994), organisations such as Water Conservation Alliance of Southern Arizona (Water Conservation Alliance of Southern Arizona, 2001; Ludwig, 2004a), and individuals such as Ludwig (Center for the Study of the Built Environment, 2003).

An Arizona study has shown that use of greywater for irrigation of trees in Arizona is common, even before regulations and guidelines were available (Water Conservation Alliance of Southern Arizona, 2001; Center for the Study of the Built Environment, 2003).

2.1.3 Discussion

Greywater use for household agriculture is becoming more widespread in countries having arid and semi-arid climates, and in countries that are becoming water-stressed, partly as result of increasing water demand (Center for the Study of the Built Environment, 2003; Ludwig, 2004a; Water Services Association of Australia, 1994). Such greywater reuse is occurring in these countries in spite of whether it is legal or not (Ludwig, 2004a; Water Services Association of Australia, 1994; Blumenthal et al, 2000). Although several countries have carried out assessments on greywater use in household agriculture, including assessments on the health and environmental implications of such use, little statistical information on actual greywater use at the household level is available in the literature (Center for the Study of the Built Environment, 2003; Ludwig, 2004a; Water Services Association of Australia, 1994).

The effectiveness of strict water conservation measures, incorporated as part of municipal water demand management, is limited for households that already use strict conservation measures, where any further reduction in consumption of municipal water supplies would impact on occupants' health and quality of life (Center for the Study of the Built Environment, 2003). Households then have to turn to alternative ways of benefiting from reduced municipal water supplies, a major one being to reuse water that has already been used in the house for "higher-level" purposes (Alcock, 2002). Greywater use for irrigation is one example, flushing toilets with greywater is another and cleaning floors is another (Center for the Study of the Built Environment, 2003; Alcock, 2002). Thus it can be expected that the more water-stressed a municipal area becomes, the more greywater will be used by households for crop irrigation once conservation measures have been put into practice (Ludwig, 2004a; Center for the Study of the Built Environment, 2003).

It is generally believed that greywater use for agricultural purposes will benefit a nation's water-balance (Ludwig, 2004a; Center for the Study of the Built Environment, 2003), but at least one literature source indicates that it won't necessarily make an improvement on a nation's net water balance (Pettigrove *et. al*, 1984). Taking into account both water availability and suitability for end use (quality aspects) (Blumenthal *et. al*, 2000) the aforementioned may need further investigation.

Studies have shown that usable domestic greywater could satisfy up to 35% of the total domestic demand in Jordan (Center for the Study of the Built Environment, 2003).

2.2 Greywater quality

2.2.1 Introduction

There is an absence of local data on the chemical and microbiological composition of household greywater in general, and for low income households in particular (Alcock, 2002). Substitute data from semi-arid, water-stressed countries overseas should be useful as an interim measure. For greywater in upper and middle income residential areas, information on greywater quality obtained from studies done in semi-arid countries overseas can be assumed to have similar characteristics to that of greywater quality produced by upper and middle income residential areas locally. For greywater produced by low income households, the data obtained from overseas studies could be modified to take into account low volumes of available supply water resulting in lower volumes of greywater containing proportionally higher concentrations of microbes, dissolved salts and suspended particles, and these results could then be compared with local sample analyses.

2.2.2 Microbial content

Faecal coliforms typically inhabit the intestines of warm blooded animals (including humans) and one gram of faeces can contain billions of these organisms. Sewage wastewater with a high faecal coliform count indicates that a person will have a high risk of getting an infection through wastewater contact. It is not sure to what extent this risk would apply to greywater, especially if greywater production and contact is kept to within members of a single household.

Many studies on the microbial (pathogenic) character of greywater have been done overseas in the past 20 years. Results of approximately 12 studies are presented in Jeppeson and Solley (1994); Casanova *et. al*, (2001) and Eriksson *et. al* (2002). In Tables 2.1a and 2.1b the summarised results of about nine of these studies are listed.

Table 2.1a: Faecal coliform (cfu/100 mL) content of greywater from various sources

Sources	Brandes 1978	Rose *et. al* 1991	Karpiscak *et. al* 1992	Casanova *et al* 2001
Bathing / Shower	From < 10 to 200 000 000	6000	6000	
Laundry wash water		126		
Laundry rinse water		25		
Kitchen	From <10 to 400 000 000		2 000 000 000	
Combined greywater	880 000 13 000 000	From 6 to 80 1 500 180 000 to 8 000 000	173 000	563 000
Raw sewage				From 100 000 To 10 000 000
Secondary treated Sewage effluent				190 000

Sources: Jeppeson and Solley, 1994 and Casanova *et al*, 2001

Table 2.1b: Bacteriological quality of greywater, according to source

<table>
<tr><th>Indicators (cfu/100mL)</th><th>Total coliforms</th><th colspan="2">Faecal coliforms</th><th>Faecal streptococci</th></tr>
<tr><td>Laundry</td><td>From 56 to 890 000</td><td colspan="2">From 9 to 16 000</td><td>From 23 to 1 300 000</td></tr>
<tr><td>Bathroom</td><td>From 70 to 28 000 000</td><td colspan="2">From 1 to 8 000 000</td><td>From 1 to 5 400 000</td></tr>
<tr><td>Kitchen</td><td></td><td colspan="2"></td><td>From 5 150 to 550 000 000</td></tr>
<tr><td>Raw sewage</td><td>10 00 000 to10 000 000 000</td><td colspan="2">From 10 000 to 10 000 000</td><td>From 10 000 to 1000 000</td></tr>
<tr><td>Secondary sewage effluent</td><td>1500000</td><td colspan="2">190 000</td><td>21800</td></tr>
<tr><td></td><td colspan="2">Thermotolerant <i>Escherichia coli</i></td><td colspan="2"><i>Escherichia coli</i></td></tr>
<tr><td>Laundry</td><td colspan="2">84 000 000</td><td colspan="2">8 300 000</td></tr>
<tr><td>Bathroom</td><td colspan="2"></td><td colspan="2">32 000 000</td></tr>
<tr><td>Kitchen</td><td colspan="2"></td><td colspan="2">130 000 and 250 000 000</td></tr>
</table>

Sources: Ledin *et. al* 2002 and Casanova *et. al*, 2001

From the tabulated data in **Table 2.1a**, some comparisons between sewage wastewater and greywater can be made. Greywater from the kitchen has faecal coliform concentrations in the range from that of raw sewage to secondary treated sewage wastewater, whereas greywater from other sources has, on average, lower faecal coliform concentrations, closer to that of secondary treated sewage wastewater. Greywater from the kitchen has *Escherichia coli,* Faecal streptococci and Thermotolerant *Escherichia coli* concentrations that are significantly higher than for the other sources of greywater in the home, approximating those for raw sewage. From this data it is evident that greywater from the kitchen requires stricter control measures than from the other sources, when considering options for greywater use in irrigation where human contact is possible.

Southern Arizona Study

A residential greywater irrigation study was conducted by the Water Conservation Alliance of Southern Arizona (Water CASA). This study concentrated on the presence and concentration of pathogenic indicator species in greywater and in greywater irrigated soils and the results were used to help develop the greywater guidelines for Arizona (Water Conservation Alliance of Southern Arizona, 2004a, b).

Eleven Arizona households that use greywater for irrigation were selected out of a large distributed group of homes that use greywater for irrigation. Greywater and soils were sampled from the study sites and were analysed. The soil samples were from sites that were greywater-irrigated and potable-water irrigated. Samples were analyzed for faecal coliforms, faecal streptococci and *Escherichia coli*. Faecal coliforms are indicator organisms commonly used in water quality monitoring (APHA, 1999, Department of Water Affairs and Forestry, 1996). *Escherichia coli* were selected because it is considered to be a better measure of human faecal contamination (Gleeson and Gray, 1997). Faecal streptococci are considered to be indicators for enteric viruses (amongst other longer-lived pathogens). Participating homes were chosen for the presence and absence of children and animals, and for different methods of greywater storage prior to irrigation. The number of faecal coliforms/ *Escherichia coli* and streptococci in a given volume of greywater is used to indicate the level of risk to human health of irrigating with greywater where certain types of human contact occur with greywater, contaminated crops and/or irrigated soils (e.g. a toddler ingesting soil at an irrigated site). The following is a summary of results of the study (Water Conservation Alliance of Southern Arizona, 2004b):

- Faecal coliform levels were significantly higher in households including the kitchen sink in their greywater used for irrigation than in houses excluding the kitchen sink, indicating that the kitchen is a major contamination source.
- Faecal coliform levels were also significantly higher in greywater from households with children, those with animals, and those using greywater storage tanks.
- *Escherichia coli* levels were significantly higher in greywater from homes that included water from the kitchen sink in the greywater used for irrigation, than in greywater from homes that excluded greywater from the kitchen sink.
- For soils irrigated with greywater, faecal coliform levels were significantly higher in greywater irrigated soil for households including the kitchen sink in their greywater, and only slightly higher for households having small children or with animals.

A health risk assessment was then conducted using data from the analyses, and the results used to support a recommendation that kitchen sink water be excluded from greywater used for irrigation purposes in cases where human contact is considered possible. The study concluded that in terms of health risk, greywater from baths and showers presented the lowest risk, followed by laundry greywater. (Water Conservation Alliance of Southern Arizona, 2004b)

The above study tends to support other studies that show the concentration of certain indicator organisms (for example: total coliforms and faecal coliforms) could increase significantly in greywater, if greywater is stored for more than 24 hours (Al-Jayyousi, 2003). The re-suspension of previously deposited organic sludge at the bottom of a storage tank is likely to have a marked effect on the growth of certain strains of bacteria in sewage wastewater that has just entered the tank (Metcalf and Eddy, 1991). This should also be true of greywater that enters a grease trap or storage tank. Further, bacteria released from slimes that coat the inside of an “S” bend in a greywater outlet pipe are also likely to contribute to bacterial growth in greywater.

2.2.3 Chemical characteristics

There is little data available from before 2002 on the chemical characteristics of greywater in South Africa (Alcock, 2002). The chemical quality of greywater is dependent partly on the chemical quality of source water. In addition to the chemicals already in the source water, detergents contribute chemicals such as sodium and boron, and washing contributes organic particles, fats, hair and lint (Alcock, 2002; Center for the Study of the Built Environment, 2003).

One potentially important study on the impact of greywater irrigation on crops was conducted at Infruitec-Nietvoorbij, Stellenbosch (Beukes, 2001). The greywater used for irrigation was a mixture of kitchen, laundry and bathroom greywater, taken from a household in Stellenbosch. Of all the chemical parameters measured, the sodium adsorption ratio (SAR) and sodium concentrations in the grey water showed the greatest increases over that of the source water, at levels indicating that sodium accumulation could occur in fine textured soils (Beukes, 2001). Chemical analyses of samples of the greywater used for the study (See Table 2.2a) show that sodium is the major constituent of concern, in terms of the increase in concentration of the chemical constituent in greywater above that of the same constituent in the source water. In spite of the increased concentrations of sodium in the greywater, the report states that production of beans and tomatoes in the pots irrigated with greywater were higher than those irrigated with municipal water, and that there was no observable reduction in the infiltration rates of the soils irrigated with greywater (Beukes, 2001).

Table 2.2a: The chemical characteristics of municipal water and grey water samples taken in the Infruitec-Nietvoorbij study

Parameter	Municipal water Mean ± SD	Grey water Mean ± SD	Acceptable norms
pH	8,0 ± 1	6,8 ± 0,4	4,5 - 9
Electrical conductivity (mS/m)	11 ± 1,4	60 ± 22	≤ 100
Na (mg/l)	7 ± 2	75 ± 26	< 70
K (mg/l)	0,7 ± 0,3	10,4 ± 2,9	0 – 2
P (mg/l)	0	5,2 ± 1	< 10
Ca (mg/l)	8,2 ± 0,8	9,9 ± 2,6	-
Mg (mg/l)	1,3 ± 0,4	4,2 ± 4,8	0 – 300
Fe (mg/l)	0,04 ± 0,03	0,50 ± 0,21	0 – 5
Cl (mg/l)	40 ± 9	75 ± 27	150
SO_4 (mg/l)	2 ± 1	230 ± 35,4	200
B (mg/l)	0,01 ± 0,01	0,03 ± 0,02	0,5
Sodium adsorption ratio (SAR)	0,6 ± 0,1	5,3 ± 1,9	< 5

Source: Ms O. Beukes, ARC Infruitec-Nietvoorbij, Private Bag X5026, Stellenbosch, 7599.

The data show that greywater has higher concentrations of salts and other contaminants than does the source water. It should be noted that the user has a major influence over greywater quality: For example, the more conservative the use of water for washing, the higher the concentrations of salts and other contaminants will be in the resultant greywater.

Greywater crop irrigation studies are being conducted at a poor community in eThekwini (Durban). Research, as part of a Master's thesis, has recently been conducted on the content of sodium in a certain brand name of South African soaps and detergents at the University of KwaZulu-Natal (Rodda, 2004). At the time of completing this report, the results of the study had just become available. These are not reported on here.

Various studies on the chemical characteristics of greywater have been published in overseas literature. **Table 2.2b** presents some chemical characteristics of greywater from different studies. **Table 2.2c** presents some further chemical characteristics of greywater, split in accordance to greywater source, from other studies.

Table 2.2b: Some chemical characteristics of combined greywater, from different studies

Reference	BOD5 (mg/l)	SS (mg/l)	pH	EC mS/m
Jeppesen & Solly 1994 Combined greywater	90-120	45-330	6.6-8.7	32.5-114
Christova – Boal *et. al* 1995 Bathroom greywater	45-330	43-380	6.4-8.1	8.2- 25.0
Christova – Boal *et. al* 1995 Laundry greywater	10-520	26-400	6.3-9.5	8.3- 88.0
Casanova *et. al* 2001) Combined greywater	65	35	7.47	4.3

Sources: Center for the Study of the Built Environment, 2003; Casanova *et. al* 2001

Table 2.2c: Some chemical characteristics of greywater, according to greywater source

	Laundry	**Bathroom**	**Kitchen sink**
pH	9.3 – 10	5 – 8.1	6.3 – 7.4
BOD7 mg/l	150	170	387-1000
Total Nitrogen mg/l	6-21	0.6-7.3	13-60
Total Phosphorus mg/l	0.062-57	0.11-2.2	3.1-10
Chloride mg/l	9.0 – 88	3.1 – 18	
Sodium mg/l	44 – 480	7.4 – 21	29 – 180
Potassium mg/l	1.1 – 17	1.5 – 6.6	19 – 59
Calcium mg/l	3.9 – 14	3.5 – 21	13 – 30
Magnesium mg/l	1.1 – 3.1	1.4 – 6.6	3.3 – 7.3

Sources: Ledin *et. al* 2002 and Casanova *et. al*, 2001

Of the chemical constituents in greywater, in terms of potential impact on plants and soils, sodium is considered to present the major problem, followed by boron (Alcock, 2002; Beukes, 2001; Center for the Study of the Built Environment, 2003). Although vegetated soils can remove nutrients and pathogens from greywater, very little can be done about removing highly-soluble salts such as sodium and chlorides in greywater, and it is the latter aspect that presents difficult-to-resolve problems for soils, crops and water resources, especially over the longer term (Thompson, 1985). The most feasible measures to take regarding dissolved salts is to prevent them entering greywater in the first place, where practical (Ludwig, 2004a; Alcock, 2002), and to reduce the consequent build-up of salt concentrations in soils through accepted mitigation measures (Department of Water Affairs and Forestry, 1996).

Greywater has the following concerns regarding quality issues, in terms of greywater source (Center for the Study of the Built Environment, 2003):

- Bath/ shower: Hair can cause orifice, pipe and pump blockage with a consequent increase in pathogens and insect vectors;
- Clothes washing: Sodium, boron, lint, increased pH, (high temperature), chemicals in bleaches and fabric softeners;
- Sodium - Large contributions from soaps, detergents and water softeners (Water softeners add significant amounts of sodium to water, with a consequent increase in sodium concentrations in greywater);
- Lint (from clothes) and hair can cause orifice, pump and soil pore blockage, with a consequent increase in pathogens and insect vectors;
- Dishwashing: Washwater contains organic matter (including fats), bacteria and suspended solids (organic materials and fats can cause odours, orifice and soil pore blockage, increase in pathogens and insect vectors).

Greywater quality depends very much on the quantity of water used for washing and food preparation (i.e. the dilution factor), and on whether greywater is reused in the home prior to disposal (Alcock, 2002). Water conservation measures and greywater reuse in the home can therefore be expected to increase the concentrations of dissolved chemicals in greywater significantly, thus impacting on its potential suitability for irrigating plants unless measures are taken to reduce the quantity and types of chemicals used for washing and cleaning.

2.3 Greywater production

2.3.1 Introduction

Greywater volume production from residences is generally not measured, and therefore needs to be estimated from alternative data sources. Monthly greywater production volumes on a municipal scale could be obtained from municipal water supply and sewage production data. No information in the literature was found to support the feasibility or usefulness of using this approach, however. Alternatively, greywater volume production for private households may be estimated given the water consumption of a household, given some knowledge of how much of this water is used outside the house (e.g. for the garden and swimming pool), whether the house has water-borne sanitation, whether water conservation measures are being practiced in the home, the cost of water, amongst other factors. A significant amount of practical information using the latter approach was sourced in the literature. Alcock (Alcock, 1999; Alcock, 2002) presents much useful information on household water consumption and greywater production in South Africa, especially in relation to poor communities. Other information sources containing useful information on household greywater production in other countries include: Jeppesen and Solley (1994), Kourik (2002), Ludwig (2004a), Californian Department of Water Resources (1995), Western Australia Department of Health (2002) and the New South Wales Department of Health (2000).

2.3.2 Volume production estimation

Alcock (Alcock, 2002) lists factors influencing water consumption in a Western-style household which include:

- ☐ family size and age/sex composition,
- ☐ culture,
- ☐ household income,
- ☐ the cost of water,
- ☐ diet,
- ☐ technological level (including the number of taps on the property),
- ☐ the availability of alternative supplies (such as boreholes),

- ☐ educational standing,
- ☐ social and any home business activities,
- ☐ water losses through leaks, and
- ☐ the size of the land holding, the type of garden and plants.

Alcock states further that seasonal and climatic parameters influence demand for municipal water supplies. Variable weather conditions are generally responsible for short-term fluctuations in demand (Alcock, 1999a, b).

Table 2.3: Approximate volumes of greywater generated in an average Western-style home in Australia (Average of 2.6 occupants).

(Source: Dept of Health, Western Australia - Greywater Reuse Draft Guidelines – July 2002)

Greywater Source	% total	Litres per day
Hand basin	7	28
Bath/shower	48	193
Kitchen	11	44
Laundry	34	135
Total	100	400

From **Table 2.3** above, the average greywater produced per person within a Western-style home (averaging 2.6 occupants) is 154 L per person per day. Australia and South Africa are examples of semi-arid, water stressed countries, so the above data (**Table 2.3**) could be relevant for a Western-style house with a small family, in South Africa.

For poor communities in South Africa, relevant data can be obtained from sources such as the United Nations Environment Program (UNEP) and Alcock's studies (Alcock, 2002;1999a,b).
It is estimated that the average person in developing countries uses 60-150 litres per day (UNEP 2002), and if about 90 % of this ends up as greywater, then between 55 and 135 litres of greywater per day would be produced per person.

Alcock has conducted studies of water consumption and greywater production/ reuse amongst poor communities in South Africa (Alcock, 1999a, b; Alcock, 2002). Alcock (1999a,b) estimated that the average water consumption for households with more than one tap inside the house, and connected to a waterborne sewage system, is likely to be between 180 to 300 litres per person per day; for households with a standpipe outside the house or a tap in the home (not connected to a waterborne sewage system) is likely to be between 30 and 80 litres per day; where water has to be brought in from a source at least 250 metres away from the home, a consumption of 9 - 50 litres per person per day is likely. Greywater production volumes may then be estimated from these figures.

For dwellings in peri-urban areas supplied by public standpipes, Alcock (1999a, b) noted the following:

- ☐ There was a high degree of water reuse, with water being used for successively lower grade requirements.
- ☐ The final greywater was often thrown on the vegetable patch, fruit trees, or the lawn.

There is likely to be little variation in demand for household water over the seasons for poor communities except where rainwater runoff is used to augment the household water supply, or unless source water is used for irrigating plants. The availability of rainwater in sufficient quantities at the home will result in a higher consumption, and therefore more greywater will be produced. (Alcock, 1999a, b)

According to Alcock (2002), greywater reuse, both within the home as well as for growing plants, is evident amongst rural communities, the extent of reuse depending on the cost and/or effort required to obtain source water.

Alcock (2002) reported on a study by Van Schalkwyk (1996) that assessed water use and consumption in poor settlements, villages and towns in the previously-named Northern Transvaal. The study estimated an average greywater production of up to 150 litres per day per household, assuming that 50% of the water brought in to the house is discharged as greywater (Alcock, 2002). What happened to the other 50 % of water brought into a house is not made clear, assuming that the houses did not have water-borne sanitation.

2.4 Regulatory aspects

2.4.1 South Africa

Preliminary investigation shows there is no fundamental objection in principle to the use of household greywater for yard irrigation (Alcock, 2002). Normal precautions with regard to nuisances are required - in terms of common law, the Health Act No. 63 of 1977, and the National Water Act No. 36 of 1998. Nuisances are here defined inter alia as fly/mosquito breeding, objectionable odours, the surface ponding of water, and the entry of polluted water onto a neighbouring property.

Though specific reference is not made to greywater disposal or agricultural use in the South African National Water Act (NWA), it is covered by some sections of the act. Most notable among these are references to the "disposal of waste or water containing waste". The act recognises the discharge of water containing waste to a water resource, as a water use. As such, any person who discharges water containing waste needs to obtain an authorization before doing so. However, more applicable to greywater use is the fact that the act lists the use of water containing waste for irrigation purposes as a "controlled activity".

On March 26th 2004, a revision of the applicability of general authorizations to certain controlled activities was made (Department of Water Affairs and Forestry, 2004). The authorisation permitted in terms of the revision does not require a wastewater irrigator, who is owner or legal occupier of the irrigated land, or who has legal access to the land, to apply for a licence in terms of the National Water Act provided that irrigation complies with the limits and conditions set out in the revised authorisation. Applicable wastewater types allowed under the revised authorization include domestic wastewater.

For greywater irrigation, the applicable authorization is covered under the requirement (Section 2.7(iii)) that the irrigator is allowed to irrigate up to 50 cubic metres of wastewater on any given day, provided (Department of Water Affairs and Forestry, 2004):

- electrical conductivity does not exceed 200 milliSiemens per metre (mS/m);
- pH is not less than 6 or more than 9 pH units;
- Chemical Oxygen Demand does not exceed 5 000 mg/l after removal of algae;
- faecal coliforms do not exceed 100 000 per 100 ml; and
- Sodium Adsorption Ratio (SAR) does not exceed 5.

and if the irrigation of wastewater (Department of Water Affairs and Forestry, 2004):

- does not impact on a water resource or any other person’s water use, property or land; and
- is not detrimental to the health and safety of the public in the vicinity of the activity.

And the irrigated site is located (Department of Water Affairs and Forestry, 2004):

- above the 100 year flood line, or alternatively, more than 100 metres from the edge of a water resource or a borehole which is utilised for drinking water or stock watering, which ever is further; and
- on land that is not, or does not, overlie a Major Aquifer (identification of a Major Aquifer will be provided by the Department, upon written request).

Greywater irrigation is unlikely to benefit from the above requirement, seeing that greywater quality is unlikely to comply with at least one of the restrictions, specifically the one limiting the faecal coliform concentration restriction, even assuming that only bathroom greywater is considered for irrigation.

A strong case can be made for a further relaxation on greywater use for irrigation. Aspects include:

- ☐ The fact that greywater production represents relatively small volumes of water (at the individual family unit scale).
- ☐ The fact that greywater irrigation is carried out on land owned by the greywater producer.
- ☐ The fact that greywater irrigation is likely to have a beneficial social impact in times of water scarcity.

Particulars of potentially-suitable relaxation requirements would need to be researched, or else greywater could be specifically excluded from the above requirements, and instead included under other legislation.

2.4.2 Other countries

Greywater use for agriculture is being practiced and encouraged in an increasing number of countries. These are typically countries that experience some degree of water stress. Examples of countries where progressive greywater irrigation legislation has been adopted include Jordan and the United States of America (U.S.A.). (Center for the Study of the Built Environment 2003)

Due to problems experienced with permitting the use of greywater for irrigation, several states in the more arid parts of the U.S.A. and other countries have developed legislation to allow greywater use for irrigation in different circumstances (Bennet, 1995). California, Arizona and New Mexico have been the first and most active in undertaking research and implementing regulations and guidelines for greywater irrigation (Kourik, 2002; Little, 2001a). California has had the most restrictive guidelines, but these have been relaxed over the last ten years as more research results have become available (Ludwig, 2004a). Arizona is considered to have the most practical and progressive regulations (Little, 2001a; Ludwig, 2004a), and similar ones to these have recently been adopted by New Mexico (New Mexico State University, 1994; Ludwig, 2004a). Twenty-two western states in the U.S.A. have regulations that govern the use of greywater for irrigation (Kourik, 2002). Other countries that have carried out research and that have regulations and guidelines that help govern the use of greywater for irrigation include Australia, Cyprus and The Kingdom of Jordan. Most guidelines are for greywater use for irrigating ornamental plants, shade and fruit trees, with little on grass and vegetables (Ludwig, 2004a; Little, 2001b). In countries with a federal system of government, like Australia and the

U.S.A., the individual states are responsible for the development of regulations and guidelines that govern greywater use. Experience in researching and regulating greywater irrigation for private garden purposes in Arizona and California has provided some insight into the way in which regulations affect public attitude to irrigating home gardens with greywater. For example, it has been noted that the California greywater irrigation legislation is complex and expensive to comply with, and has not lead to popular use of greywater for irrigation (Ludwig, 2004a).
The legislation introduced in Arizona follows a different philosophy, and has led to a more successful use of greywater for garden irrigation by the public in that state (Center for the Study of the Built Environment, 2003; Ludwig, 2004a).

2.5 Summary and conclusion

The quality of greywater varies depending on the volume of supply water consumed per person in a household, on the quality of the water supply, the source of the greywater, and on chemicals used in the washing/bathing process. The volume of supply water consumed by a household depends on the scarcity/ costs of supply water and on the water conservation measures being taken within the household. The more saline the source water is and the more chemicals added in the washing process, the less suitable greywater is for irrigating crops. The health risk associated with greywater is related to the microbial quality of greywater at the point of irrigation, on how irrigation is carried out, and the type of crops being irrigated. The microbial quality of kitchen greywater is generally poorest of the greywater sources (at the point of irrigation). In terms of chemical quality, the least suitable greywater for irrigating sensitive crops and soils is laundry greywater.

Given relevant population statistics, the average daily greywater production for a population can be estimated from the average daily water used per household, or per person per residential category. The average greywater volume produced per person per day in a dwelling connected to a municipal water supply and serviced by a waterborne sewerage system is estimated to lie in a range of 90 to 150 litres per day. Where water has to be carried in to the dwelling, the range is much lower, at 4 to 70 litres per person per day.

Greywater use for irrigation is identified as a “controlled activity” in the “general authorizations” regulations promulgated under the South African National Water Act. A licence is not required for this activity if certain conditions are adhered to. However, greywater is unlikely to comply with these conditions unless it is treated prior to irrigation. The Arizona and California greywater regulations are examples that could be used to guide greywater regulation development in South Africa. These regulations are briefly discussed in **Table 2.4** (After Ludwig, 2004b).

Table 2.4: Comparison of Arizona and California greywater reuse legislation (After Ludwig, 2004b)

Components of Greywater Reuse Legislation in Arizona and California (Ludwig, 2004b)	
Arizona	**California**
The Arizona regulations follow a three-tiered approach whereby systems using under 1500 L per day must meet a list of reasonable conditions, and are covered by a general permit without the need for the householder to apply for a permit. Systems producing over 1500 L per day require a permit, while those over 13,000 L per day are dealt with on a case by case basis. In the legislation, greywater is defined as wastewater collected separately from clothes washers, bathtubs, showers, and sinks. Use of wastewater from a kitchen sink, dishwasher, or toilet for irrigation is specifically prohibited. The greywater system should be operated to maintain a minimum vertical separation distance of at least 1.5 metres from the point of greywater application to the top of the seasonally high groundwater table. The tiered approach makes reuse easy for the ordinary householder and allows for innovation and flexibility of design. The regulations do not prescribe particular design specifics and follow a performance-based approach, while the blanket prohibitions ensure the protection of human and plant health.	The "Graywater Systems for Single Family Residences Act" (California Department of Water Resources, 1992) allows for the use of greywater for subsurface landscape irrigation in single-family dwellings. The revised "California Graywater Standards" (California Department of Water Resources, 1997) allows for the use of such systems in commercial, industrials, and multifamily projects, as well as single-family residences. The Californian regulations apply to water from bath tubs, showers, bathroom wash basins, and water from washing machines and laundry tubs. A permit must first be obtained from the Administrative Authority before the construction of a greywater irrigation system may commence. Final approval of the irrigation system is subject to inspection and testing of the constructed irrigation system. The following exclusions are stipulated by the act: " Greywater shall not include laundry water from soiled diapers. " Greywater shall not be applied above the land surface or allowed to surface or to discharge directly into a storm sewer system or to any surface water body. " Greywater shall not be used for the irrigation of vegetable gardens.

CHAPTER 3

3 Production and potential demand for greywater in South Africa

3.1 Introduction

In the arid and water-stressed countries of the world, water conservation and treated sewage wastewater use for crop irrigation receive a lot of attention. Many large scale wastewater irrigation schemes have been initiated in the drier parts of the U.S.A., in Israel, the Arab nations, Australia, and also in South Africa (Asano, 1998). At a smaller (household) scale, greywater is potentially suitable for recycling in and around the home, thus allowing individuals other ways of saving water supply costs besides just using conservation measures. Individuals need, however, to understand how to safely and effectively use greywater for irrigation. Amongst the aspects a householder needs to know in order to successfully use greywater for irrigation purposes are:

- ☐ what greywater source is safe to use?
- ☐ how much greywater is available to be used?
- ☐ what areas of land can it be used to irrigate?
- ☐ what crops/plants can be safely irrigated?
- ☐ what treatment / management measures should be applied?
- ☐ what laws and regulations are applicable?

This chapter discusses greywater volume estimation, greywater volumes potentially available in South Africa, estimation of land area required for irrigating crops with greywater and factors affecting the potential demand for greywater.

3.2 Estimation of greywater volumes produced in South Africa

3.2.1 Information from municipalities

In order to help determine what information is available to estimate greywater production for different residential areas, the decision was made to conduct a survey in order to determine the existence of, and where possible to obtain, information on water consumption, sewage return flow and greywater production. A survey questionnaire on water consumption and greywater production was sent to potential respondents in relevant municipal and government departments, and it was also used as a basis for follow-up telephone interviews. The responses to the questionnaire sent to a variety of municipalities show that municipalities do not generally keep a statistical record or a data summary of the amount of water supplied to formal / informal residential areas, or of the amount of sewage that reaches wastewater treatment plants. Hence the amount of greywater produced cannot be estimated from water supply records or wastewater treatment plants (/sewage pump stations) records. It is evident from preliminary work that most municipalities are not yet looking at potential greywater use for home garden irrigation as a water demand management tool. Greywater production and greywater potential for irrigation use will thus have to be evaluated, in the short term, on factors other than recorded water supply/ sewage flow figures.

Knowledge of the amount of water supplied to a specific household/ residential area, as well as the population or housing density for that area might yield an approximate amount of greywater produced per household or per person. However, this assumes that municipal water supply data or sewage volume production data is available in a form suitable for research purposes, to enable estimates of greywater production.

A few municipalities were selected for the survey based on their different environments or needs with respect to water supply, water demand, water source and shortages. The selected municipalities include:

- ❑ A Karoo town - possibly a groundwater dependant community;
- ❑ Polokwane - where water shortages are already a big problem and many restrictions are placed on the population;
- ❑ Kimberley - Selected as a semi-arid area dependent on low quality river water;
- ❑ Stellenbosch municipality – Kayamandi - This represents an informal settlement where dense housing and high population exists, for this area; greywater may be a hazard as disposal may be inadequate;
- ❑ eThekwini Municipality - This municipality was selected because lots of work has been done with respect to greywater use in the Durban area;
- ❑ The city of Cape Town - selected on the basis that water shortages are currently becoming a serious issue for this city and the city is seriously considering greywater use for home garden irrigation as a water demand management tool at household level.

The limited feedback received was helpful in determining water supply statistics linked to residential areas and residential water-use types for one municipality, and in giving a picture of what some municipalities are doing with respect to greywater. However, too little feedback has been received to draw any concrete conclusions.

It is evident from personal communication with some municipal officials that an education drive may prove very useful in terms of informing communities of the benefits and possible dangers of greywater use for home garden irrigation. Most municipalities have not considered greywater as an alternate water source for irrigation, and have not made any measurements or estimates of greywater production.

3.2.2 Estimation of greywater production based on residential categories

Water consumption and hence the volume of greywater generated by households depends on a variety of factors, including family size and age, gender composition, culture, household income, the availability / cost of water and the number of taps on the property, amongst others (Alcock, 2002). It is at present not known how much greywater is being generated by South African households. Water consumption figures are more readily available, and provide a good starting point for calculating the volumes of greywater that are generated in residential areas.

In terms of water consumption, residential areas can be split into categories (StatsSA, 2001; Alcock, 1999a, b; Alcock, 2002):

Table 3.1: Water consumption estimates versus water service supply category

Sources: StatsSA (2001); Alcock (1999a, b); Alcock, (2002).

Category	Water service supply type	% of all dwellings in South Africa	Approx. water consumption per dwelling (L/day)	Comments
1	Commercial and industrial areas			No greywater irrigation use feasible
2	Water supplied to dwelling	32 to 36	576 to 1200 (Mean: 888)	Assume all dwellings are directly connected to a water supply.
3	Water supplied to tap in yard	32	120 to 320 (Mean: 220)	
4	Water supplied to community standpipe less than 200 m away	14	150	
5	Water supplied to community standpipe more than 200 m away	12	36 to 200 (Mean: 118)	
6, 7,8	Alternative sources: rain tank, borehole, spring	Approx. 5		Applicable mostly to rural areas.

The City of Cape Town reports that 65% of its distributed water is consumed by households and that water used in baths and showers represents 31% of household water consumption (City of Cape Town, 2005). The latter corresponds well with Laak's data presented in **Table 3.2**. Water used in baths, showers, washing machines and for dishwashing purposes represents between 30 and 50% of total household consumption in the City of Cape Town (City of Cape Town, 2005). This agrees reasonably well with Laak's and Perkins' data (**Table 3.2**), where the average percentage is estimated at 53 % (Laak) and 42 % (Perkins) of the household total.

Table 3.2: Mean daily water consumption/ greywater production data according to household use type. (Alcock, 2002; Dept of Health Western Australia, July 2002)

Plumbing fixture	**Mean percentage volume used and percentage range** (Laak, 1974)	**Mean daily per-person consumption and range (L)** (Perkins, 1990)	**Greywater production: Mean daily per person volume produced (L)** (Dept of Health, Western Australia, 2002)*
Kitchen	9 (5 - 16)	11 (4 - 19)	17
Bathroom	26 (12 - 40)	34 (23 - 49)	85
Laundry	18 (4 - 22)	38 (26 - 45)	52
Toilet flushing	47 (41 - 65)	61 (34 -76)	
TOTAL of means	**100 (%)**	**144 (L)**	**154 (L)**

***** Data derived from **Table 2.3**

Determination of greywater production volumes at the municipal level could be attempted based on water services level (**Table 3.3**). In the City of Cape Town, the average water consumption per 'typical' 4 person household (two adults and two children) amounts to about 423 m^3/year, or approximately 292 L per person per day (City of Cape Town, 2005). This amount (292 L per person per day) is at the upper end of the range of Alcock's estimate of between 180 and 300 litres per person per day for a multiple tap household connected to a sewage system (Alcock, 1999a, b) and is in fair agreement with the data given by the Department of Health, Western Australia (2002), assuming greywater production represents about 60% of total household water consumption. In the foregoing discussion, it is not known what proportion of household water consumption is used for purposes outside the house. Comparing the household water consumption and greywater production data in **Table 3.2** with the water consumption data presented by the City of Cape Town (2005) and Alcock (1999a,b), it is likely either that the water used outside the home is excluded from the published data or else forms only a small part of the data. For the purposes of this study, it is assumed that all water consumption occurs within the home, or is used for food preparation and washing (kitchen), laundry and bathroom/ toilet purposes. It is therefore assumed that the average water consumption figure of 292 L per person per day (or 423 m^3/year) (City of Cape Town, 2005) is a realistic estimate for Cape Town's households that receive piped water inside the dwelling (**Table 3.3**) and that the volume of greywater produced can be estimated using data relevant for such dwellings from the abovementioned data sources.

Assuming that the average household water consumption for dwellings supplied with piped water is about 423 m^3/year (City of Cape Town estimate), total water consumption for such dwellings at national level amounts to 223 Mm^3/year **(Table 3.3)**. The percentage of household water consumption that becomes greywater is assumed to be between 30 % and 50 % for households connected to waterborne sanitation systems (**Table 3.2**) or that receive piped water inside the dwelling (Urban Category 2) (**Table 3.3**). Assuming that 40 % (range: 30 to 50%) of water consumption for these households ends up as greywater, greywater generation for all these dwellings in Cape Town amounts to 89.2 Mm^3/ year (range: 66.6 to 111 Mm^3/year).

At a national level, the average water consumption for "multiple-tap" dwellings in South Africa is estimated from Alcock's data in Table 3.1. The average household water consumption for dwellings supplied with piped water is 888 L/day or 324 m^3/year per dwelling (Source: **Table 3.1**). Total water consumption for all such dwellings in South Africa amounts to 1172 Mm^3/year **(Table 3.3)**. Assuming that 40 % of this water ends up as greywater, greywater generation for all these dwellings at a national level amounts to 468 Mm^3/ year

Regarding communities without waterborne sanitation, the percentage of water discharged to sewer is nil, therefore it can be assumed that most of the water consumed within a dwelling is discharged as greywater. For the current study, the quantity of water that is discharged as greywater for dwellings without waterborne sanitation is assumed to be 90 % of the water consumed. The following information on water consumption for dwellings without a direct connection to a piped water supply is derived from **Table 3.1**:

- ☐ For dwellings with piped water inside the yard, the average water consumption is assumed to be 220 L/day (or 80 m^3/year).
- ☐ For dwellings with the water source less than 200m from dwelling, the average water consumption is assumed to be 150 L/day (or 55 m3/year).
- ☐ For dwellings where the water source is more than 200m from dwelling, the average water consumption is assumed to be 118 L/day (or 43 m^3/year).

Table 3.3: Greywater household production estimates according to domestic water supply service categories. Data sources: StatsSA (2001); Alcock (1999a, b; 2002).

Census (2001) service categories	**City of Cape Town**			**National***		
	No. of dwellings	**Approx. water consumed Mm^3/year**	**Estimate of greywater volume produced. Mm^3/year**	**No. of dwellings**	**Approx. water consumed. Mm^3/year**	**Estimate of greywater volume produced. Mm^3/year**
Piped water inside dwelling. (Category 2). Ave. dwelling consumption = 423 m^3 /yr (Cape Town) = 324 m^3 /yr (National)	526 866	223*	89.2***	3 615 263	1172 **	469***
Piped water inside yard (Category 3). Ave. dwelling consumption = 80 m^3 / yr (National)	114 552	9.2	8.28****	3 253 877	261.3	235.3 ****
Piped water on community stand: distance < 200m from dwelling (Category 4). Ave. dwelling consumption = 54.7 m^3 /yr (National)	51 405	2.81	2.53****	1 392 635	76.25 ****	68.6 ****
Piped water on community stand: distance > 200m from dwelling (Category 5) Ave. dwelling consumption = 43 m^3 /yr (National)	57 315	2.47	2.22****	1 202 276	51.78	46.6****
TOTALS	750 138	237.5	102.3	9 464 051	1 561	819

* Based on average water consumption of 423 m3 /year by serviced households for Cape Town
** Based on estimate of average water consumption of 324 m3 /year by serviced households at National level.
*** Greywater production volume assumed equal to 40% of water consumption for dwellings with waterborne sanitation
**** Greywater production volume assumed equal to 90% of water consumption for dwellings with no waterborne sanitation

Note: Dwellings that obtain their domestic water supplies directly from rainwater tanks, boreholes and springs are excluded from this study because they make up less than 5% of the total number of dwellings, and because they are generally located outside of urban/ peri-urban areas.

It is assumed that the above dwelling categories do not have waterborne sanitation, so most of the water brought into households in the above categories will become greywater. If the above average household water consumption values for the relevant dwellings are applied to national services distribution statistics (See **Table 3.3**) (StatsSA, 2001), consumption by all such households in South Africa would amount to 389 Mm^3 /year, with greywater generation of about 350 Mm^3/year (approximately 90 % of water consumption for unsewered dwellings).

For all dwellings in South Africa that obtain their water from water supply services (service categories **2** to **5** in **Table 3.1**), the annual water consumption therefore amounts to 1561 Mm^3/ year, and the associated greywater generation may therefore be about 858 Mm^3/ year (468 Mm^3 + 389 Mm^3) (**Table 3.3**). The latter translates to about 2.5 percent of South Africa's total dam capacity (32 400 Mm^3) or to about 6.5 percent of South Africa's total annual water requirements (12 871 Mm^3) (Department of Water Affairs and Forestry, 2004). The assumption made in this study is that most communities in South Africa that are serviced by water supply services are located within urban/ peri-urban areas, as opposed to dwellings whose water supplies come from rainwater tanks, boreholes and springs. Given the large degree of error inherent in estimating greywater production volumes, the annual greywater generation estimate of 858 Mm^3 is therefore assumed to be applicable to all dwellings in urban and peri-urban areas in South Africa.

The National Water Resources Strategy (Department of Water Affairs and Forestry, 2004) reports that annual urban water demand in South Africa (year 2000 figures) amounts to 2 897 Mm^3. Assuming that annual domestic water demand is 65 % of this (City of Cape Town, 2005), at 1883 Mm^3, then the total annual urban domestic greywater generation, at between 40 % and 90 % of the domestic water demand, is estimated to be approximately 1 224 Mm^3.

Taking the average of the two greywater production figures of 858 and 1224 Mm^3 per annum results in a revised estimate of 1040 Mm^3 of greywater produced by dwellings in urban/ peri-urban areas in South Africa per annum.

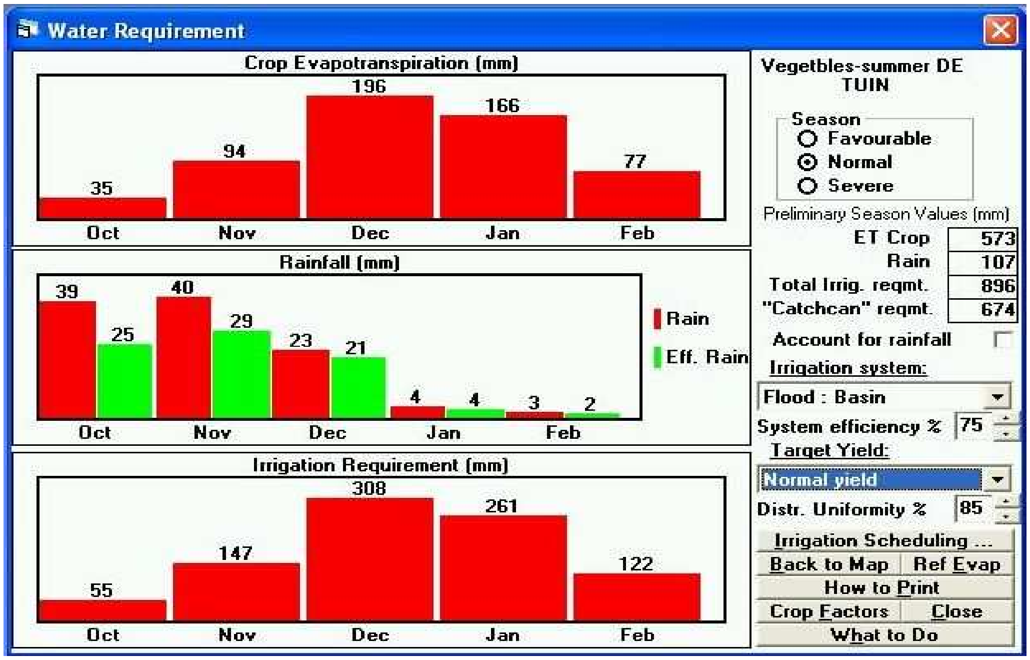
3.2.3 Area of land required for greywater irrigation

Based on data in **Table 3.4** it should be possible, assuming effective irrigation, to irrigate a patch of land of 20 m^2 in area with 496 litres of water per week in the inland winter rainfall area, assuming an evapotranspiration rate of 50 mm per week and a crop factor of 0.5. Greywater irrigation efficiency depends on the type of irrigation (e.g. drip versus basin), on the uniformity of distribution and on other factors such as the quantity of extra water needed for leaching purposes (the leaching fraction) in order to flush accumulated salts out of the topsoil. Crops require less water at the beginning and end of their growth season, and more during the most vigorous period of growth, so crop water requirements change during the crop growth season. For the above and other reasons, more sophisticated data tools than tables similar to the one shown in **Table 3.4** are needed.

Table 3.4: Calculated crop irrigation needs in winter rainfall climates (After Bennet, 1995)

Climate	Relative water need of crop	Litres per week		
ET (evapo-transpiration)	Crop Factor	Land Area = 20 m^2	Land Area = 10 m^2	Land Area = 5 m^2
Coastal ET = 25 mm/wk	low water using (0.3) medium water using (0.5) high water using (0.8)	152 248 400	76 124 200	40 64 100
Inland ET = 50 mm/wk	low water using (0.3) medium water using (0.5) high water using (0.8)	304 496 800	152 248 400	76 124 200
Arid ET = 75 mm/wk	low water using (0.3) medium water using (0.5) high water using (0.8)	456 744 1200	228 372 600	112 188 300

The irrigation software package SAPWAT (Crosby and Crosby, 1999) was used in the current study to determine its potential suitability as a tool to estimate initial irrigation requirements for subsistence crops. **Figure 3.1** shows SAPWAT's water requirements for vegetables grown during summer in the winter rainfall area near De Tuin, located in a semi-arid area about 90 km inland from the west coast near Porterville, where irrigation system efficiency (basin) is assumed to be 75% and distribution uniformity is assumed to be 85% (See **Figure 3.2**). Note that rainfall is not accounted for in this example.



Vegetbles-summer DE TUIN

Season
○ Favourable
● Normal
○ Severe

Preliminary Season Values (mm)
ET Crop 573
Rain 107
Total Irrig. reqmt. 896
"Catchcan" reqmt. 674

Account for rainfall ☐

Irrigation system: Flood : Basin

System efficiency % 75

Target Yield: Normal yield

Distr. Uniformity % 85

Figure 3.1: Screen showing SAPWAT's water requirements for summer vegetables in the Winter rainfall area, assuming no rainfall occurs in the period shown.

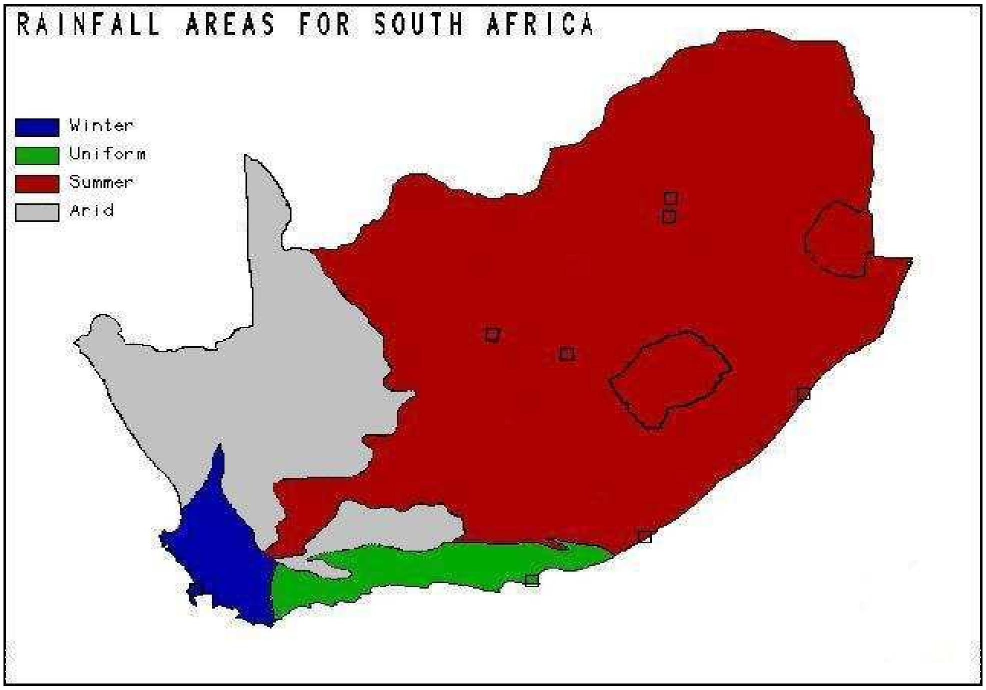


Figure 3.2: Seasonal rainfall areas for South Africa (Poynton, 1984)

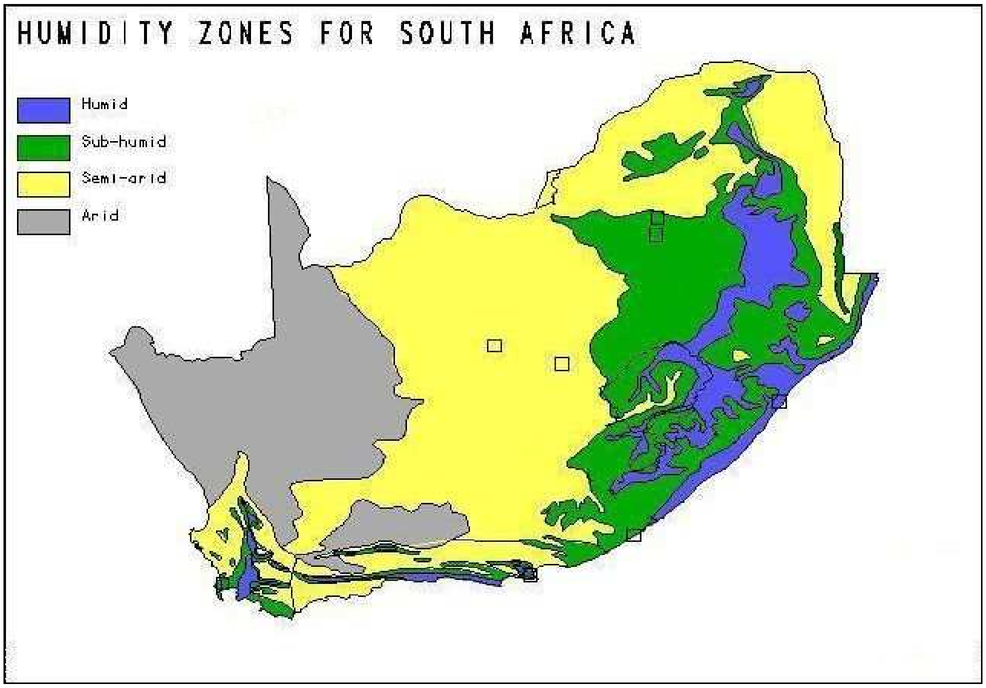


Figure 3.3: Humidity zones for South Africa (Poynton, 1984)

Results show that crop evapotranspiration rates over the season range between 35 mm and 196 mm per month (between 1.1 mm and 6.3 mm per day) assuming daily irrigation close to the individual plants (25% percent of soil area is wetted by irrigation) and 100 % crop cover of the wetted area at the full growth stage. The crop irrigation requirements range from 55 mm to

308 mm per month (between 1.8 mm and 10 mm per day). If rainfall is accounted for, then a reduction in peak crop water requirement of about 2 % occurs. The calculations were repeated for vegetables grown during summer in the summer rainfall area at Roodeplaat Dam, located North of Pretoria. Results show that peak monthly water requirements are similar for summer vegetables grown at “de Tuin”, when rainfall is not accounted for. However, accounting for an average summer rainfall at Roodeplaat Dam results in almost a 50% reduction in the peak monthly crop water requirement. This reduction in the peak crop water requirement is significantly more than the 2 % reduction shown for de Tuin in the winter rainfall area. Thus when accounting for rainfall, the peak summer irrigation requirement for summer vegetables grown at de Tuin in the winter rainfall area is nearly double (at about 10 mm per day) that for summer vegetables grown at Roodeplaat Dam (at about 5 mm per day), in the summer rainfall area. When accounting for rainfall, crop irrigation requirements for summer vegetables typically range from about 3 mm per day (humid areas) up to 10 mm per day (arid areas) given an irrigation efficiency of 75% and a distribution uniformity of 85% (estimates derived from using SAPWAT).

- ☐ Given that 100 litres of water is sufficient to irrigate 1 m^2 of land with 100mm of water, 100 litres of water per day would then be sufficient to irrigate 10 m^2 with 10 mm per day. This is roughly the same requirement as that calculated (using SAPWAT) for summer vegetables at de Tuin, at the peak monthly irrigation demand (December). For sub-humid summer rainfall areas, 100 litres of water per day should then be sufficient to irrigate 20 m^2 (5 mm per day), and for humid rainfall areas, 100 litres per day should be sufficient to irrigate 33 m^2 (3 mm per day).

Changing the irrigation frequency to 7 days (using SAPWAT) has the effect of significantly reducing monthly crop irrigation requirements at the beginning (October) and end (February) of the crop growth season, but it has a small affect on the irrigation requirements for the other months (November, December and January).

The irrigation rate of 10 mm per day is very high, but should be suitable for summertime crops in well-drained, highly permeable soils in semi-arid to arid areas experiencing negligible rain in summertime. This amount (10 mm per day) could be reduced by 50 % (to 5 mm per day), to accommodate crop irrigation requirements in sub-humid summer rainfall areas, or by 70 % (to 3 mm per day) to accommodate crop irrigation requirements in humid summer rainfall areas.

Monthly greywater production volumes remain essentially constant throughout the year, so the use of monthly crop irrigation requirements to calculate greywater volumes for irrigation has the following implications:

- crops will be over-irrigated for part of the season or some greywater will need to be diverted elsewhere (e.g. to sewer) for part of the season or else
- supplementary water will be needed for part of the season,

dependent on crop growth and seasonal climate characteristics. The area that can be irrigated with greywater was calculated in this study from the maximum monthly irrigation demand of the crop in question, dependent on climatic and other factors. This should allow the surplus greywater to be utilised to flush excess salts out of the soil for part of the season, thus helping to prevent a build-up of salts in irrigated soils.

SAPWAT is useful software, freely available in South Africa. It is able to provide detailed results, taking into account a variety of factors, relevant for this country. It is recommended that SAPWAT be used to determine land area requirements for greywater irrigation when planning site-specific irrigation cases. It should be noted that users of SAPWAT need to take into account factors specific to each case, and need to be knowledgeable about irrigation, crops and soils. Simplified assumptions have been made in this study, and care is needed when using the results of this study for areas that have clay soils, areas with high water tables, soils with poor drainage, crops that are not vegetables (grown in summer), and other factors.

For this study, the following data was assumed to be useful for a preliminary assessment of the areas required for greywater irrigation of summer vegetables in South Africa:

- For semi-arid inland winter rainfall areas, 100 litres of greywater per day should be sufficient to irrigate 10 square metres (10 mm per day). This represents a maximum daily irrigation demand for the country. Extrapolating this irrigation demand to the rest of the country should thus yield the minimum area that can be irrigated with greywater in South Africa.

- For sub-humid summer rainfall areas, 100 litres of water per day should be sufficient to irrigate 20 square metres (5 mm per day). This represents an average daily irrigation demand for the country. Extrapolating this irrigation demand to the rest of the country should thus yield an approximate average area that can be irrigated with greywater in South Africa.

- For humid summer rainfall areas, 100 litres per day should be sufficient to irrigate 33 square metres (3 mm per day). This represents close to the minimum daily irrigation demand for the country. Extrapolating this irrigation demand to the rest of the country should thus yield close to the maximum area that can be irrigated with greywater in South Africa.

Assumptions inherent in the above are that average monthly rainfall and evapotranspiration occur.

From **Table 3.3**, for communities required to get their water from a community stand or a tap in the yard (about 5 848 800 dwellings), approximately 350 Mm^3 of greywater is produced in a year (about 1.0 Mm^3 per day). This should be sufficient to irrigate a minimum of 10 000 ha and a maximum of 33 000 ha of summer vegetables in South Africa. This is equivalent to land areas of about 17 m^2 and 56 m^2 respectively, per dwelling.

Similarly, for communities with piped water directly to their homes (about 3 615 300 dwellings), approximately 469 Mm^3 of greywater is produced in a year, or about 1.28 Mm^3 per day. This should be sufficient to irrigate a minimum of 12850 ha and a maximum of 42405 ha of summer vegetables, equivalent to land areas of about 35 m^2 and 116 m^2 respectively, per dwelling.

Regarding the above estimations on irrigation volumes and land area requirements, the following comments are made:

- ☐ Irrigation is here considered for vegetable crops (as a surrogate for crops with similar irrigation requirements) grown in summertime as opposed to other cooler seasons;
- ☐ although household greywater contains plant nutrients, the limiting constraint to irrigation application is assumed to be moisture rather than nutrients such as nitrogen (as ammonium and nitrate) and phosphorus (as phosphate);
- ☐ Irrigation with untreated greywater assumes the use of simple, although efficient, irrigation methods – no spray or furrow irrigation;
- ☐ all the available greywater produced each day, including kitchen greywater, is used for irrigation (If kitchen greywater is to be excluded, then for preliminary assessments reduce the irrigated area by 10 %);
- ☐ leaching of accumulated salts should occur during months when the crop irrigation requirements are lower than peak monthly requirements (monthly greywater application volumes are expected to remain constant);
- ☐ Many simplifying assumptions have been made in this study. It is recommended that the irrigation results only be used for preliminary planning purposes for irrigating summertime vegetables (or crops with a similar irrigation requirement), on permeable (well-drained) soils. Special care is needed when using the results of this study for areas that have clay soils, areas with high water tables, soils with poor drainage, and for crops not grown in summer.

3.2.4 Conclusions

The response to a survey questionnaire on water consumption and greywater production sent to potential respondents at selected municipalities shows that municipalities do not generally keep a record of the amount of water supplied to formal / informal residential areas, or of the amount of sewage that reaches wastewater treatment plants. Hence the amount of greywater produced could not be estimated from municipal water supply records or wastewater treatment plant records.

Greywater production and greywater potential for irrigation use were estimated from Census 2001 data, with some knowledge on average water consumption figures for different socio-economic groups in South Africa, as supplied by Alcock (1999a,b; 2002). From these estimates, greywater production estimates were made.

Although water consumption, and hence the volume of greywater generated by households, depends on a variety of factors, the latter were not all explicitly accounted for in this study. Annual water consumption figures were estimated for dwellings, categorised according to water supply service categories presented in the Census 2001 data base. The water consumption estimates were used to give a preliminary estimate of annual greywater production volumes per water supply service category. In the report, these are grouped into two categories: dwellings with piped water supplies directly to the house, and dwellings where water has to be obtained from piped supplies to a tap in the yard or further away. A preliminary estimate of the total greywater production from households that obtain their water from municipal water supply systems in South Africa in the year 2000 is 1020 Mm^3.

Preliminary irrigation requirements for irrigating vegetable crops in summer are presented in order to obtain an estimate of the land area required by the two greywater producer categories. Based on the average greywater volume produced per dwelling, and assuming that sufficient greywater is produced to satisfy the peak monthly crop irrigation requirements of summer vegetables, then:

- ☐ For communities required to get their water from a community stand or a tap in the yard, a minimum area of about 17 m^2 per dwelling (for areas experiencing dry summers), and a maximum area of about 56 m^2 (for areas normally experiencing high rainfall in summer) are required.
- ☐ For communities with piped water directly to their homes, a minimum area of about 35 m^2 per dwelling (for areas experiencing dry summers), and a maximum area of about 116 m^2 (for areas normally experiencing high rainfall in summer) are required.

It is expected that the production of greywater will become less and be of lower quality during periods of water shortage, at a time when there is likely to be a greater need for its use for irrigation. During periods of low demand for irrigation, excess greywater will need to be disposed. Where an alternative option such as disposal to sewer does not exist, the issue of ensuring that excess greywater is disposed appropriately needs to be considered.

A significant amount of further work is needed to extract all the relevant municipal data from the Census records. The feasibility of doing this, either as part of this project or as part of a future proposed project needs further discussion, taking into account the relevance of the Census 2001 and other records in light of the rapidly changing percentage of households being serviced by higher levels of service in terms of municipal water supply options.

3.3 Potential demand for greywater

3.3.1 Introduction

Greywater use for irrigation has greatest potential amongst water-stressed nations and communities in semi-arid and arid areas of the world (Pettigrove et al., 1984; Center for the Study of the built Environment, 2003), areas that experience droughts, and where water restrictions for irrigation are applicable, where availability of water from other sources (rainfall, groundwater) is limited and/or costs of water are high enough to restrict use of water supplies for household gardens. Countries that experience water restrictions due to limited water supplies, attendant with high costs of water, are also likely to reuse water for alternative purposes.

Southern Africa is projected to experience increased water demand, with South Africa in particular projected to experience a significant increase in water stress (Hirji et al., 2002). Projected figures for 2025 (UNEP, 2002) suggest that water availability in South Africa per person will decrease to below 1000 m^3/year. This decline in water availability is largely due to increasing water demand and a reduction in resource accessibility as a result of factors such as increasing urban populations, environmental change (including climatic change) and water resource pollution (Beekman, et al., 2005).

Factors affecting the potential demand for greywater include:

- ☐ Housing/ population density (e.g.: high rise flats have little potential demand);
- ☐ Presence of enabling/ restricting legislation and of practical guidelines;
- ☐ Potential ease of greywater disposal to sewer and/ or existence of facilities to

facilitate use of greywater for irrigation;

- Water availability / cost;
- Climate (rainfall, humidity, temperature, sunshine, windspeeds etc.),
- Availability of suitable land;
- Where conditions are normally suitable for growing subsistence crops using greywater but where criminal activity is high;
- In the case of irrigation, the volumes required by crops and the suitability of greywater for irrigating those crops.

Each of these parameters relates to the demand (/potential demand) for greywater use, demand here being either negative or positive.

Negative demand refers to a situation where an excess of greywater is present, and due to the existence of associated nuisance and health conditions, requires safe disposal. Negative demand can occur seasonally due to excess rainfall, to lack of irrigation requirements in the fallow season, and where no action is taken by greywater irrigators to switch to an alternative (safe) disposal option. It may also occur where there is a lack of suitable land due to densely populated settlements and where there is a lack of suitable greywater disposal facilities. In the latter case, greywater may be something of a hazard as it may accumulate in areas not demarcated for greywater.

Positive demand (i.e. demand) refers to the need for growing plants in areas where space/ area and soils are sufficient for gardening or growing crops in the vicinity of dwellings, there is insufficient rainfall and fresh water supplies are limited or costly. Here greywater may be seen as an alternate source of water for activities like irrigation.

According to Alcock (2002), in South Africa greywater is used for irrigation by low, middle and high income households. Relatively few negative effects as a result of greywater irrigation have been reported in South Africa up to 2002. High and middle income householders are motivated primarily by the need to save money, and also by the desirability of conserving a precious resource in a semi-arid land. Low income householders (limited data available) are likewise motivated by a desire to save water where basic water supply systems mainly in the form of street standpipes have been installed, or where water has to be carried some distance to the household. The benefits of using greywater as a valuable irrigation supplement and plant nutrition resource for low income households has been realised by some community participation programmes in South Africa (Alcock, 2002). Potential uses for greywater in South

Africa include:

- ☐ for poor communities the irrigation of plants used for subsistence purposes (e.g. those that are fairly tolerant of elevated sodium in soil water, such as tomatoes and cabbages), security purposes, screening (i.e. for domestic privacy), shade, animal fodder and compost, and
- ☐ for more wealthy communities the irrigation of flowers, shrubs, vines and lawns.

Amongst poor communities greywater is often reused for other purposes in the home (Alcock, 2002), such as the use of dish rinse water for washing dirty dishes, use of dirty dish water for washing out pots, and the use of this greywater for compost. Similarly, clothes rinse water may be used for washing the next batch of dirty clothes, and clothes wash water may be used for cleaning floors (Alcock, 2002). The greywater discharged from these homes can thus be expected to be of poor quality, and may only be suitable for compost or for irrigating tolerant plants.

3.3.2 Geographic distribution

Greywater is potentially suitable for irrigating lawns, trees, ornamentals, and food crops (New Mexico State University, 1994) and the greatest potential demand for this use is amongst water-stressed nations and communities in semi-arid and arid areas of the world (Pettygrove *et al*, 1984; Center for the Study of the built Environment, 2003; Ludwig, 2004a). Communities that experience water restrictions due to limited water supplies and high costs of obtaining water are likely to use greywater for irrigation (Pettygrove et *al*, 1984; Center for the Study of the built Environment, 2003; Ludwig, 2004a).

Demand for greywater for irrigation will be less during cooler, rainy seasons and in the more humid areas of the country (Pettigrove *et al*, 1984). Higher demand will occur during periods of drought, during the dry season, and in the more arid areas of the country. Higher demand for greywater is likely to be experienced in expanding municipal areas with limited access to water resources, especially those in the more arid areas that do not have an assured long-term water supply (examples: Beaufort West, Calvinia, Bloemfontein and Polokwane).

3.3.3 Dependence on the quality of greywater supply

The quality of greywater varies depending on the quality of the water supply, the source of the greywater (sink, washing machine, bath, etc.), and scarcity/ costs of fresh water. The poorer the quality of greywater, the less suitable it is for irrigating crops, and the lower the consequent demand for its use. The quality of greywater for irrigation needs to be considered from the perspectives of risk to human health, potential impact on quality of life and potential impact on plants, soils and water resources, especially groundwater (Tredoux, 2004) (See **Table 3.5**).

Table 3.5: Potential impacts of greywater contaminants (Center for the Study of the Built Environment, 2003; Tredoux, 2004; Ludwig, 2004; Water Conservation Association of Southern Arizona, 2002)

	Contaminant	**Source**	**Potential impact on:**
1	Pathogens	soiled clothes and nappies, decaying organic particles, etc.	Human health
2	Insect vectors, odours, etc.	Decaying greases, proteins and blockages from lint, hairs	Quality of life (odours, aesthetics); human health (insect vectors)
3	Greases and suspended solids	Dish washing, body ablutions, bath soaps, dirty clothes	Soils (clogging of soil pores)
4	Sodium	Soaps, detergents and water softeners	Soils and crops
5	Boron, dissolved salts, pH, enzymes, chemicals	Detergents, water softeners, fabric softeners	Crops
6	Nitrates, dissolved salts, pathogens	Decaying organic particles, detergents, soiled clothes, etc.	Groundwater
7	Phosphates, dissolved salts, pathogens	Detergents, decaying organic particles, soiled clothes, etc.	Surface water resources

In terms of demand for greywater for irrigation, items **1** to **3** in **Table 3.5** are likely to have the greatest influence on demand, followed by item **4**.

In terms of risk to human health for a family with no sick members, greywater from baths and showers generally presents the lowest risk, followed by laundry greywater. The highest health risk is presented by water from the kitchen sink, and this risk is highest at the place where irrigation occurs (assuming that the potential for human contact after the greywater passes from the kitchen sink is highest at the place where it is irrigated). (Water Conservation Association of Southern Arizona, 2002)

The chemical quality of greywater depends on the concentrations of chemicals that are in the source water to start with, in addition to the chemicals that are added to it in the washing process. Source water normally contains dissolved salts of calcium, magnesium, sodium, carbonates, sulphates and chlorides. The higher the concentration of total dissolved salts, and particularly of sodium and chlorides in source water, the less suitable for irrigation the resultant greywater is likely to be. The quality of greywater also depends on the source of greywater, whether from clothes washing (laundry), from the bathroom or from the kitchen. In terms of suitability for irrigating crops (excluding risk to human health), laundry greywater is likely to be least suitable, followed closely by kitchen greywater and then by greywater from the bathroom.

The less source water there is available for washing, the more concentrated the wash-related contaminants will be in the resultant smaller volumes of greywater. Similarly, the more reuse of greywater there is within the household, such as use of laundry rinse water for the next wash cycle, the lower will be the quality the resultant greywater. Amongst poor communities greywater is often reused for other purposes in the home (Alcock, 2002), such as the use of dish rinse water for washing dirty dishes, use of dirty dish water for washing out pots, and the use of this greywater for compost. Similarly, clothes rinse water may be used for washing the next batch of dirty clothes, and clothes wash water may be used for cleaning floors (Alcock, 2002). The greywater discharged from these homes can thus be expected to be of poor quality, and may only be suitable for compost or for irrigating a limited number of tolerant species of plants. Thus, implementing conservation measures and reusing greywater in the home results in lower volumes of poorer quality greywater being produced.

Irrigating with poor quality greywater requires careful management, especially on certain types of soil and for sensitive plants (Department of Water Affairs and Forestry, 1996) and for plants whose edible portions are likely to come in contact with greywater (Department of National Health and Population Development, 1978). The more onerous the management requirements, the lower the demand for greywater for irrigating crops is likely to be.

The factors influencing a positive demand for greywater for irrigation should be those that result in production of greywater of sufficiently good quality for irrigating high-value crops successfully with least effort or least cost. Thus the use of bathroom greywater or of rinse water on suitable land should help stimulate a positive demand. During times of drought however, when the need to use greywater for irrigation is high, the quality of greywater is likely to drop due to water conservation measures. Wise management of greywater for irrigation is therefore required to reduce the negative effects of greywater irrigation.

The quality of the greywater produced is likely to have a marked affect on the demand for greywater for irrigating crops. The negative effect on demand will probably be the most in terms of perceived implications firstly on human health and quality of life, then on potential impact on plants and soils. User-friendly guidelines and educational drives should help to stimulate successful greywater irrigation, and thus help to stimulate demand.

3.3.4 Dependence on access to available land and to other water resources

Availability of suitable land for greywater irrigation is a factor in creating demand (Ludwig, 2004a). Demand will be greater where households have access to suitable land at a low elevation adjacent to the bathroom or washing area (Ludwig, 2004a). A constraint to greywater use in the garden is that existing plumbing fixtures at residences may not enable greywater to be diverted to a place where it can be used in the garden, making such greywater use unlikely (Ludwig, 2004a). Poor residential areas without waterborne sanitation are unlikely to be constrained by inappropriate plumbing fixtures or land elevation problems, as irrigation of plants is most likely to be by bucket or basin. Lack of suitable land need not negate the demand for use of greywater for irrigating crops, as alternatives such as "hanging gardens" and "tower gardens" can be used to grow subsistence crops where space is limited (Center for the Study of the built Environment, 2003; Crosby, 2004).

Residential properties with access to groundwater resources are unlikely to be constrained as much by the cost of municipal water supplies as other properties. As water supply costs rise and more restrictions are imposed, residential properties with larger gardens will very likely turn to groundwater for water use needs outside the house. In such cases, greywater produced by such properties is unlikely to be used in the garden. In residential areas with no access to groundwater resources, rainwater tanks could provide households with an alternative source of water. Due to its low salt content, stored rainwater should be suitable for diluting greywater, and for effective leaching of accumulated salts out of soils irrigated with greywater.

3.3.5 Economic aspects

Water is becoming a scarce resource. As demand outstrips supply, this forces up the cost of water and imposes more severe restrictions on water use (Ludwig, 2004a).

In South Africa, greywater irrigation is being practiced amongst both poor and rich communities. Affluent users of greywater for irrigation seek to reduce municipal water bills. Users who have to carry water home from a distant tap or water source save water by re-using greywater either in the home or on subsistence crops (Alcock, 2002).

The real costs of water supply and distribution are generally not passed on to the domestic consumer. In urban areas water supplies to low income communities are usually heavily subsidized. Current domestic water tariffs increase with usage, with most municipalities providing the first 6 Kilolitre per month free. Heavy subsidies serve as a disincentive to conserve for the low to medium income user (Alcock, 2002). Also, water supplied for general public or communal use is often considered a free good, and so is used generously, if not wasted.

Over the years, with expanding populations there has been an increasing demand for water and it is during periods of lower than normal rainfall that this demand for water cannot be met, so the demand has to be managed. The approach used by municipalities is to attach a sliding scale of costs to water, so that the more is used, the higher the cost per kilolitre (cubic metre) charged to the consumer. This is an incentive for consumers who normally use large volumes of water to use less. During periods of drought, more severe restrictions on water use have to be implemented. Such restrictions include steeper tariffs, a partial ban on using municipal water for irrigating gardens and restrictions on types of allowable use, etc.

During periods of drought, household water conservation efforts result in smaller volumes of poorer quality greywater being produced, making the greywater potentially less suitable for crop irrigation. This would probably be a good time to switch to a low sodium detergent or one that is marketed as biocompatible (essentially, compatible with plants), as opposed to biodegradable (able to be degraded, or broken down, naturally).

3.3.6 Summary and Conclusions

Greywater use for irrigation has greatest potential amongst water-stressed nations and communities in semi-arid and arid areas of the world. Southern Africa is projected to experience increased water demand, with South Africa in particular projected to experience a significant increase in water stress within the next 20 years, not only because of limited volumes of available water, but also because of deteriorating quality of water resources.

There is a potential demand for using an alternate source of water, such as greywater, for irrigating plants in areas where space/ area and soils are sufficient for gardening or growing crops in the vicinity of dwellings and when fresh water supplies are limited or costly, and rainfall is lacking. Demand for greywater will be low in areas that do not have access to suitable land for growing crops, and where crops are at risk of being stolen.

Regarding the types of use for greywater amongst low-income communities, the demand for greywater irrigation would very likely be for subsistence crops and plants that provide shade, privacy, security, firewood, poles, fodder, and herbal remedies, especially where these are lacking and are expensive to obtain otherwise. For more affluent communities, the demand for greywater is expected to be for irrigation of flowers, shrubs, vines and lawns.

Demand will be greater for high quality greywater than for greywater of lower quality, therefore the greatest need would be for bathroom water and laundry rinse water. The volumes and quality of greywater produced will be lower when water restrictions are in effect, occurring when the need for re-using greywater and other sources of water (e.g. groundwater) is high.

Legislation and guidelines influence the potential demand for greywater for irrigation. Legislation tends to inhibit demand, whereas the presence and application of user-friendly guidelines and educational initiatives should help to increase the demand (Ludwig, 2004a).

In terms of risk to human health for a family with no sick members, greywater from baths and showers generally presents the lowest risk, followed by laundry greywater. The highest health risk is presented by water from the kitchen sink, and this risk is highest at the place where irrigation occurs. In terms of suitability for irrigating crops (from a chemical-content perspective), laundry greywater is likely to be least suitable, followed closely by kitchen greywater and then by greywater from the bathroom. Use of low sodium-content detergents or ones that are biocompatible (essentially, compatible with plants), as opposed to biodegradable (able to be degraded, or broken down, naturally) should help stimulate demand once it is realised by householders that the resultant greywater has a lower negative effect on irrigated plants and on soils.

CHAPTER 4

4 Field sites and analyses

4.1 Introduction

Due to the lack of information on the quality of greywater and in order to evaluate the fitness for use of greywater, it was decided to establish the greywater quality in relation to different social and economic settings. This chapter discusses the results from:

> (i) a greywater quality evaluation from 18 households from Stellenbosch, Somerset West, Kyamandi and Khayelitsha;
> (ii) a social survey in the Eastern Cape, and
> (iii) a pilot study on the use of treated effluent to test the local authorities and communities' willingness in using greywater.

4.2 Stellenbosch, Somerset West, Kyamandi and Khayelitsha

4.2.1 Greywater quality

As an “initial” greywater quality evaluation, 18 individuals (staff members of the Water Programme of CSIR in Stellenbosch and staff form the cleaning services) were requested to bring samples of dishwater; bathwater and clothing wash water for analysis. To ensure individual privacy, an identification code (ID code = A to R) was allocated to each participant. This ID code was again randomly changed to numbers for the purpose of this report. Thus no information related to the socio-economic status of the participants was obtained.

4.2.2 Methodology

The choice of households selected, was based on their residential location, their social setting and their economic level. Sample bottles were prepared for chemical, microbiological and for fats, oils and grease analysis and supplied to the participants the day before sampling. It was suggested that fresh samples be collected and brought to the laboratories on the same day as sampling. Every individual had to supply an ID code; sampling time; soap type; washing powder used and bath oil together with the samples. The samples were to be collected in the process container used.

The following parameters, listed in **Table 4.1**, were selected by the project team for the quality evaluation of sampled greywater.

Table 4.1: Greywater quality evaluation parameters

Potassium
Sodium
Calcium
Magnesium
Ammonia
Sulphate
Chloride
Alkalinity
Nitrate plus nitrite
Ortho phosphate
Conductivity
pH

Sodium absorption ratio
Boron
Dissolved Organic Carbon
Chemical Oxygen Demand
Kjeldahl Nitrogen
Total Phosphorus
Suspended Solids
Total Dissolved Solids
Fats and oils
Heterotrophic plate count
Faecal coliform bacteria
Escherichia coli

4.2.3 Results

Eleven of the participants sampled dishwater and ten also sampled clean source water on Monday 19 July 2004. One of the participants sampled dishwater the previous evening. Eleven of the participants sampled bathwater on Monday 3 August 2004. Four participants sampled the bathwater the previous evening. The dishwater (**A**) and source water (**B**) results are listed in **Table 4.2**. The bathwater results are listed in the **Table 4.3**. All the results (dishwater, bathwater and source water) are also graphically presented in **Figures 4.1** to **4.10** for better visualisation of the differences.

Table 4.2: Dishwater and source water results - Monday 19 July 2004

Parameter		1A	1B	2A	3A	3B	8A	8B	9A	9B
K	mg/L	7.4	0.33	28	6.3	0.40	6.7	0.35	3.8	0.31
Na	mg/L	72	4.9	164	155	6.0	30	5.3	39	5.0
Ca	mg/L	8.4	6.5	4.4	20	19	8.4	8.3	8.0	7.1
Mg	mg/L	1.2	0.56	0.5	2.0	1.3	0.9	0.65	0.8	0.62
Ammonia (N)	mg/L	0.8	<0.1	1.0	2.3	<0.1	3.0	<0.1	0.8	<0.1
Sulphate	mg/L	6.4	4.0	13	23	17	9.0	6.2	5.9	4.0
Cl	mg/L	75	10	117	144	11	31	11	37	11
Alkalinity	mg/L	26	13	181	47	31	12	12	10	13
Nitrate (N)	mg/L	0.17	<0.1	0.25	0.35	0.10	<0.1	<0.1	0.13	<0.1
Ortho P	mg/L	1.0	<0.1	2.9	0.66	<0.1	0.85	<0.1	0.77	<0.1
DOC	mg/L	479	<1	571	283	<1	177	<1	233	<1
B mg/L		<0.1	-	<0.1	<0.1	-	<0.1	-	<0.1	
EC 25EC	mS/m	39	7.1	76	83	14.6	23	8.7	24	7.4
pH	25EC	7.4	7.7	8.3	6.9	8.8	5.6	8.7	5.5	7.6
pHs	20EC	9.2	9.6	8.7	8.6	8.8	9.5	9.5	9.7	9.6
Hardness	mg/L	26	19	13	57	53	25	23	23	20
SAR		6.2	0.5	20	8.9	0.4	2.6	0.5	3.5	0.5
COD	mg/L	4358	-	7821	7088	-	1283	-	1914	-
Kjeldahl N	mg/L	40	-	44	62	-	57	-	30	-
Total P	mg/L	2.7	-	6.8	2.3	-	1.4	-	1.6	-
SS	mg/L	318	-	1173	364	-	148	-	534	-
TDS 180EC	mg/L	1686	-	1412	1966	-	578	-	394	-
FOG	mg/L	<10	-	1360	<10	-	342	-	38	-
HPC	mL	15250	-	880000	83500	-	1700000	-	35700	320
FC	100mL	40000	-	140	17900	-	1.0×10^8	-	4700	0
E. coli	100mL	100	-	140	0	-	1.0×10^8	-	0	0

Table 4.2: (continued)

Parameter		10A	10B	11A	11B	12A	12B	13A	13B
K	mg/L	5.4	0.32	2.5	0.44	19	0.23	5.1	0.40
Na	mg/L	25	4.9	52	6.0	655	4.4	64	5.9
Ca	mg/L	6.0	6.6	16	20	19	14	20	20
Mg	mg/L	1.1	0.58	1.2	1.2	2.1	0.83	1.5	1.3
Ammonia (N)	mg/L	1.1	<0.1	1.2	<0.1	1.4	<0.1	2.7	<0.1
Sulphate	mg/L	2.7	4.0	21	17	483	5.0	26	17
Cl	mg/L	33	10	17	12	102	7.9	27	12
Alkalinity	mg/L	20	13	70	31	572	32	46	32
Nitrate (N)	mg/L	0.19	<0.1	0.04	0.10	0.25	<0.1	0.29	0.10
Ortho P	mg/L	0.31	<0.1	0.23	<0.1	9.3	<0.1	0.48	<0.1
DOC	mg/L	64	<1	93	1.0	186	<1	129	<1
B mg/L		<0.1	-	<0.1	-	9.5	-	<0.1	-
EC 25EC	mS/m	19	6.8	27	15.2	265	10.3	30	14.9
pH	25EC	6.2	8.4	7.0	8.7	9.9	8.7	7.8	9.0
Hardness	mg/L	20	19	46	54	56	38	55	54
SAR		2.5	0.5	3.4	0.4	38	0.3	3.8	0.3
COD	mg/L	713	-	1385	-	4114	-	2240	-
Kjeldahl N	mg/L	15	-	36	-	28	-	55	-
Total P	mg/L	0.87	-	0.64	-	131	-	1.1	-
SS	mg/L	102	-	73	-	743	-	60	-
TDS 180EC	mg/L	212	-	434	-	2990	-	988	-
FOG	mg/L	466	-	1135		1107		<10	-
HPC	mL	600000	-	3500000	320	700	-	842000	-
FC	100mL	97000	-	142000	0	0	-	0	-
E. coli	100mL	0	-	0	0	0	-	0	-

Parameter		14A	14B	15A	15B
K	mg/L	9.9	0.43	2.5	0.73
Na	mg/L	51	6.1	26	11
Ca	mg/L	20	20	11	12
Mg	mg/L	1.9	1.3	4.9	2.3
Ammonia (N)	mg/L	0.3	<0.1	0.9	<0.1
Sulphate	mg/L	24	17	21	18
Cl	mg/L	53	12	22	18
Alkalinity	mg/L	27	31	19	17
Nitrate (N)	mg/L	0.21	0.10	<0.1	<0.1
Ortho P	mg/L	1.9	<0.1	0.27	<0.1
DOC	mg/L	443	1.0	51	<1
B mg/L		<0.1	-	<0.1	-
EC 25EC	mS/m	35	14.5	20	14.5
pH	25EC	6.0	8.9	6.9	8.0
Hardness	mg/L	57	54	47	39
SAR		2.9	0.4	1.7	0.8
COD	mg/L	3992	-	774	-
Kjeldahl N	mg/L	26	-	22	-
Total P	mg/L	3.1	-	0.36	-
SS	mg/L	595	-	36	-
TDS 180EC	mg/L	1176	-	376	-
FOG	mg/L	2741	-	-	-
HPC	mL	20000000	-	30	320
FC	100mL	3000000	-	0	0
E. coli	100mL	3000000	-	0	0

1A = Dishwater from Participant 1
DOC = Dissolved organic carbon
SAR = Sodium adsorption ratio
SS = Suspended solids

1B = Source water from Participant 1
EC = Electrical conductivity
COD = Chemical oxygen demand
TDS = Total dissolved solids

FOG = Fats, Oils & Greases
HPC = Heterotrophic plate
FC = Faecal coliform bacteria
E. coli = *Escherichia coli*

Table 4.3: Bathwater and source water results - Monday 3 August 2004

		1	2	3	7	8	11
K	mg/L	4.3	11	30	0.58	0.58	1.2
Na	mg/L	34	188	192	14	6.6	16
Ca	mg/L	4.2	5.3	13	3.5	5.6	11
Mg	mg/L	0.15	0.34	0.53	0.69	0.51	0.70
Ammonia (N)	mg/L	1.7	3.0	57	0.55	0.63	0.65
Sulphate	mg/L	4.2	5.4	51	2.9	2.8	5.5
Cl	mg/L	16	60	127	6.8	10	9.1
Alkalinity	mg/L	54	323	453	23	14	45
Nitrate (N)	mg/L	<0.1	0.40	0.60	<0.1	<0.1	<0.1
Ortho P	mg/L	<0.1	1.8	11	0.10	<0.1	0.12
DOC	mg/L	24	113	330	4.3	9.5	8.5
B mg/L		0.11	0.13	<0.1	<0.1	<0.1	<0.1
EC 25EC	mS/m	18	68	145	9.0	8.0	13
pH	25EC	6.9	9.9	8.8	6.9	6.7	7.1
Hardness	mg/L	11	15	35	12	16	29
SAR		4.4	21	14	1.8	0.72	1.3
COD	mg/L	1080	8619	4247	320	181	305
Kjeldahl N	mg/L	33	67	224	6.4	3.0	5.7
Total P	mg/L	1.2	2.4	14	0.14	<0.1	0.14
SS	mg/L	231	1553	712	95	12	65
TDS 180EC	mg/L	296	1622	1274	84	78	118
FOG	mg/L	990	1656	510	21	24	250
HPC	mL	248000	22200000	1810000	3330000	2350	3530000
FC	100mL	4820	20	130	392	145	190
E. coli	100mL	4600	0	20	1656	0	260

		12	13	16	17	18
K	mg/L	0.58	0.71	7.1	0.65	0.71
Na	mg/L	16	33	19	21	15
Ca	mg/L	13	12	21	16	19
Mg	mg/L	0.74	0.67	1.7	0.91	1.8
Ammonia (N)	mg/L	0.19	<0.1	2.1	<0.1	<0.1
Sulphate	mg/L	17	22	22	16	20
Cl	mg/L	6.8	8.0	25	18	17
Alkalinity	mg/L	38	62	45	39	35
Nitrate (N)	mg/L	<0.1	<0.1	<0.1	<0.1	<0.1
Ortho P	mg/L	<0.1	0.30	2.6	0.12	<0.1
DOC	mg/L	9.9	26	25	13	5.8
B mg/L		<0.1	<0.1	0.16	<0.1	<0.1
EC 25EC	mS/m	15	17	27	19	19
pH	25EC	7.5	6.8	7.1	7.2	7.5
Hardness	mg/L	35	33	59	45	55
SAR		1.2	2.5	1.1	1.4	0.86
COD	mg/L	330	866	58	326	70
Kjeldahl N	mg/L	2.1	1.7	39	13	1.1
Total P	mg/L	<0.1	0.31	3.1	0.24	<0.1
SS	mg/L	91	139	0	51	16
TDS 180EC	mg/L	120	286	164	142	96
FOG	mg/L	13	116	182	228	<10
HPC	mL	300000	886000	4200	115000	96000
FC	100mL	2850	296000	0	5000	5
E. coli	100mL	2220	20000	0	10	5

The above results are presented graphically in **Figures 4.1 to 4.10**, as "radar" charts. The numbers 1 to 18 on the outside circumference represent the participant IDs. The inside numbers are the concentrations (log scale), with zero in the middle. Some participants sampled all the greywater sources, some sampled one only, and some did not sample any at all.

In order to compare relevant analytical results from previous studies with the results from this study, data from Jeppeson and Solley (1994); Beukes (2001); Casanova *et. al* (2001) and Ledin *et. al* (2002) are presented as numbers 19 and 20 on the radar graphs.

Potassium

The potassium concentrations are presented in **Figure 4.1**.

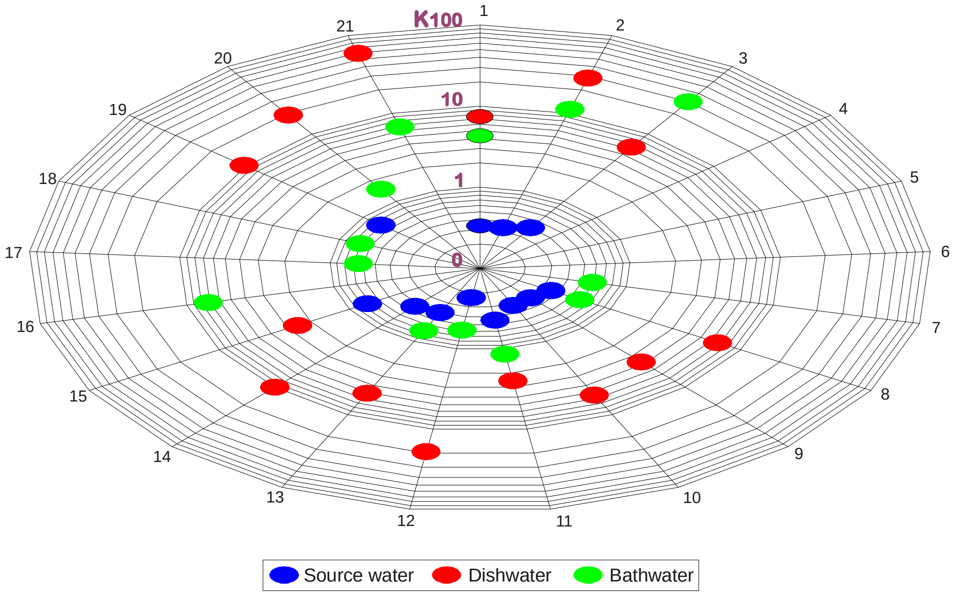


Figure 4.1: Potassium in sampled greywater

The potassium concentration range in the different waters from the 18 individuals (1st column) and from the literature (2nd column) is shown below. The 3rd column shows the concentrations where all three samples were collected by the same participant although all three have the same social and economic setting. The 4th column shows the bathwater concentrations from three participants from the same area but with different culture and economic settings.

Source water	0.23 - 0.73	0.40 - 1	0.3	0.3	0.4	16s bathwater	7.10
dishwater	2.5 - 28	7.5 - 59	7.4	28	6.3	17s bathwater	0.58
bathwater	0.58 - 30.0	1.5 - 6.6	4.3	11	30	18s bathwater	0.71

It appears that the potassium concentrations will differ from household to household in the same area and elsewhere and that there is no specific concentration range for it. However, all the results show a increased concentration in the greywater compared to the source water.

There are no potassium guidelines in the South African Water Quality Guidelines, Volume 4 Agricultural Use (SAWQG4) of the Department of Water Affairs and Forestry (Department Of Water Affairs And Forestry, 1996).

Sodium

The sodium concentrations are presented in **Figure 4.2**.

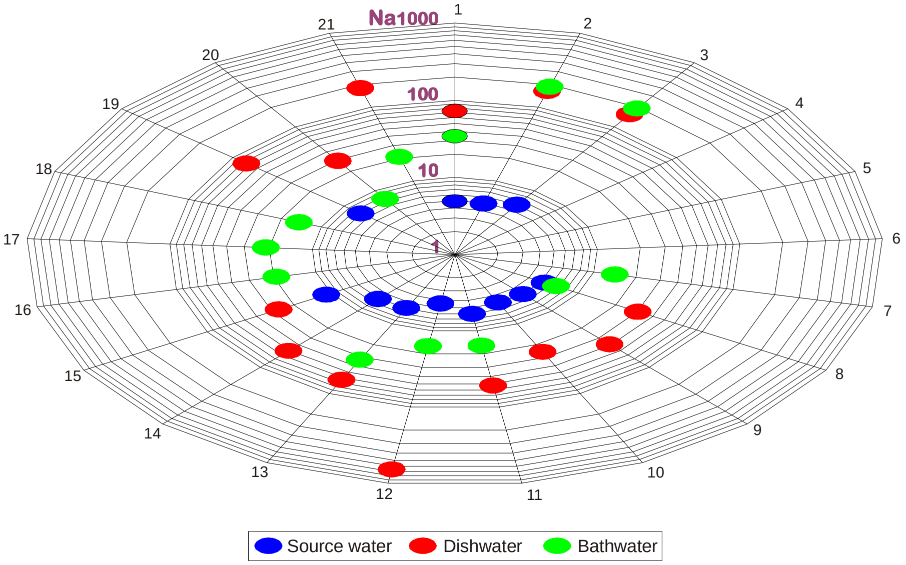


Figure 4.2: Sodium in sampled greywater

The sodium concentration range in the different waters from the 18 individuals (1st column) and from the literature (2nd column) is shown below. The 3rd column shows the concentrations where all three samples were collected by the same participant although all three have the same social and economic setting. The 4th column shows the bathwater concentrations from three participants from the same area but with different culture and economic settings.

Source water	4.4 - 11	5 - 9	4.9	4.9	6.0	16s bathwater	19
dishwater	25 - 655	29 - 180	72	164	155	17s bathwater	21
bathwater	6.6 – 192	7.4 – 21	34	188	192	18s bathwater	15

The effects of sodium on the foliage of plants are shown in **Table 4.4**; i.e. where plant leaves are wetted during irrigation. The colouring is adopted from the Quality of domestic water supply, Volume 1, Assessment Guide (WRC TT101/98 ISBN 1 86845 416 9) for easy visualisation as decided on at a steering committee meeting.

Table 4.4: Effects of sodium on foliar crop yield and quality

Concentration Range mg/L	Crop Yield and quality	
Target Water Quality Range	Should prevent the accumulation of sodium to toxic levels in all but the most sensitive plants, even when crop foliage is wet	Negligible risk Class 0
70 - 115	Crops sensitive to foliar absorption accumulate toxic levels of sodium when crop foliage is wetted. They display symptoms of foliar injury and yield decrease	Risk to sensitive plants Class 1
115 - 230	Crops moderate sensitive to foliar absorption accumulate toxic levels of sodium when crop foliage is wetted. They display symptoms of foliar injury and yield decrease	Risk to moderate sensitive plants Class 2
230 - 460	Crops moderate tolerant to foliar absorption increasingly accumulate toxic levels of sodium when crop foliage is wetted. They display symptoms of foliar injury and yield decreases	Risk to moderate tolerant plants Class 3
> 460	Crops tolerant to foliar absorption increasingly accumulate toxic levels of sodium when crop foliage is wetted. They display symptoms of foliar injury and yield decreases	Risk to tolerant plants Class 4

From the results it is clear that sodium in greywater may exceed the concentration ranges for tolerant crops when foliage is wetted. In the case of sodium, it would be a good management practice to classify greywater as a Class 3 water until otherwise proven. The sodium is also used to calculate the Sodium Absorption Ratio (SAR). The SAR is an index of the potential of water to induce sodic soil conditions, and is calculated from sodium, calcium and magnesium concentrations in water. The higher the concentration of calcium and magnesium in water, the lower is the SAR for a fixed concentration of sodium. This will be discussed under section 3.5 of this chapter.

Calcium

The calcium concentration range in the different waters from the 18 individuals (1st column) and from the literature (2nd column) is shown below. The 3rd column shows the concentrations where all three samples were collected by the same participant although all three have the same social and economic setting. The 4th column shows the bathwater concentrations from three participants from the same area but with different culture and economic settings.

source water	6.5 - 20	7.4 - 9	6.5	6.5	19	16s bathwater	21
dishwater	4.4 - 20	7.3 - 30	8.4	4.4	20	17s bathwater	16
bathwater	3.5 - 21	3.5 - 21	4.2	5.3	13	18s bathwater	19

From the results it appears that the calcium concentrations in the greywater does not differ significantly from the source water. There are even cases where the calcium is lower in the greywater than in the source water. There are no calcium guidelines in SAQWG4. However, calcium is used to calculate the sodium adsorption ratio (SAR). This will be discussed under Sodium Adsorption Ratio on page 53.

The calcium concentrations are presented in **Figure 4.3.**

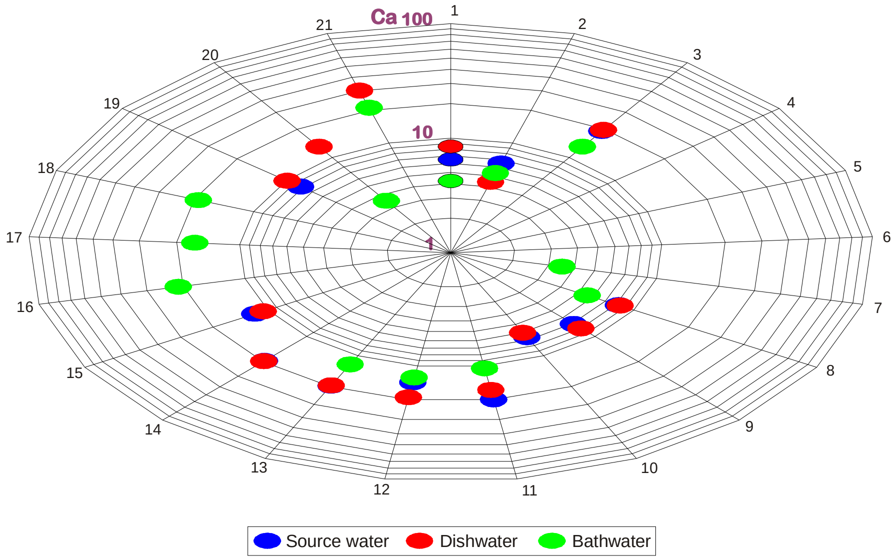


Figure 4.3: Calcium in sampled greywater

Magnesium

The magnesium concentrations are presented in **Figure 4.4**

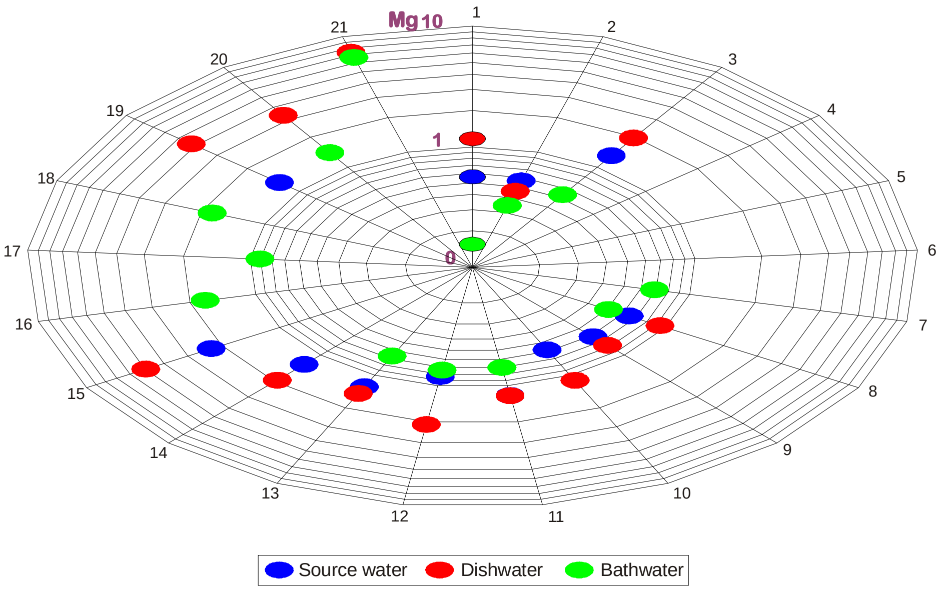


Figure 4.4: Magnesium in sampled greywater

The magnesium concentration range in the different waters from the 18 individuals (1st column) and from the literature (2nd column) is shown below. The 3rd column shows the concentrations where all three samples were collected by the same participant although all three have the same social and economic setting. The 4th column shows the bathwater concentrations from three participants from the same area but with different culture and economic settings.

source water	0.5 - 2.3	0.9 - 1.7	0.5	6.5	1.3	16s bathwater	1.7
dishwater	0.5 - 4.9	3.3 - 7.3	1.5	4.4	2	17s bathwater	0.9
bathwater	0.1 - 1.8	1.4 - 6.6	0.1	5.3	0.5	18s bathwater	1.8

From the results it appears that the magnesium concentrations in the greywater does not differ significantly from the source water. However, it is interesting to note that in the dishwater, the magnesium concentrations are slightly higher than in the source water while in the bathwater the concentrations is slightly lower than the source water. This may be due to some cation exchange. The maximum concentrations from the literature are slightly elevated compared to the results from this study There are no magnesium guidelines in SAQWG4. However, as stated above, magnesium is also used to calculate the SAR of water.

Sodium Adsorption Ratio

The SAR are presented in **Figure 4.5**

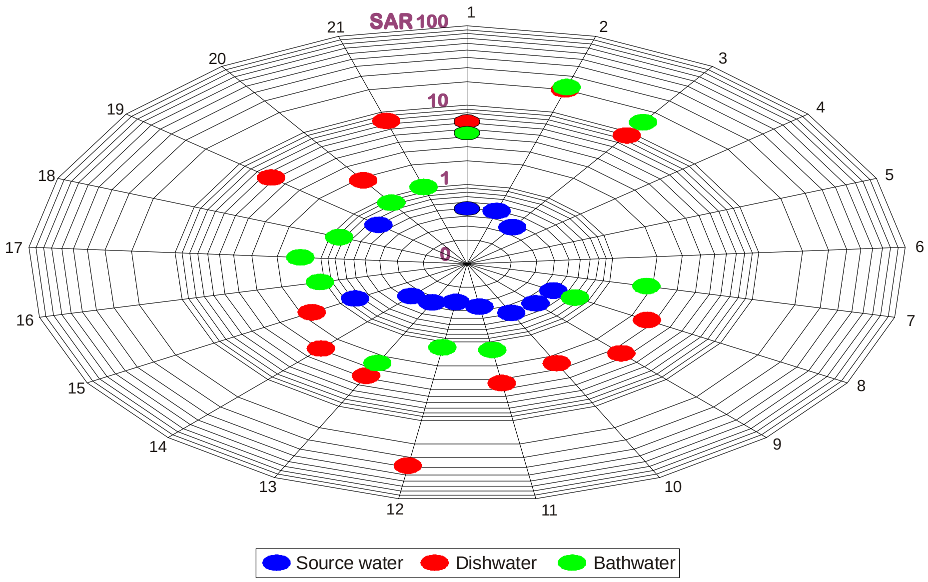


Figure 4.5: SAR of sampled greywater

The SAR range in the different waters from the 18 individuals (1st column) and from the literature (2nd column) is shown below. The 3rd column shows the concentrations where all three samples were collected by the same participant although all three have the same social and economic setting. The 4th column shows the bathwater concentrations from three participants from the same area but with different culture and economic settings.

source water	0.3 - 0.8	0.9 - 1.7	0.5	0.5	0.4	16s bathwater	1.1
dishwater	1.7 - 20	3.3 - 7.3	6.2	20	8.9	17s bathwater	1.4
bathwater	0.7 - 21	1.4 - 6.6	4.4	21	1.4	18s bathwater	0.8

SAR is calculated using the following formula: $\text{SAR} = [\text{sodium}]/([\text{calcium}] + [\text{magnesium}])^{0.5}$ where the concentrations of sodium, calcium and magnesium in solution are measured in mmol/L. SAR is also determined on saturated soil extracts to give an indication of the exchangeable sodium percentage of the soil. In this report only the effects of SAR on crop yield and quality will be discussed. The effects of SAR on plants as found in the SAQWG4 are shown in **Table 4.5**

Table 4.5: Effects of SAR on foliar crop yield and quality

Concentration Range mg/L	Crop Yield and quality	
Target Water Quality Range	Should prevent the sodium toxicity from developing in plants sensitive to sodium, providing that irrigation water is applied to the soil surface (that is, crop foliage is not wetted), limiting sodium uptake through the roots.	Negligible risk Class 0
2 - 8	The most sodium-sensitive crops absorb toxic levels of sodium through roots (that is, crop foliage is not wetted). Crops vary in sensitivity	Risk to sensitive plants Class 1
8 - 15	Sodium-sensitive crops absorb toxic levels of sodium through roots (that is, crop foliage is not wetted). Crops vary in sensitivity	Risk to moderate sensitive plants Class 2
> 15	All sodium-sensitive crops absorb toxic levels of sodium through root uptake (that is, crop foliage is not wetted) when crop foliage is wetted). Crops that are more tolerant of sodium increasingly absorb toxic concentrations of sodium through root uptake. A number of economically important crops can be irrigated without developing sodium toxicity.	Risk to moderate tolerant plants Class 3

From the results it appears that SAR of greywater may under certain conditions exceed the safe concentration ranges for crops that are prescribed by SAWQG4. However, it should be noted that sensitivity of crops is also dependent on the prevalent soil conditions, and that both SAR and EC (or TDS) have an effect on soil permeability, soil hydraulic conductivity and hard-setting. In the case of SAR, greywater should be regarded as a Class 3 water.

Chloride

Chloride is the anion of the element chlorine, but chlorine does not occur in nature and is found only as chloride. The chlorides of sodium, potassium, calcium and magnesium are highly soluble in water.

The chloride concentrations are presented in **Figure 4.6**.

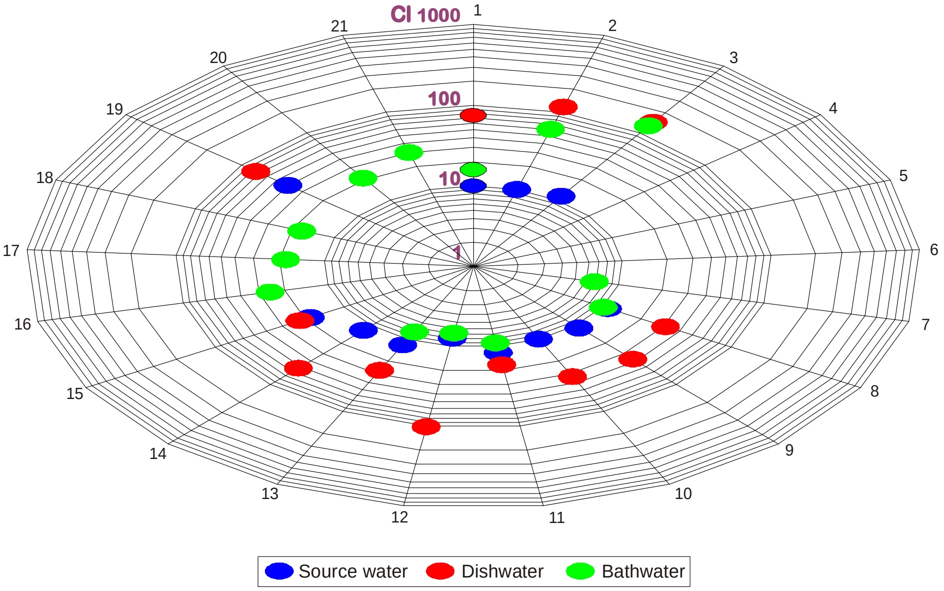


Figure 4.6: Chloride in sampled greywater

The chloride concentration range in the different waters from the 18 individuals (1st column) and from the literature (2nd column) is shown below. The 3rd column shows the concentrations where all three samples were collected by the same participant although all three have the same social and economic setting. The 4th column shows the bathwater concentrations from three participants from the same area but with different culture and economic settings.

source water	7.9 - 18	31 - 49	10	10	11	16s bathwater	25
dishwater	17 - 144	48 - 102	75	117	144	17s bathwater	18
bathwater	6.8 - 127	3.1 - 18	16	60	127	18s bathwater	17

From the results it appears that sodium in greywater may exceed the TWQR, but will only be toxic to sensitive plants. In the case of chloride, greywater should be seen as a Class 2 water

The effects of chloride on plants are shown in **Table 4.6**.

Table 4.6: Effects of chloride on foliar crop yield and quality

Concentration Range mg/L	Crop Yield and quality	
Target Water Quality Range	Should prevent the accumulation of chloride to toxic levels in all but the most sensitive plants, even when chloride uptake is through foliar absorption, that is crop foliage is wetted	Negligible risk Class 0
< 140	Should prevent the accumulation of chloride to toxic levels in all but the most sensitive plants, when chloride uptake is through root absorption, that is, water is applied to the soil surface, thereby excluding wetting of crop foliage	Negligible risk Class 0
140 - 175	Only slight problems with the accumulation of chloride to levels toxic to crops can be expected when chloride uptake is through root absorption, that is, water is applied to the soil surface, thereby excluding wetting of crop foliage	Risk to sensitive plants Class 1
100 - 175	Crops sensitive to foliar absorption accumulate toxic levels of sodium when crop foliage is wetted. They display symptoms of foliar injury and yield decrease	
175 - 350	Some problems with the accumulation of chloride to levels toxic to crops can be expected when chloride uptake is through root absorption, that is, water is applied to the soil surface, thereby excluding wetting of crop foliage Crops moderate sensitive to foliar absorption accumulate toxic levels of sodium when crop foliage is wetted. They display symptoms of foliar injury and yield decrease	Risk to moderate sensitive plants Class 2
350 - 700	All moderate sensitive and most moderately tolerant crops accumulate chloride to levels toxic to crops can be expected when chloride uptake is through root absorption, that is, water is applied to the soil surface, thereby excluding wetting of crop foliage Crops moderate tolerant to foliar absorption increasingly accumulate toxic levels of sodium when crop foliage is wetted. They display symptoms of foliar injury and yield decreases	Risk to moderate tolerant plants Class 3
> 700	Increasing problems with the accumulation of chloride to levels toxic to crops can be expected when chloride uptake is through root absorption, that is, water is applied to the soil surface, thereby excluding wetting of crop foliage Crops tolerant to foliar absorption increasingly accumulate toxic levels of sodium when crop foliage is wetted. They display symptoms of foliar injury and yield decreases	Risk to tolerant plants Class 4

Total dissolved Solids & Electrical Conductivity

The total dissolved solids (TDS) are a measure of the quantity of various inorganic salts that are dissolved in water. The TDS is directly proportional to the electrical conductivity (EC). EC is a measure of the ability of water to conduct an electrical current. This ability is a result of the presence of ions in water such as carbonate, bicarbonate, chloride, sulphate, nitrate, sodium, potassium, calcium and magnesium, all which carry an electrical charge. Most organic compounds dissolved in water do not dissociate into ions and consequently do not effect the EC.

The EC are presented in **Figure 4.7**

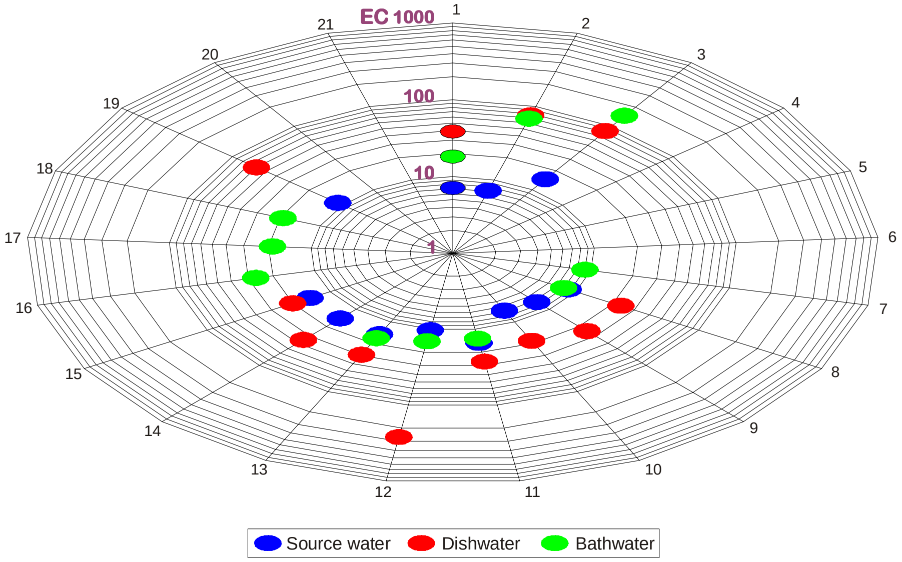


Figure 4.7: EC in sampled greywater

The EC concentration range in the different waters from the 18 individuals (1st column) and from the literature (2nd column) is shown below. The 3rd column shows the concentrations where all three samples were collected by the same participant although all three have the same social and economic setting. The 4th column shows the bathwater concentrations from three participants from the same area but with different culture and economic settings.

source water	7 - 15	10 -12	7	7	15	16s bathwater	27
dishwater	19 - 265	38 -82	39	76	83	17s bathwater	19
bathwater	8 - 145	-	18	68	145	18s bathwater	19

The effects of electrical conductivity on plants are shown in **Table 4.7**. From the results it appears that EC/TDS of greywater may exceed the TWQR and that the effect may be detrimental. In the case of TDS and EC, greywater should be regarded as Class 2 water.

Table 4.7: Effects of electrical conductivity on foliar crop yield and quality

Concentration Range mg/L	**Crop Yield and quality**	
Target Water Quality Range	Should ensure that salt-sensitive crops can be grown without yield decreases when using low frequency irrigation systems. A leaching fraction of up to 0.1 may be required and wetting of the foliage of sensitive crops should be avoided.	Negligible risk Class 0
40 - 90	A 95% relative yield of moderately salt-sensitive crops can be maintained by using a low-frequency irrigation system. .A leaching fraction of up to 0.1 may be required and wetting of the foliage of sensitive crops should be avoided.	95% relative yield Class 1
90 - 270	A 90% relative yield of moderately salt-sensitive crops can be maintained by using a low-frequency irrigation system. A leaching fraction of up to 0.15 may be required and wetting of the foliage of sensitive crops should be avoided.	90% relative yield Class 2
270 - 540	A 80% relative yield of moderately salt-sensitive crops can be maintained by using a low-frequency irrigation system. A leaching fraction of up to 0.2 may be required and wetting of the foliage of sensitive crops should be avoided.	80% relative yield Class 3
> 540	These waters can still be used for irrigation of selected crops providing sound irrigation management is practised and yield decreases are acceptable. However, the management and soil requirements become increasingly restrictive and the likelihood of sustainable irrigation decreases rapidly	Selected crops Class 4

Faecal coliforms

The faecal coliform counts are presented in **Figure 4.8**.

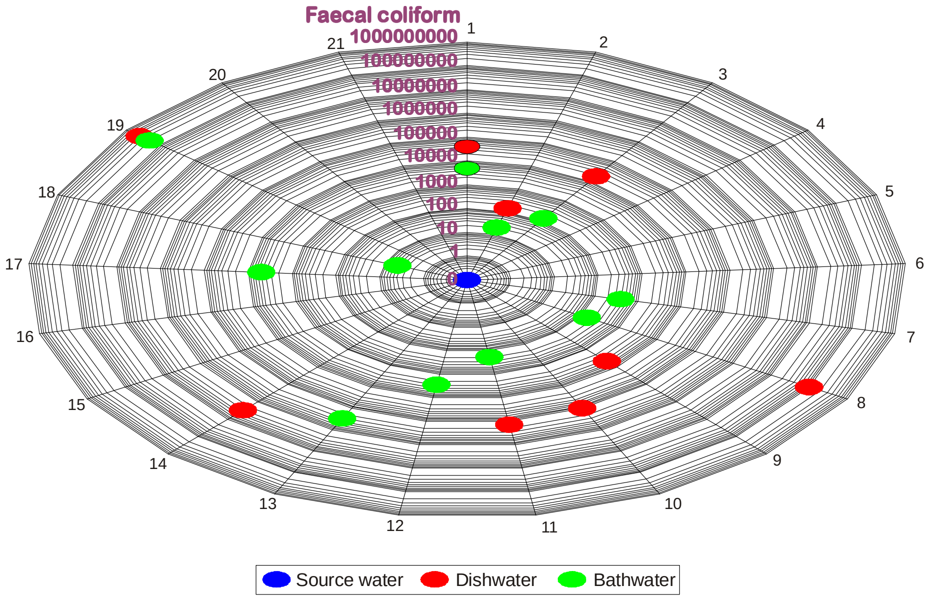


Figure 4.8: Faecal coliforms in sampled greywater

The range of faecal coliforms in the different waters from the 18 individuals (1st column) and from the literature (2nd column) is shown below. The 3rd column shows the concentrations where all three samples were collected by the same participant although all three have the same social and economic setting. The 4th column shows the bathwater concentrations from three participants from the same area but with different culture and economic settings.

source water	0	0	0	0	0	16s bathwater	0
dishwater	0 - 100000000	0 - 400000000	40000	20	17900	17s bathwater	5000
bathwater	0 -296000	0 - 200000000	4820	68	130	18s bathwater	5

The effects of bacteria on plants are shown in **Table 4.8**.

Table 4.8: Effects of faecal coliforms on crop quality

Concentration Range mg/L	**Crop Yield and quality**	
Target Water Quality Range	Irrigation water can be applied with any irrigation method to any crop with little likelihood that this will lead to the spread of human pathogens....	Negligible risk Class 0
1 - 1000	Likelihood of contamination from vegetables and other crops eaten raw and of milk from cows grazing on pastures will result in the transmission of human pathogens Fruit trees and grapes may be irrigated provided that the fruits are not wetted. Crops and pastures not consumed raw can be irrigated with any method provided crops and pastures are allowed to dry before harvesting or grazing.	Medium to high risk Class 3
> 1000	Provided water treatment quality is equivalent to or better than primary and secondary treated water, and that no contact is allowed to take place with humans, water can be used in irrigation for the production of fodder, tree plantations, nurseries, parks, etc.	High risk Class 4

From the results it appears that faecal coliforms and *Escherichia coli* numbers in greywater may exceed the TWQR and under certain conditions not be used in agriculture. With regards to bacterial numbers, greywater should be handled as polluted water and seen as a Class 4 water

Nitrogen (Inorganic)

Nitrogen, as used in SAWQG4, refers to all inorganic nitrogen forms present in water. Nitrogen in irrigation water is of concern because of:

plant growth is stimulated when applied in excess of requirements;
leaching to groundwater and contamination thereof;

- stimulation effect on all growth that interferes with flow, distribution and clogging of the irrigation system.

Only the effects of nitrogen on crop yield and quality and groundwater contamination will be addressed In this report.

The nitrogen concentrations are presented in **Figure 4.9**.

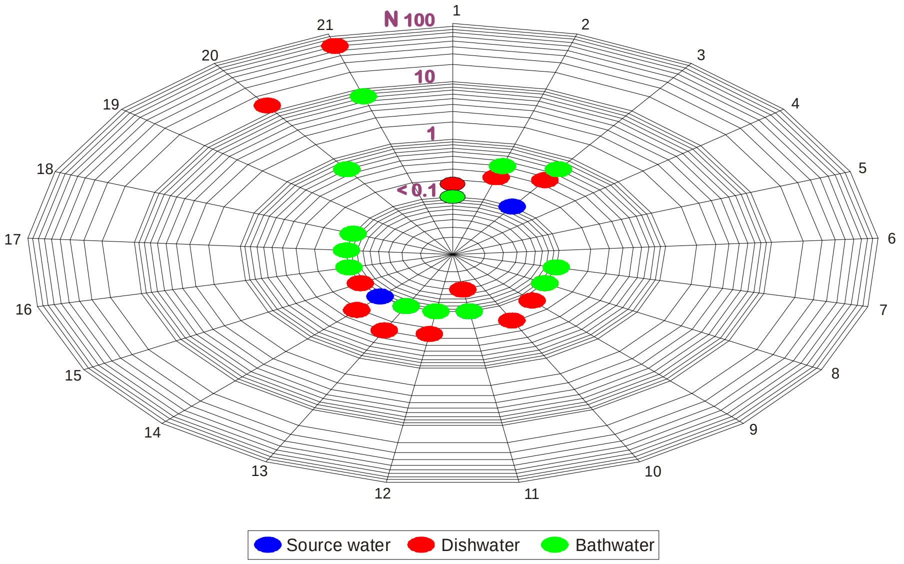


Figure 4.9: Nitrogen in sampled greywater

The nitrogen range in the different waters from the 18 individuals (1st column) and from the literature (2nd column) is shown below. The 3rd column shows the concentrations where all three samples were collected by the same participant although all three have the same social and economic setting. The 4th column shows the bathwater concentrations from three participants from the same area but with different culture and economic settings.

source water	<0.1 - 0.1	-	<0.1	<0.1	0.1	16s bathwater	<0.1
dishwater	<0.1 - 0.35	13 - 60	0.17	0.25	0.35	17s bathwater	<0.1
bathwater	<0.1 - 0.6	0.6 - 7.3	<0.1	0.4	0.6	18s bathwater	<0.1

The effects of nitrogen on plants as found in the SAQWG4 are shown in **Table 4.9**. From the results from the literature is appears that the nitrogen concentration in the dishwater can be detrimental to crop yield and that groundwater will be contaminated. Most of the anthropogenic activities of local communities for example, on-site sanitation, grouping of animals and waste water disposal lead to groundwater contamination (Tredoux, 2004). Greywater should be handled as a Class 4 water in the case of nitrogen.

Table 4.9: Effects of nitrogen on crop yield and quality and groundwater contamination

Concentration Range mg/L	Crop Yield and quality	Groundwater contamination	Class
Target Water Quality Range # 5	The unintended nitrogen application should, at normal irrigation applications, be low enough not to affect even sensitive crops such as grapes and most fruit trees...	The unintended nitrogen application should, at normal irrigation applications, be low enough so that most of it would be used by the irrigated crop and little be available for leaching to groundwater	Negligible risk Class 0
5 - 30	Sensitive crops increasingly likely to be affected (depending on magnitude of irrigation application). Other crops remain largely unaffected in the lower concentration range, but are increasingly affected as the concentration increases.	Likelihood of groundwater contamination increases, depending on actual volume of irrigation water applied and uptake by irrigated crop.	Medium to high risk Class 3
> 30	.Most crops are affected. A limited range of crops can use the nitrogen applied. Severe restrictions are placed on the use of these water	Increasingly serious likelihood of groundwater contamination	High risk Class 4

Fats, oils and Grease

The fats, oils and grease (FOG) results are presented in **Figure 4.10**.

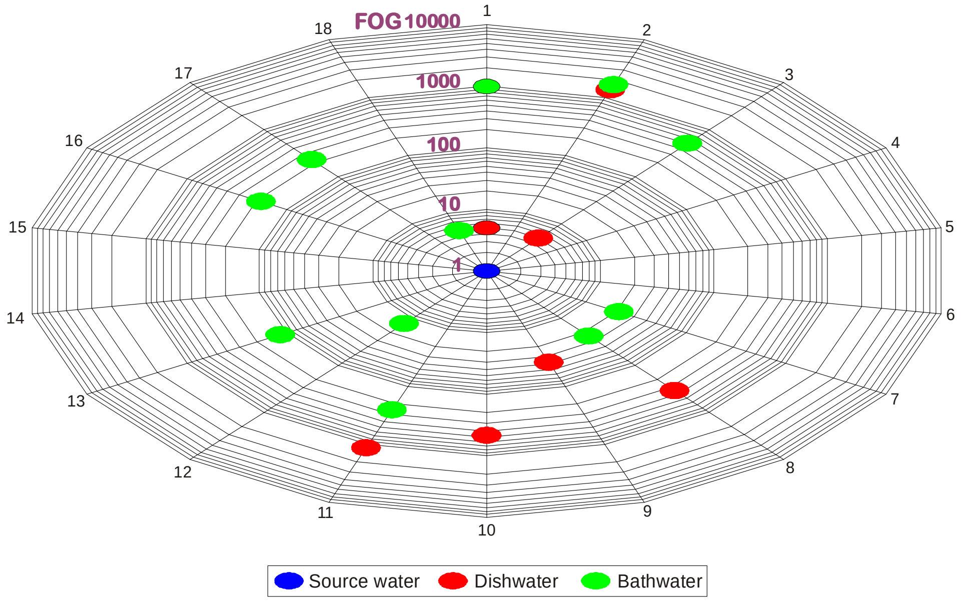


Figure 4.10: Fats, oils and grease in sampled greywater

The FOG range in the different waters from the 18 individuals (1^{st} column) is shown below. The

2nd column shows the concentrations where all three samples were collected by the same participant although all three have the same social and economic setting. The 3rd column shows the bathwater concentrations from three participants from the same area but with difference culture and economic setting.

source water	0	0	0	0	16s bathwater	182
dishwater	5 - 2741	5	1360	5	17s bathwater	228
bathwater	5 -1656	990	1656	510	18s bathwater	5

The fats, oils and grease in greywater are directly dependent on the user and will differ from all the time. Although, there are no fats, oils and grease guidelines in the South African Water Quality Guidelines, Volume 4 Agricultural Use (SAWQG4) of the Department of Water Affairs and Forestry (Department of Water Affairs and Forestry, 1996) this may create a problem.

Boron

The boron concentrations are presented in **Figure 4.11**.

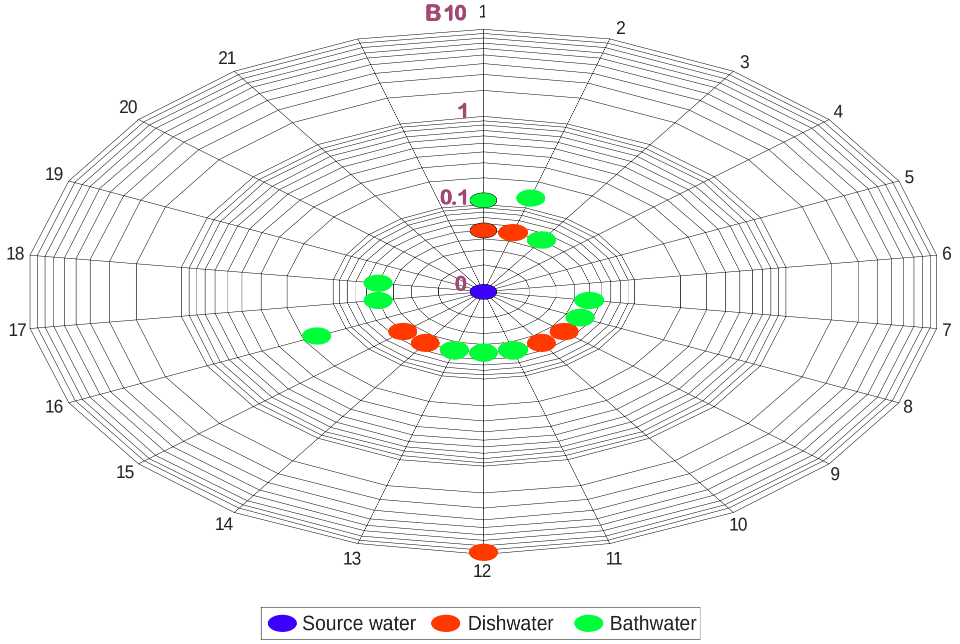


Figure 4.11: Boron in sampled greywater

The boron range in the different waters from the 18 individuals (1st column) is shown below. The 2nd column shows the concentrations where all three samples were collected by the same participant although all three have the same social and economic setting. The 3rd column shows the bathwater concentrations from three participants from the same area but with different culture and economic settings.

source water	<0.1	<0.1	<0.1	<0.1	16s bathwater	0.16
dishwater	<0.1 - 9.5	<0.1	<0.1	<0.1	17s bathwater	<0.1
bathwater	<0.1 – 0.16	0.11	0.13	<0.1	18s bathwater	<0.1

Boron is an essential plant nutrient in the Φg/L range, but becomes toxic to plant growth at higher concentrations (mg/L range). However, due to the fact that boron concentrations in the soil solution are largely buffered by sorption to and desorption from the soil, several seasons may be required before the effects of boron in irrigation water manifest in plant responses. The effects of boron on plants as found in the SAQWG4 are shown in **Table 4.10**.

Table 4.10: Effects of boron on crop yield and appearance

Concentration Range mg/L	Crop Yield and quality	Class
Target Water Quality Range 0.5	Should prevent the accumulation of boron to toxic levels (through root uptake) in all but most sensitive plants.	Negligible risk Class 0
6- 15	Crops tolerant to boron accumulate toxic levels through root uptake. They start to display symptoms of foliar injury and/or yield decreases.	Medium to high risk Class 3

All the measured boron concentration during this survey was below 0.5 mg/l except in one case where the dishwater was 9.5 mg/L. Therefore, greywater should be handled as a Class 3 water in the case of boron until proven otherwise.

4.2.4 Conclusions

This section reported the results of a preliminary greywater quality evaluation to compare the quality of different greywaters from different residential locations in the Cape peninsula area and with greywater quality as found in the literature.

The results show that there are significant differences in quality between the different types of greywater as well as between the different locations where greywater is produced. The concentrations as found in the literature are similar to the results from this study. Only in the case of nitrogen were higher concentrations found in the other studies.

The detrimental change in quality from source water to greywater is in a sense understandable except for the high faecal bacteria in dishwater. In the latter case, it is possible that contamination of the water from preparing foods and from washing used dishes and utensils can take place and that under certain conditions, bacterial growth in greywater can be extremely rapid.

It is obvious that the quality of greywater, in relation to the South African Water Quality Guidelines, Volume 4 Agricultural Use (SAWQG4) of the Department of Water Affairs and Forestry, is such that greywater should not be used for unrestricted crop irrigation. However, this is not the main consideration of this greywater study and should not be, in the end, the controlling factor. With enough information, knowledge sharing, good management and control, “fresh” greywater may be successfully used for agricultural purposes.

4.3 Eastern Cape social study

4.3.1 Introduction

A social survey was conducted of individuals in 9 towns and villages in the Eastern Cape and one town in KwaZulu-Natal by researchers from the University of Cape Town. The questions asked relate to various aspects of water supply and greywater disposal and greywater reuse, at household level. Their responses were compared to results of a greywater reuse survey conducted in residential areas in various counties around Tucson, Arizona to determine what the similarities and differences were, and whether relevant issues relating to the use of greywater for irrigating plants were being identified.

4.3.2 Methodology

Researchers from the Department of Environmental and Geographical Science, University of Cape Town, questioned 44 residents in the following Eastern Cape towns and villages: Orange Grove, Fort Grey, Silvertown, Queenstown, Idytywa, Phakamisa, Mpathi, Emahobemi, Bongweni, and the town of Zolani in KwaZulu-Natal. These are relatively poor communities, most of whom do not have ready access to reticulated fresh water and none of whom are serviced by a sewer system.

Although the questions asked of the residents concerned the potential impact of greywater disposal in unsewered communities, some questions related to the reuse of greywater, and for this study, the latter data was used to help identify perceived benefits and threats of using greywater for irrigating plants by poor communities, some of whom do not have ready access to reticulated fresh water and are not serviced by a sewer system.

Twenty-eight issues were considered in the survey for greywater disposal. Of these, about six issues have potential relevancy for greywater use for irrigating plants:

- ☐ Distance from house to water point / time taken fetching water per day / daily water use per household;
- ☐ The brands of soaps, detergents, etc. used;
- ☐ What is done with first-use greywater
- ☐ Respondents view on potential usefulness of greywater recycling
- ☐ Respondents view on perceived health problems of greywater in the community;
- ☐ Respondents view on potential solutions to the problems associated with greywater disposal.

Responses to the last four issues have been assessed in the current study, in terms of identifying potential requirements for increasing the demand for greywater use for irrigating plants.

4.3.3 Conclusions

Survey participants' households use, on average, between 20 to 150 L per day of water. Sanitation systems consist of pit latrines in most cases, in some cases no sanitation system exists at all, and in one case "other" was used to describe the sanitation system. In all except possibly three cases, greywater is thrown outside the house onto the ground, into a gulley, or into a pit latrine.

Thirty seven (84 percent) of the survey participants indicated they do not reuse greywater. Reasons offered for this are reported in **Table 4.10**. According to survey responses to perceived problems with discarded greywater, the problems most community members associate with discarded stagnant greywater are smells, dirt (muck), dissolved chemicals/salts, mosquitoes and poor health. These problems are perceived by 26 (65 %) of the 40 negative responses to be relevant to discarded greywater, and therefore could be motivating factors for the reasons given for not using greywater to irrigate plants or for washing purposes. Other reasons for not using greywater to irrigate plants are "don't know how." and "need info/assistance" (28 % of the negative responses). This suggests that if these respondents were to be advised on safe ways to use greywater for irrigating plants, then such greywater use could increase considerably.

Table 4.11: Reasons offered for not re-using greywater

Reason	**Local study (Greywater reuse for washing, irrigation)**		**Tucson, Arizona study (Greywater for irrigation, composting, other)**	
	Number of responses	**% of negative responses**	**Number of responses**	**% of negative responses**
don't know how; need info./ assistance	11	28%	257	36%
not worth the effort; not enough time; not worth the cost Admit need to recycle (but not doing it).	2	5%	171	24 %
water not near use	0	0	67	9 %
no worthwhile use for the water	1	2%	94	13 %
water is too salty /has chemicals	10	25%	42	6 %
too dirty/ too smelly not sure if safe/ sanitary	14	35%	88	12 %
brings mosquitoes	2	5%		
Other				
Total	40	100%	707	100%

Of the 44 survey participants, seven (16 %) reported re-using their greywater. Five of the latter reported re-using high-quality greywater for further washing purposes, and two reported using greywater for watering their grass. It is not clear whether greywater reuse is on a regular basis or only when water supplies are severely restricted.

These results can be compared with results of a postal survey of residents in the area of Tucson, Arizona (Water Conservation Alliance of Southern Arizona, 2004a). Of the 581 respondents, 49 (8.5 %) reported that they reuse greywater. Of these, all reported that they use their greywater for irrigating plants (compared with 4 % in the Eastern Cape study). Fourteen percent of these (i.e. 1.2 % of all respondents) use greywater for irrigating grass. The rest (84 % of these) use greywater mostly for watering shrubs, trees, vegetables and herbs. Nine percent of these reported irrigating fruit and nut trees, while four percent reported irrigating vegetables and herbs.

The remaining 532 respondents in the Arizona study indicated that they do not use greywater for irrigating plants, and 707 reasons were given for this. Reasons offered for this are presented in **Table 4.11**.

The top reasons for not using greywater for irrigating plants are:

- "too dirty/ smelly/ salty"; has chemicals"; "not sure if safe/ sanitary" (60% Local study; 18% Arizona study);
- "don't know how"; "need info./assistance" (26% Local study; 36 % Arizona study);
- "not worth the effort", "not enough time" and "not worth the cost" (5% Local study; 24 % Arizona study);

These suggest that if respondents from the Eastern Cape and Arizona studies were to be advised on safe ways to reuse greywater beneficially, and if there was some form of motivation (e.g. increased cost of water supplies), then greywater use for irrigating plants could increase significantly. The largest difference between the two groups of respondents relates to the apathy of a large number (24%) of the Arizona respondents, who responded that using greywater for watering plants was not worth doing. Perhaps the reason for the apathy is due to past experiences of high costs, lack of success, and low benefits in reusing greywater, either due to failure of greywater systems, the installation of costly sophisticated systems that did not return the benefits expected, the inability to retrieve greywater from existing plumbing systems and/ or the lack of available expertise (Ludwig 2004 a, b). Such apathy could occur amongst South African homeowners who have piped water supplies to their homes, and who buy inappropriate greywater reuse kits and services, or who have negative experiences concerning past attempts at greywater irrigation.

4.4 Treated sewage wastewater

4.4.1 Introduction

In terms of enteric pathogen indicator characteristics, greywater quality lies between that of raw sewage wastewater and secondary treated sewage wastewater (Casanova et al., 2001; Alcock, 2002; Gleeson and Gray, 1997). In terms of inorganic chemical constituents, the quality of greywater is somewhat similar to that of sewage wastewater, although it may have higher sodium concentrations. Extensive research results and practical experience exist on the use of treated sewage wastewater for agricultural purposes. Much of this information is pertinent also for greywater irrigation, especially in terms of health risk and the potential impact of inorganic chemical constituents on crops and soils (Alcock, 2002; Pettigrove et al, 1984). Several land and soil management practices designed to help overcome salinity, sodicity, toxicity and health hazards potentially associated with the use of treated sewage wastewater, could also be adopted for use with greywater irrigation. Thus it is recommended that sections of existing guidelines on treated sewage wastewater for irrigation be also applied to greywater use for irrigation (Alcock, 2002). This could also reveal to what extent and in what way future proposed guidelines for greywater use in agriculture may be combined with existing South African legislation on sewage wastewater use for agriculture. It therefore also makes sense to investigate the usage of sewage wastewater for irrigating crops in South Africa, where this can shed light on the acceptability and constraints of re-using greywater for such purposes.

In order to test the feasibility of using greywater for irrigation, a pilot investigation into the use of treated sewage wastewater in the Western Cape was initiated. The main objective of this investigation was to gauge the level of treated sewage wastewater use for irrigation purposes in the Western Cape in addition to helping municipalities to use their treated wastewater more efficiently while conserving water which is a scarce commodity. It is believed that the use of treated sewage wastewater for agricultural irrigation will significantly augment current water supply sources.

4.4.2 Methodology

The project was divided into two phases. Phase I comprised a questionnaire sent out to 24 local municipalities in the Western Cape gauging the percentage of sewage wastewater reuse in the various municipal regions and how the lack of an explicit sewage wastewater reuse policy affects their wastewater reuse efforts. Fifteen municipalities responded to the questionnaires. Between 0% and 80% wastewater reuse were reported and 12 out of the fifteen municipalities agreed that there is further potential for wastewater reuse.

Phase II comprised follow-up meetings to the municipalities that responded on the questionnaire. The Wastewater Treatment and Reuse Group of CSIR managed to meet with nine of the fifteen municipalities. It was found that most of the municipalities are already making use of their treated sewage wastewater. No social or religious objections towards the use of treated sewage wastewater for irrigation purposes were encountered. Even though the municipalities are keen to use their treated wastewater for irrigation purposes, the major obstacle identified was the capital outlay for the required infrastructure. In instances where treated sewage wastewater is being used, the end-users approached the municipality for the use of treated wastewater and generally provided the infrastructure required for the water supply to the preferred location.

4.4.3 Conclusions

The questionnaire sent out to the municipalities was not entirely effective in collecting accurate information on the level of sewage wastewater use in the municipalities and how the lack of an explicit wastewater reuse policy affects wastewater reuse in the various municipal areas.

The municipalities and the public were not found to be averse to wastewater reuse, since the reuse of treated sewage wastewater was not a new initiative to most of the municipalities. Social and religious issues are not hampering wastewater reuse initiatives.

The municipalities are practicing treated wastewater use for irrigation in collaboration with the Department of Water Affairs and Forestry. Every opportunity for such use is considered on merit and following appropriate measures with the Department of Water Affairs and Forestry.
The lack of an explicit sewage wastewater reuse policy has not hampered treated wastewater use for irrigation purposes in areas where it has been done successfully. Where treated sewage wastewater irrigation is being practised, no cases of related illness have been reported.

Treated wastewater is used in the Western Cape Province to irrigate crops which include wheat and Lucerne and for grassed fields such as those at sports facilities.

End-users, including farmers and golf course developers, are willing to use treated sewage wastewater provided that the water quality meets the requirements for its intended use. In some cases they are willing to provide the capital outlay for the infrastructure to transport the treated wastewater to the identified area of use.

CHAPTER 5

5 Impacts, mitigation measures and guidelines

5.1 Potential positive and negative impacts

5.1.1 Introduction

Greywater generation, along with other forms of wastewater generation, can have a potential environmental impact at local and regional/national levels and can have both short term and long term consequences (Pettigrove *et al*, 1984; Shuval *et al*, 1986). Greywater irrigation for crop growth purposes is seen as a way to reduce demand for fresh water, to save costs associated with water and fertilizer use, and to some extent, to save costs on wastewater (sewage) treatment (vegetated soil acts as a natural treatment medium) (Shuval *et al*, 1986; Pettygrove et al, 1984; Ludwig, 2004a; Bouwer, 1985).

5.1.2 Regional and national level impacts

Municipal sewage consists of industrial effluents, blackwater (toilet water) and greywater. Sewage is considered to present too great a hazard for direct irrigation of crops, and it requires treatment to remove pathogens, organic particles, trace elements and nutrients prior to disposal or use in irrigation (Metcalf and Eddy, 1991; Crook, 1984; Eckenfelder, 1989). Greywater from the laundry and the bathroom is considered to be equivalent to secondary treated sewage wastewater in terms of pathogen content (Jeppeson and Solley, 1994; Casanova *et al*, 2001). Greywater irrigation management for salinity and sodicity control should be very similar to that applicable for treated sewage wastewater irrigation (Oster and Roades, 1984) which in turn is similar to irrigation management of saline and sodic irrigation waters (Pettigrove *et al*, 1984). Thus the Department of Water Affairs and Forestry guidelines for irrigation with water containing dissolved salts (Department of Water Affairs and Forestry, 1996) should be applicable for greywater irrigation management. References to the impact of treated sewage wastewater on the environment in the following discussion should also apply in many respects to greywater.

Sewage wastewater treatment is required in order to reduce the impact of sewage wastewater on human health, on aquatic ecosystems and on downstream users of water resources that receive treated wastewater (Metcalf and Eddy, 1991). Although modern sewage wastewater treatment plants are able to remove nutrients, pathogens, suspended solids, most organic contaminants and most trace elements, they are generally not able to remove highly soluble salts such as sodium and chlorides (Metcalf and Eddy, 1991) that present difficult-to-resolve problems for soils, crops and water resources, especially over the longer term (Thompson, 1985). It is therefore hypothesized that the greatest negative impact of discharge of treated sewage wastewater on water resources at a regional level and over the longer term is presented by salinity. This should also be true of greywater where it forms a component of sewage. The removal of the greywater component from sewage therefore represents a positive, albeit small, impact in this regard.

An increase in salinity of water resources will generally have an increased negative impact on water resource users. In the case of rivers during drier periods, increases in river water salinity are dependent on the number and kinds of users as the water travels downstream. For example, dissolved salts in wastewater, discharged to a river, will cause the salinity of the river water to increase, and hence will have a negative impact on river-dependent ecosystems and on downstream (human) water users. Downstream users, including people who use river water to irrigate crops, in turn cause a further increase in river water salinity thus affecting users further downstream.

Users likely to contribute the smallest negative impact in terms of an increase in salinity of surface water resources are those at the coast, where the water ends up in estuaries or in the sea.

Dissolved salts in irrigation water applied to land are likely to build up to levels representing a significant negative impact to crops and soils unless the salts are regularly leached out. Salts leached out from irrigated soils will eventually reach aquifers or surface waters and contribute to an increase in salinity of water resources. Given the option of irrigating soils with greywater as opposed to discharging treated sewage wastewater to rivers, it seems likely that the irrigation option will contribute a lower additional salt load to surface water resources over the short term. Percolating saline irrigation water that enters high quality groundwater resources will increase the salinity of this groundwater, resulting in an impact of long duration. In the case of greywater irrigation, this impact is likely to be of small magnitude. High concentrations of dissolved sodium salts in irrigation water tend to contribute to soil sodicity, especially in clayey soils, and if not mitigated will result in long-term negative impacts.

The impact of an increased salt load on water resources will tend to be smaller at the coast than inland (Pettygrove *et al*, 1984; Murphy, 2000).

Irrigating with treated sewage wastewater in place of using municipal water supplies does not increase the net quantity of water available to a country for additional uses unless the wastewater would otherwise be irretrievably lost to the atmosphere or to the sea (Pettygrove et al, 1984). This should be true also for greywater irrigation, thus irrigating with greywater in areas close to the coast should increase the net quantity of water available to the country, in cases where the greywater would otherwise be lost to the sea.

To conclude:

- The problem of salinisation of surface water resources will not be made worse by irrigating crops with treated sewage wastewater or with greywater as opposed to direct discharge of treated wastewater to rivers.
- The salinisation threat to aquifers will be greater for wastewater/ greywater irrigation than if the treated sewage wastewater is discharged down rivers (assuming downstream users do not use the river water for irrigation purposes).
- Irrigating with greywater instead of with municipal supplies in areas close to the coast should increase the net quantity of water available to the country, in cases where the greywater would otherwise be lost to the sea.
- Perhaps the most relevant mitigation measure at a national level is to reduce greywater salinity at its source, whether greywater is used for irrigation or else is disposed to a sewerage system. The recommended approach is to replace and/or cut down the contribution of salts such as sodium and chlorides by washing powders (Patterson, 1997), soaps and condiments to greywater. This would most probably require an educational and promotional drive, involving detergent producers and municipalities, with the aim of stimulating detergent manufacturers to market biocompatible detergents and soaps in South Africa (many of these are available in other countries), and stimulating greywater producers to use biocompatible detergents and soaps.

5.1.3 Impacts at the municipal level.

At a municipal level, the overriding positive environmental impact of greywater reuse is the reduction in municipal demand for fresh water. There is a growing argument against the production of high quality potable water for purposes that do not require such high quality water (e.g. for toilet flushing and for the irrigation of garden plants) (Shuval *et al*, 1986).

At a municipal level, positive environmental impacts of irrigating with greywater include:

- ☐ A reduction in demand on municipal water supplies,
- ☐ a reduction in municipal wastewater treatment costs (soil and plants treat the greywater, thus saving on conventional treatment costs at sewage treatment plants) and
- ☐ a reduction in the urgency of sourcing new raw water supplies and of building new storage and water abstraction facilities.

For municipalities located at the coast, the negative impact of greywater irrigation is likely to be lower in terms of its effect on downstream users than for municipalities located further inland.

For a municipality overlying an aquifer: It is arguable as to whether greywater irrigation will have a significant impact in terms of organic contaminants or nutrients on an underlying aquifer that is more than 1,5 m below the ground surface, where overlying soils do not consist of sands or gravels, although a long term deterioration in quality of high quality aquifers is possible (Alcock, 2002; Morris et al, 2003; Californian Department of Water Resources, 1995; Little, V.L. 2001b; Ludwig, 2004a). Where irrigated areas over-lie unprotected high-quality aquifers, the long-term salinisation threat to such aquifers will be greater for greywater irrigation than if the greywater is treated and discharged down rivers (assuming downstream users do not use the river water for irrigation in areas that over-lie high-quality aquifers). The salinisation threat to a high-quality aquifer from greywater irrigation is unlikely to be significantly higher than that from freshwater irrigation, for similar volumes: So if a switch from freshwater to greywater irrigation is made, then the relative salinisation threat may not be large. Other contamination threats relevant for greywater irrigation relate to nitrates and certain other chemicals in greywater that are mobile in soils, and which could contaminate groundwater (Tredoux, 2004). The threat would depend on factors such as the volume and quality of greywater that is irrigated, the quality of groundwater in the underlying aquifer, whether the aquifer is confined (covered by impervious geological strata) or not, the permeability of underlying soil layers and the soil layer slope, etc.

Municipal sewerage systems

Removal of all the greywater at source from domestic sewage could result in about a 40% reduction in domestic sewage flows (City of Cape Town, 2005). Taking Arizona as an example, potential greywater usage for irrigation may represent up to about 10 % of domestic greywater production volumes for some arid countries (Water Conservation Alliance of Southern Arizona, 2004b), or about 5% of domestic sewage volume.

For flat-gradient networks, a reduction in sewage volumes results in reduced flow velocities and in shallow flows, leading to an increase in the frequency of blockages. Blockages and reduced flow velocities result in longer transport times for sewage, leading to an increase in anoxic/ anaerobic conditions further downstream in the sewerage network, resulting in the production of hazardous, odorous and corrosive sulphur compounds. This in turn leads to odour problems at pump stations and at sewage works and leads to accelerated deterioration of sewer networks due to attack on cementitious material by sulphide compounds (Metcalf and Eddy, 1991). A reduction of less than 5% (or even 10 %) of total sewage volume is highly unlikely to have a significant affect in terms of the above, unless this volume reduction occurs during times of very low sewage flows.

5.1.4 Impacts at the household level.

Feachem *et. al* (1981) conclude that the use of household greywater for watering private vegetable gardens is likely to create few, if any health problems, provided that stagnant pools do not form and that hygiene standards are upheld. Greywater irrigation for crop growth purposes is seen as a way to save costs associated with water and fertilizer use, at a household level.

Greywater generation, along with other forms of wastewater generation, can have a potential environmental impact at local and regional/national levels and can have both short term and long term consequences.

- Irrigation with greywater instead of with municipal supplies in areas close to the coast should increase the net quantity of water available to the country, in cases where the greywater would otherwise be lost to the sea.
- Greywater supplies plant nutrients thus saving on fertilizers.
- Greywater irrigation in home gardens is seen as a way to reduce regional demand for fresh water.
- It helps to prevent overloading and improves the treatment efficiency of a septic tank sewage treatment system if one is installed at a dwelling.
- Greywater with a sufficient concentration of certain types of soap kills or weakens certain garden pests and helps prevent damage to vegetables caused by specific plant diseases (Alcock, 2002; Lindgren et al, 1999);
- In times of water scarcity, greywater could provide the only water resource available for growing subsistence crops for poor households.

Negative impacts

Potentially major negative environmental impacts of greywater irrigation are related to the relatively high concentration of sodium ions in relation to other chemical ions in greywater from clothes washing activities and to the pathogen, organic solids, and fat content of greywater from dishwashing and food preparation activities (kitchen greywater).

The potential negative effects of high pH, high sodium, and to some extent raised chloride and boron concentrations in greywater used for irrigation, on crop growth / yields and on soils may be determined from the following statements derived from irrigation guidelines:

- High sodium, chloride and boron concentrations are toxic to crops on uptake through roots and (especially) leaves;
- High salinity (high concentrations of dissolved salts such as sodium, chlorides and sulphates) reduces crop yield, and can have a negative effect on the quality of harvested fruit;
- High soil pH reduces the bio-availability of certain plant micro-nutrients and has a potential negative effect on growth/health of many crops;
- High sodium concentrations can cause a reduction in soil infiltration rate, in soil hydraulic conductivity and can cause hard-setting when the soil dries out. (Depends on SAR / EC ratio of irrigation water/ soil water – See **Appendix A**);

Problems can occur when rainfall (by itself) is relied upon to leach out sodium ions from "sodic" soils, as rainfall increases the ratio SAR / EC at the soil surface and so reduces its permeability (Foster *et al*, 2000). Also, raindrops mechanically help break down the surface soil structure, forming a sealing affect, and thus causing increased runoff and erosion. (For the discussion on SAR, ESP and ESP / EC ratios, see Item 1.2 in Appendix A.)

Other potential negative impacts or risks related to the pathogen, organic solids, and fat content of greywater include:

- Irrigation with kitchen greywater presents potentially significant health risks, unless it is treated prior to irrigation. This treatment requires careful management.
- Irrigation with greywater that contains faeces from washed nappies, or where persons with infectious gastro-enteric diseases form part of the household, represents a potentially significant health risk.
- Soil pores can become clogged by grease and suspended solids, and as a result, plant roots can suffocate.
- If improperly managed, greywater irrigation areas can become sources of public

nuisance, with the development of nuisance conditions such as insect breeding, odours, unsightly discolouration, etc.

- ❑ If stored for longer than 24 hours, greywater can represent an increased health risk, and become a source of public nuisance in terms of insect breeding and odour generation.

The above represents a long list of potential negative impacts (environmental costs) associated with greywater use.

The costs of reusing greywater need to be also balanced against the costs of not reusing greywater, especially in the case of unsewered communities, where the environmental costs of disposing greywater indiscriminately are higher than the costs of reusing the greywater for beneficial purposes.

The magnitude of the longer-term salinity impact on high quality aquifers needs to be considered in the light of the small volumes of greywater likely to be used for irrigation, when compared with the high volumes of water from other sources currently used for irrigation. The total salt load contributed to high-quality aquifers by the latter is likely to be orders of magnitude larger than that contributed by future greywater irrigation.

5.2 Interim guidelines

In the arid and water-stressed countries of the world, water conservation and wastewater reuse receive a lot of attention. Many large scale wastewater reuse schemes have been initiated in the drier parts of the U.S.A., in Israel, the Arab nations, Australia, and also in South Africa (Asano, 1998). On a smaller scale, greywater is potentially suitable for recycling in and around the home, thus allowing individuals other ways of saving water supply costs beside in-house water conservation measures. Individuals need, however, to understand how to safely and effectively use greywater. Amongst the aspects a householder needs to know in order to successfully reuse greywater are:

- ❑ how much greywater is available to be used and from which source?
- ❑ what areas of land can the greywater from alternative sources irrigate?
- ❑ what crops/plants can be safely irrigated?
- ❑ what treatment / management measures should be applied?
- ❑ what laws and regulations are applicable?

Some suggested answers to the above follow:

In order of preference, use

1. bathroom greywater,
2. laundry greywater (preferably use only rinse-wash water),
3. kitchen greywater (preferably use only rinse water).

Estimate the volume of greywater produced per source per day:

- ☐ A bath uses between 60 L (shallow) and 180 L (deep). A shower uses between 6 and 19 litres per minute.
- ☐ Laundry: between 20 to 80 litres per 3 kg load.
- ☐ Dishwashing: Approximately 18 litres per basin.

For preliminary planning purposes, assume that 10 litres of greywater will irrigate the following areas of land per day:

- about 1 m^2 in arid (dry) summertime conditions
- about 2 m^2 in sub-humid summertime conditions
- about 3.3 m^2 in humid summertime conditions.

Calculate the area of land that can be irrigated using each greywater source.

- ☐ Determine whether the area of land required is available and accessible for irrigating with greywater from each source, and that the soils are suitable.
- ☐ Select crops/ plants that can be grown in the area, and that are not sensitive to the concentration levels of dissolved salts in the greywater from the source used for irrigation (See **Appendix A**), and are not sensitive to medium-to-high pH irrigation water.
- ☐ Determine what management measures and what regulations (municipal bye-laws) may be applicable for greywater irrigation.

If a decision to proceed with greywater irrigation is to be made, then more detailed information should be sought on irrigation system design, on selection and care of suitable plants, on site management, and other aspects. Ludwig (2004a) has produced useful guidelines on choosing, building and using greywater irrigation systems. The Department of Water Affairs and Forestry (1996) has produced irrigation water guidelines for agriculture that are considered applicable for greywater irrigation from the perspective of salinity, sodicity, SAR, boron, pH and other chemical determinants, in terms of the impact on crops and soils. Potentially suitable crops as well as relevant ameliorative measures are also presented in the guidelines (The Department of Water Affairs and Forestry (1996). See **Appendix A** also for further details on the potential effects of irrigation with high SAR low EC greywater on soil physical properties, and management measures to minimize/reduce impacts on soils.

Guidelines specific to greywater sources and to potential problems are now presented.

If kitchen greywater is to be used for irrigation, then:

- ☐ Preferably only use rinse water for irrigation (Alcock, 2002), or
- ☐ Treat kitchen greywater using a grease and a sediment trap and a filter. Regarding the latter, a simple filter in the form of a nylon stocking may be sufficient. (Ludwig, 2004a; Center for the Study of the Built Environment, 2003); Irrigate subsurface only.
- ☐ Do not use greywater from an automatic dishwasher.

If clothes-wash greywater is to be used for irrigation, then:

- ☐ Use low sodium-content and zero-content boron detergents and soaps. (Patterson, 1997; Center for the Study of the Built Environment, 2003);
- ☐ Do not use fabric softeners in clothes-wash water - or else use less than is normally required. Alternatively use ones designed for clothes driers (Ludwig, 2004a);
- ☐ Change to a non-chlorine based bleach that does not contain enzymes (Ludwig, 2004a);
- ☐ Dilute "first-wash" greywater prior to irrigation, and allow hot washwater to cool down before irrigating plants with it (Alcock, 2002; Center for the Study of the Built Environment, 2003; Ludwig, 2004a);
- ☐ When irrigating with saline and high sodium concentration water (Department of Water Affairs and Forestry, 1996):
    - ☐ Choose sodium-tolerant, saline-tolerant and high-pH tolerant plants;
    - ☐ Use gypsum to mitigate infiltration problems;
    - ☐ Increase leaching fraction (and ensure there is adequate aeration of soils and subsoil drainage) OR Apply freshwater (with a little gypsum if necessary) alternately with greywater or directly with greywater;
    - ☐ Do not apply irrigation water to plant leaves.

- Ensure greywater does not pass through small orifices (< 5 mm) unless there is a filter present to remove lint, hair, and organic solids at the source. A simple filter in the form of a nylon stocking may be sufficient. (Ludwig, 2004b; Center for the Study of the Built Environment, 2003).
- Do not use high sodium content and very high pH detergents (liquid detergents are usually low in sodium). (Patterson, 1997; Ludwig, 2004a).
- Where possible, apply greywater to infiltration basins filled with organic mulch or compost (Ludwig, 2004b).
- Do not use a chlorine-based bleach or one that contains enzymes (Ludwig, 2004a).
- Dilute the greywater with low-sodium/ low boron content water prior to irrigation (Ludwig, 2004a) or else periodically leach the salts out of the irrigated soil (Department of Water Affairs and Forestry, 1996).

If bathroom greywater is to be used for irrigation, then:
For gravity feed greywater systems, ensure greywater does not pass through small orifices (< 5 mm) unless there is a filter present to remove lint, hair, and organic solids at the source. A simple filter in the form of a nylon stocking may be sufficient. (Ludwig, 2004b; Center for the Study of the Built Environment, 2003).

The following guidelines apply to greywater irrigation in general:

- When designing houses, ensure that greywater outlet pipes (washing machine, bath, shower, handbasin, kitchen sink) are kept separate until outside the house. (Center for the Study of the Built Environment, 2003);
- Simplify greywater irrigation by designing and using gravity-feed systems where feasible. Use a fine mesh screen to pre-treat greywater where irrigation is through small orifices, or the greywater is pumped. (Ludwig, 2004b);
- Ensure irrigated soils have adequate subsurface drainage;
- Never apply greywater to one place for long periods of time, and do not over-irrigate to cause ponding. (Alcock, 2002; Center for the Study of the Built Environment, 2003);
- Ensure the greywater irrigation system can be completely and easily drained if required (Center for the Study of the Built Environment, 2003; Ludwig, 2004a);
- Cover greywater storage tanks. (Center for the Study of the Built Environment, 2003);
- Ensure there is a simple greywater diversion facility to sewer or French drain, able to be easily applied when required (Center for the Study of the Built Environment, 2003;

Ludwig, 2004b);

- No possibility of back flow or cross-flow of greywater to potable water system should be allowed (Center for the Study of the Built Environment, 2003; Ludwig, 2004b);
- Avoid the need for a pump if and where possible - preferably use gravity feed;
- Preferably use not less than 2% continuous slope in all rigid lines. This also prevents airlocks. For single dwellings and where piping is used, the pipe diameter should preferably be 40 mm or 50 mm (Ludwig, 2004b) ;
- Do not allow greywater to exit the property on which it has been generated, except by sewer. (Center for the Study of the Built Environment, 2003);
- Ensure surges can be accommodated with a surge tank or mulch basin. (Center for the Study of the Built Environment, 2003; Ludwig, 2004a);
- Greywater should be irrigated as soon as possible (within 24 hours, but preferably within 12 hours) to help prevent offensive odours and growth of potentially pathogenic bacteria;
- The main human health risks arise from physical contact with the greywater, and from eating fruit or vegetables that have been irrigated with the greywater (Center for the Study of the Built Environment, 2003). One way to minimise human health risk is to eliminate contact between the householders and the greywater. For this reason, most sources recommend a greywater collection and distribution system that does not require regular user intervention. Irrigation, other than by subsurface drip irrigation, of lawns and other areas where children or animals may play generally is discouraged, also to reduce the chance of contact. (Center for the Study of the Built Environment, 2003);
- Spray irrigation of greywater could present a health hazard and therefore should be avoided except in areas where large buffer zones exist (Alcock, 2002);
- Do not use greywater contaminated with faeces for irrigating crops. Hence, do not allow animal and human faeces or other wastes to come into contact with greywater. In this context, do not allow wastes or faeces to collect in irrigation channels or depressions where greywater may collect;
- Greywater should not be directly applied to root crops or leafy vegetables that will be eaten raw, such as carrots, lettuce, or herbs, and it should not come in contact with the edible portion of fruits and vegetables (Center for the Study of the Built Environment, 2003). Edible parts of crops should be raised above the soil surface so that they will not touch the ground or become wet from greywater surface irrigation. Preferably, use only good quality rinse water to irrigate leaf crops and root crops (Alcock, 2002);

- Store or wash produce that has been in contact with greywater. Preferably lay the produce in full sunshine for a day (Alcock, 2002);
- Preferably cook produce well before eating. Produce eaten raw should be well washed with clean water before being eaten (Alcock, 2002);
- Do not allow people or animals access to recently irrigated soils;
- Surface irrigation of lawns where any humans or pets contact the grass, should not be allowed (Center for the Study of the Built Environment, 2003);
- Most authorities emphasize that the introduction into the greywater of pathogens from the washing of heavily soiled laundry and diapers, or of clothes with blood or vomit should be avoided, and that where there is a particularly infectious illness in the household (e.g. diarrhoea, hepatitis, measles or intestinal parasites), the greywater should be disposed of through the black water sewerage system and not reused. Also, large greywater storage containers may pose a safety hazard to children. Therefore, storage containers must be tightly covered to prevent easy access, and to keep away mosquitoes, other insects, and small rodents. (Center for the Study of the Built Environment, 2003; Ludwig, 2004a);
- Monitor crops for symptoms indicating plant health problems - which if sustained also suggests declining soil properties (Center for the Study of the Built Environment, 2003; Alcock, 2002; Ludwig, 2004a);
- If any signs of plant injury appear, use of greywater should be discontinued or reduced. 'Burning' of leaf edges may be caused by excess salts in the water. Acid-loving plants may experience some chlorosis or yellowing of the foliage, due to the alkaline nature of the greywater. If plants appear to be injured, the surrounding area should be flushed with freshwater. (Alcock, 2002; Center for the Study of the Built Environment, 2003; Department of Water Affairs and Forestry, 1996);
- Application of greywater should be rotated with fresh water for susceptible grasses and fruit trees. (Alcock, 2002; Center for the Study of the Built Environment, 2003; Ludwig, 2004a);
- Applying greywater to the same plants all the time should be avoided. Particular care should be taken with water containing detergents, bleach or boron, and the use of rinse water containing fabric softeners should be avoided whenever possible. (Center for the Study of the Built Environment, 2003; Ludwig, 2004a; Alcock, 2002);
- Applying the greywater directly to foliage or stems should be avoided. Greywater poured directly on the base of trees and shrubs is not recommended - preferably, apply greywater over the whole area where the root system is, and slightly away from the stem or trunk. (Center for the Study of the Built Environment, 2003; Ludwig,

2004a; Department of Water Affairs and Forestry, 1996);

- Greywater should only be used on well-established plants, not on seedlings or young plants as they are more sensitive to the impurities in the greywater. (Center for the Study of the Built Environment, 2003; Department of Water Affairs and Forestry, 1996);
- Crops that have a low sensitivity to sodium and boron in irrigation water should be selected for greywater irrigation (Department of Water Affairs and Forestry, 1996).
- Do not use greywater for irrigation if sodium-based water softeners are used in the home (Ludwig, 2004a);
- Irrigated soils with a pH of 7.5 or above may suggest that the soil has become overloaded with sodium. Add flowers of sulphur, ammonium-nitrate fertiliser or an organic mulch to help reduce the pH levels. If the soils have a high pH and are relatively impermeable, adding gypsum to soils should help increase permeability (Department of Water Affairs and Forestry, 1996);
- It is a general recommendation that mulches and/or compost be regularly added to the surface of soils irrigated with greywater (this helps reduce evaporation and to keep the pH of surface soils down) (Ludwig, 2004a; Department of Water Affairs and Forestry, 1996)
- Apply greywater to infiltration basins filled with organic mulch, and preferably don’t allow it to surface (i.e. pond) above the mulch (Ludwig, 2004a; Center for the Study of the Built Environment, 2003);
- For detailed crop-irrigation and soil management guidelines, the water quality guidelines for agriculture published by the Department of Water Affairs and Forestry for crop irrigation (1996) are recommended.

Guidelines on the selection of crops based on tolerance to sodium and boron in irrigation water

The sensitivity of crops to sodium as indicated by the UN FAO (Ayers and Wescott, 1985):

- "no problems" in terms of crop toxicity at sodium levels of < 69 mg/l;
- "increasing problems" at sodium levels of 69 - 207 mg/l; and
- "severe problems" at sodium levels of > 207 mg/l)

Crops sensitive to sodium (where uptake is through roots only), ordered according to sensitivity (most sensitive to less sensitive), are (Department of Water Affairs and Forestry, 1996):

- avocados; deciduous fruits; grapes; nuts; green beans; maize; peas; grapefruit;

oranges; peaches; tangerines; mung beans; mash beans; lentils; groundnuts and cowpeas

Less sensitive crops, ordered according to sensitivity, are:

- carrots; lettuce; sugar cane; onions; radish; sorghum; spinach; tomatoes and vetch.

Tomatoes and sorghum are examples of crops that are relatively tolerant to sodium and should be suitable for greywater irrigation taking into account the requirement that edible parts of a crop should not come into contact with greywater (for health reasons).

The sensitivity of crops to boron includes (Department of Water Affairs and Forestry, 1996) – (High boron concentrations are not usually a problem in greywater unless detergents or fabric softeners containing boron are used by the household.):

- Very sensitive - boron levels 0,5 mg/l - lemons;
- Sensitive - boron levels 0,5 to 1 mg/l - lemons; avocados; grapefruit; oranges; apricots; peaches; plums; kadota figs; grapes; onions; garlic; sweet potatoes; sunflowers; strawberries; Jerusalem artichokes; beans (various types) and peanuts;
- Moderately sensitive - boron levels of 1 to 2 mg/L - broccoli; red peppers; peas; carrots; radish; potatoes; cucumbers and lettuce;
- Moderately tolerant (2 - 4 mg/l): cabbages; turnips; barley; cowpeas; maize; artichokes; mustard; squashes and cauliflowers; Tolerant - boron levels of 4 to 6 mg/L - Lucerne; purple vetch; parsley; red beet and tomatoes;
- Very tolerant - boron levels of 6 to 15 mg/l - sorghum; celery and asparagus.

Constraints and concerns

- The greywater irrigation system should be as simple and easy to use and maintain as possible (Ludwig, 2004a; Center for the Study of the Built Environment, 2003);
- The greywater irrigation system should minimize risks to human health, either by providing for adequate treatment of the greywater, or by minimizing contact between the greywater and humans (and animals) (Center for the Study of the Built Environment, 2003; Ludwig, 2004a);
- Greywater should never be applied too long or excessively, at any time to one place in the garden, as this could promote negative impacts such as ponding, odours, insect breeding and other nuisances, as well as cause plant root death as result of anaerobic conditions in the soil (Alcock, 2002; Center for the Study of the Built

Environment, 2003; Ludwig, 2004a);

- Greywater should be prevented from entering a pit latrine or borehole: Greywater entering a pit latrine or borehole has the potential to contaminate groundwater.

Using pumps for irrigating with greywater:

In cases where suitable soils do not exist at a lower elevation than the greywater outlet, a pump may be needed so as to lead the greywater to the place where it can be used. The following issues then need to be considered (amongst others):

- A pump normally requires electricity, so an electrical connection is needed;
- A filter is usually required to remove hair, lint and organic solids that could clog pump impellers (Ludwig, 2004a);
- A sensor or switch is required that will automatically switch the pump on and off, dependent on water levels in the sump where the pump is situated (Ludwig, 2004a);
- Regular monitoring and cleaning of the filter, the pump and the sump is needed (Ludwig, 2004a).
- Washing machines have built-in pumps that could be used in certain situations to pump water to a higher elevation, so the use of greywater from a washing machine may be the best option to use when greywater irrigation is needed for ground at a higher elevation than the house floor level (Ludwig, 2004a).

Summary

A summary of specific guidelines follows:

- For newly designed houses, ensure that greywater outlet pipes (washing machine, bath, shower, handbasin, kitchen sink) are kept separate until outside the house.
- Use simple gravity-feed greywater irrigation systems where feasible.
- For greywater from the laundry and kitchen, preferably only use rinse water for irrigation
- For clothes-wash greywater, preferably use low sodium-content and zero-content boron detergents/ soaps and preferably do not use fabric softeners and chlorine-based bleaches.
- Do not use water softeners.
- For piped irrigation systems, preferably use at least a simple filter, such as a nylon stocking, where possible, and ensure the irrigation piping can be completely and easily drained. Cover any greywater storage tanks.
- For piped systems at dwellings connected to sewerage systems, ensure there is an

easy diversion facility to the sewerage system near or at the greywater source outlet.

- ☐ Do not allow greywater to exit the property on which it has been generated, except by sewer.
- ☐ Ensure surges can be accommodated in the greywater irrigation system (e.g.: use a surge tank or mulch basin).
- ☐ Do not store greywater for longer than 24 hours.
- ☐ Prevent spray irrigation of greywater.
- ☐ Use mulch and/or compost on the soil surface and in irrigation trenches to reduce evaporation and help prevent accidental contact with greywater, and ensure irrigated soils have adequate subsurface drainage.
- ☐ Preferably do not apply greywater to one place for long periods of time.
- ☐ Prevent the contact of greywater with edible parts of crops and preferably cook the produce well before eating. Do not apply greywater to crop foliage.
- ☐ Greywater containing particularly infectious pathogens should not be irrigated.
- ☐ Apply greywater only to mature crops. If any signs of plant injury appear, reduce or stop greywater irrigation of the plants in question, and flush the soils with freshwater.
- ☐ When irrigating with greywater and water that has high concentrations of dissolved salts:
  - ☐ Choose sodium-tolerant, saline-tolerant and high-pH tolerant plants.
  - ☐ Use gypsum to mitigate soil infiltration problems.
  - ☐ Increase the leaching fraction (and ensure there is adequate aeration of soils and subsoil drainage) OR Apply freshwater (with a little gypsum if necessary) alternately with greywater, OR rely on sufficient rainfall to leach the salts out (a little gypsum may be applied directly to the surface soils to stimulate percolation, if necessary).
  - ☐ Do not apply irrigation water to plant leaves.
  - ☐ For detailed crop-irrigation and soil management guidelines, use the water quality guidelines for agriculture published by the Department of Water Affairs and Forestry for crop irrigation (1996).

CHAPTER 6

6 Suggested Research Priorities

6.1 Introduction

A fair amount of information exists in the literature and other sources on greywater production and its use for irrigation of household gardens. This information relates mostly to middle-income Western-style households. There is still a significant lack of local knowledge relating to low-income households. Knowledge gaps relate to:

- Where greywater reuse for irrigating garden plants is an established practice, and where historically it was practised but is not any more, and the reasons for this.
- The proportion of household supply water used to irrigate garden plants (i) in normal times and when water restrictions are applied and (ii) in areas where water is expensive versus areas where water is relatively cheap.
- To what extent greywater can be used to supplement plant nutrient needs with, and without, contribution from organic mulches, and what the risk is of nitrogen overload.
- To what extent greywater acts as a pest deterrent for crops, dependent on greywater source and on types of detergents and soaps used.
- To what extent soil pore clogging effects of organic particles (including grease) affect infiltration.
- The chemical and microbial characteristics of greywater from poor households.
- What percentage of supply water becomes greywater for households (sewered and unsewered) in poor communities?
- To what extent perceptions of poor greywater quality, effort and cost factors, and other factors hinder greywater reuse for irrigation purposes amongst different communities, and to what extent other perceptions may promote greywater reuse.

Although significant knowledge gaps exist regarding greywater reuse especially amongst unsewered poor communities in South Africa, enough information is available to prepare preliminary greywater irrigation guidelines. Basic (draft) guidelines for greywater irrigation of household gardens are presented in this report. These need to be tested, modified, and incorporated into a protocol and a home found for them in terms of existing legislation.

Research needs have been identified from the knowledge gaps. These and other research needs have been categorised according to proposed priority and are presented in the following section.

6.2 Suggested research priorities

The following are some suggested research priorities, grouped according to priority:

High priority

- Test the basic (draft) guidelines for greywater irrigation of household gardens presented in this report, and modify them to account for South African conditions. The modified guidelines should take into account the type of grey water (bath water, laundry, etc.). Prepare a preliminary protocol to complement these guidelines and test (in consultation with authorities), with suitable institutions and with communities under different climatic and socio-economic conditions. Modify the guidelines so that they are contextualised to target different user groups (e.g. in terms of sewered versus unsewered communities; urban versus semi-rural communities; inland versus coastal areas, winter versus summer rainfall areas, arid versus humid areas, etc.).
- Legislation: Greywater irrigation is unlikely to benefit from the relaxation in requirements of the General Authorizations, seeing that greywater quality is unlikely to comply with at least one of the restrictions, specifically the one limiting the faecal coliform concentration restriction (See **Table 2.1a** and **Table 2.1b**). In conjunction with relevant authorities, review the current institutional and legal framework for use of greywater. Investigate where the protocol and guidelines (see previous item in this list of proposed research items) could find a home in terms of the legislation, and how the protocol/ guidelines could be organised into phases or components for application at national, regional and local levels. Investigate what existing legislation/ guidelines could be modified to facilitate controlled greywater irrigation, and how such changes could be implemented/ institutionalised.
- Perhaps the most important and feasible action for householders to do to improve laundry greywater for irrigation purposes (and for water recycling in general), is to use low-sodium detergents. Lists of “bio-compatible” (as opposed to “environmentally friendly”) detergents suitable for greywater irrigation purposes exist in the United States and Australia. A research priority is therefore

  (i) to investigate biocompatible detergents and soaps in terms of chemical content (specifically sodium, potassium, boron and chlorides), detergent function and potential impact on the environment and human health (in terms of chemical and microbial risks), and determine the likely improvement in greywater quality as

a result of using such detergents and soaps in South Africa,
(ii) to draw up a list of biocompatible detergents suitable for use in South Africa and (iii) identify potentially suitable ways of promoting the availability and use of such detergents.

- It is generally believed that domestic wastewater (including greywater) use for agricultural purposes will benefit a nation by freeing up higher quality water resources (Ludwig, 2004a; Center for the Study of the Built Environment, 2003), but at least one literature source indicates that it won't necessarily make an improvement to a nation's net water balance (Pettigrove et. al, 1984). Investigate this, taking into account water availability and suitability for use (volume and quality aspects, - the latter also addressing chemical and microbial risks) and taking into account the potential impact / mitigating effect of using biocompatible detergents.
- Obtain detailed chemical and microbial analyses of greywater from poor communities, and interpret the results in terms of risk to community health and suitability for irrigating specific garden crops, and identify relevant measures to reduce risk and promote sustainability.
- Modify the data obtained from overseas studies to take into account low volumes of available supply water resulting in lower volumes of greywater containing proportionally higher concentrations of microbes, dissolved salts and suspended particles. Compare these results with the results of the sample analyses of greywater produced by low income households. Discuss the relevance of using this approach. Research the impact of using biocompatible detergents on greywater quality (chemical and microbial) from low-income communities.
- Research what percentage of supply water becomes greywater for households in poor communities, both sewered and unsewered, for different categories of water supply service, during summer and winter, in wet seasons and in times of water shortage.
- Research the extent that perceptions of poor greywater quality, effort required, cost factors and other factors hinder greywater reuse for irrigation amongst different communities, and identify what beliefs or perceptions could promote greywater reuse.
- Investigate the proportion of household supply water used to irrigate garden plants
    (i) in normal times and when water restrictions are applied and
    (ii) in areas where water is expensive versus areas where water is relatively cheap.
- Identify where greywater reuse for irrigating garden plants is an established practice

in South Africa, and where historically it was practised but is not any more, and identify the reasons for the latter.

- A significant amount of further work is needed to extract relevant municipal data from the latest Census records. Investigate the feasibility of doing this, taking into account the relevance of the Census 2001 and other records in light of the rapidly changing percentage of households being serviced by higher levels of water supply service.

Medium priority

- Investigate the risks associated with contamination (including salinisation) of important aquifers as a result of greywater irrigation over such aquifers. Make recommendations for management, and identify potential permitting measures, if relevant.
- Investigate the potential benefits and side-effects of using greywater (specifically kitchen greywater) for adding moisture and nutrients to compost piles.
- Investigate the potential savings on fertilisers as result of the nutrients supplied to plants by greywater irrigation.
- Investigate the potential effects of different sources of greywater on herbs, vegetables, fruit trees and on soil, based on known quality characteristics of greywater: In particular, investigate the effects of pH and dissolved/ solid organic matter. Also, investigate the effect of using organic mulch (e.g. leaves, bark, coarse grass cuttings) in combination with greywater irrigation, on the abovementioned crops and soil.
- Conduct research in terms of pathogenic and organic content of kitchen greywater in terms of its potential health risk relating to crop irrigation, and identify potentially suitable mitigation measures and guidelines for its use.
- Investigate the insecticidal properties and plant disease protection properties of greywater in terms of detergent/ soap type and concentration.
- Investigate the potential risk to health of spray irrigating bathroom and laundry greywater, and establish what residential buffer zone set-back distances may be suitable for this activity.

Low priority

- Although household greywater contains plant nutrients, the limiting constraint to irrigation application is assumed to be moisture rather than nutrients such as nitrogen (e.g.: nitrate-N) and phosphorus. Investigate greywater irrigation application rates in order to determine maximum allowable application rates from the perspective of exceeding the nitrogen requirements of irrigated crops, and exceeding certain trace element contaminant thresholds, if relevant.

- ☐ Investigate the usage of treated sewage wastewater for irrigating crops in South Africa, where this can shed light on the acceptability and constraints of using greywater for such purposes.

Most of the high-priority items for research were incorporated in a Water Research Commission (WRC) workshop held on 26th October 2005 to identify the Terms of Reference for a follow-on project.

6.3 Conclusions

Identified research needs for greywater irrigation have been grouped into High, Medium and Low priority categories. A key issue is: Is there a need at national level to promote greywater use for crop irrigation in cases where there is no net improvement to the country's net water balance ? Based on evidence from overseas (e.g. Australia and California), in spite of the presence of strict greywater legislation, illegal greywater irrigation is practiced extensively at the household level. Should the legislation be changed and regulations established that help to positively manage and control domestic greywater irrigation ? In South Africa, there are currently no regulations or guidelines that enable or promote effective management and control of greywater for irrigation of garden plants. Research priorities therefore need to address these aspects as well as the others mentioned in the introduction to this chapter. Finally, consideration needs to be given to assessing the impact of *allowing controlled irrigation* with greywater versus the impact of *not allowing any irrigation* with greywater (Alcock, 2002).

CHAPTER 7

7 Bibliography

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APPENDICES

Appendix A: Greywater Characteristics Relating To Impact On Soils And Crops

1 Greywater can have one of the following definitions:

a) household water that is not toilet water,

b) water from bathing and clothes washing activities,

c) water from bathing, clothes washing, food preparation and dishwashing activities.

1.1 Greywater Quality

The quality of greywater varies depending on the quality of the water supply, and the source of the greywater (sink, washing machine, etc.). The following table indicates the likely constituents of water from various household sources (Center for the Study of the Built Environment, 2003).

Greywater Source	Possible Contents
Automatic Clothes Washer	Suspended solids (dirt, lint), organic material, oil and grease, SODIUM, nitrates and phosphates (from detergent), increased salinity and pH, bleach, heat.
Hand clothes washing	Suspended solids (dirt, lint), organic material, oil and grease, SODIUM, nitrates and phosphates (from detergent), increased salinity and pH, heat.
Bathtub and shower	Bacteria, hair, organic material and suspended solids (skin, particles, lint), oil and grease, soap and detergent, heat.
Automatic Dishwasher	Organic matter and suspended solids (from food), bacteria, increased pH and salinity, oil and grease, detergent, (sodium), heat.
Sinks, including Kitchen	Bacteria, organic matter and suspended solids (food particles), oil and grease, soap and detergent residue, heat.

Source: New Mexico State University, College of Agriculture and Home Economics. 1996. Safe use of household greywater (Guide M106, rev., M. Duttle). http://www.cahe.nmsu.edu/pubs/%5fm/m 106.html)

Major contaminant concerns:

Pathogens,
Sodium - contributed in large amounts by soaps, detergents and water softeners,
Bleaches, fabric softeners,
Organic material, greases, hair, lint (cause odours, orifice and soil pore blockage, increase in pathogens, insect vectors),
Nitrates, boron (Impact on groundwater, plants),
Phosphates Impact on surface water resources.

The constituent of greywater of concern with respect to irrigation and impacts on soil and crop yield is sodium. The sodium adsorption ratio (SAR) can be defined as an index of the potential of a given irrigation water to induce sodic soil conditions (DWAF, 1996), and is calculated using the concentrations of sodium, calcium and magnesium in water.

The following is now discussed

Potential effects of irrigation with high SAR low EC greywater on soil physical properties,
Potentially suitable/ unsuitable soils for greywater irrigation,
Impacts on suitable/ unsuitable soils,
Management measures to minimize/reduce impacts on soils.

1.2 What is SAR and how does it affect soil physical properties?

According to the Department of Water Affair and Forestry's Water Quality Guidelines (Department of Water Affairs and Forestry, 1996) as cited in Alcock (2002):

> “The sodium adsorption ratio is an index of the potential of a given irrigation water to induce sodic conditions in soil. Soil sodicity is usually measured by the percentage of the cation exchange capacity of a soil that is occupied by sodium ions. SAR is a measure of the sodium concentration of irrigation water in relation to the combined magnesium and calcium concentration, and gives an indication of the level at which the exchangeable sodium percentage (ESP) of the soil will stabilize after prolonged irrigation. The SAR is determined for irrigation water and for the saturated-soil extracts. In the latter instance, the SAR gives an indication of the ESP of the soil. (The two values are approximately equal). The units in which SAR is measured are (mmol Litre^{-1}) $^{0.5}$. SAR values however, are frequently reported without units."

SAR and salinity of the applied irrigation water are two factors that affect infiltration. Both low salinity water and high SAR water will tend to reduce infiltration rate (Foster *et al*, 2000). Low salinity (electrical conductivity or E.C.) water tends to remove salts from the soil thus reducing soil stability and hence its permeability, whereas high SAR water helps disperse soil aggregates and the resultant suspended soil particles then move downward and block gaps between soil particles lower down in the soil column, thus impeding downward water movement (Foster *et al*, 2000). The reduced infiltration potential can therefore be measured by the ratio of SAR / E.C. of the applied irrigation water.

According to Alcock (2002): Under conditions of chemical equilibrium (in the long term), the SAR of an irrigation water determines the ESP of the irrigated soil. The ESP over the depth of the soil profile changes very slowly in response to the SAR of the irrigation water, given that the quantity of cations in irrigation water is usually small by comparison with the cations adsorbed to the cation exchange complex of a soil. A number of years or even decades may pass before steady state conditions are apparent throughout the soil profile. Changes in the ESP start in the top soil and move progressively down to the lower layers. It follows that short term changes in irrigation water SAR will marginally influence the soil profile ESP, while largely determining the ESP at the soil surface. The SAR of an irrigation water increases in soil when the sodium, calcium and magnesium content increases in conjunction with other ions (when water is lost through evapotranspiration). There is accordingly, a progressive increase in soil ESP from the top to the bottom soil layers in association with the increasing salt concentration from the top to the bottom. By decreasing the leaching fraction, both the salt concentration and the ESP in the bottom soil layers are increased.

The SAR tends to increase with the increasing salt content (the electrical conductivity or EC). The EC indirectly determines how soon the soil ESP will achieve equilibrium conditions with the irrigation water SAR. (Equilibrium ESP conditions will be achieved more rapidly the higher the irrigation water EC is at a specified SAR).

Irrigation water with high bicarbonate or carbonate concentrations results in the precipitation of calcium as calcium bicarbonate in the soil. The soil solution then becomes relatively enriched with sodium leading to an "effective" increase in the SAR and the ESP. The presence of lime and other calcium sources in the soil, however, reduces the effective SAR of the soil solution. The latter plays an important role in ameliorative procedures.

The negative impacts of irrigation with sodium-rich water - and accordingly enhanced soil sodicity – are (Department of Water Affairs and Forestry, 1996):

reduced crop yields and quality due to sodium uptake through the roots and leaves of sodium-sensitive plants, and

impaired soil physical conditions. Soil deterioration becomes apparent through a reduced soil permeability as a result of a decline in the infiltration rate and/or the soil hydraulic conductivity.

A third effect is an increased tendency for hardsetting.

The sodium concentration in the soil water that is taken up by the plants is determined by the mean soil ESP in the root zone and the total salt concentration of the soil water. The greater the total salt concentration and/or the soil ESP, the higher is the sodium concentration. Experiments undertaken to determine the uptake of sodium at toxic levels by plant roots link sodium levels to the soil ESP. There is evidence however, that the nutritional effects of sodium in soil are influenced to a greater extent by the absolute sodium, calcium and magnesium concentrations in the soil solution, rather than by soil ESP. It is important to bear in mind that the absorption of sodium by plant roots and by crop foliage (see sodium below) are additive. The most restrictive guideline values should therefore be used when crop foliage is wetted by sprinkler irrigation. (Alcock, 2002)

1.3 Ameliorative measures to reduce the impacts of an increasing water SAR on crop yields and quality include (Department of Water Affairs and Forestry, 1996)

accepting a lower crop yield or quality,

changing to crops which are more tolerant,

increasing the leaching fraction;

alternating fresh water and greywater use on a specific area;

using low-sodium content soaps and detergents in the homes where greywater is reused for irrigation;

applying greywater during periods of minimal evaporation;

by applying plant nutrients such as potassium, calcium and magnesium to the irrigation water and/or soil to overcome plant nutritional imbalances due to the excess sodium associated with a high SAR;

applying gypsum to the soils;

mulching the surface soils.

1.4 The susceptibility of South African soils to physical deterioration due to ESP-EC interactions as expressed by S.A. Water Quality Guidelines. - After Department of Water Affairs and Forestry (1996) as presented in Alcock (2002).

Table 1: Sensitivity of SA soils to changes in infiltration rate caused by SAR levels in irrigation water

Soil physical reaction	**Sensitivity of given soils with typical soil forms identified**
Infiltration rate	**Sensitive (1)** (a) Texture contrast soils with a sandy top soil overlying a structured clay horizon (poorly drained). Typical soil forms: Estcourt; Kroonstad and Sterkspruit (b)Poorly drained soils. Shallow with a plinthic horizon (especially those containing high silt and sand fractions). Typical soil forms: Cartref; Katspruit; Longlands; Wasbank and Westleigh (c)Soils with a blocky structured horizon. Typical soil forms: Swartland and Valsrivier (d)Red and yellow structureless soils with imperfectly drained plinthic horizons (excluding sand textures) Typical soil forms: Avalon; Bainsvlei; Glencoe and Pinedene
	Medium (2) (b)Clay soils (usually dark), often swelling. Typical soil forms: Arcadia; Bonheim; Inhoek and Tambankulu (c)Freely drained, structureless and red structured soils (excluding those with sand and loamy sand textures). Typical soil forms: Clovelly; Hutton and Shortlands (d)Weakly structured soils (somewhat poorly drained). Typical soil forms: Oakleaf and Vilafontes
	Tolerant (3) (a)Exclusively drained soils (sandy). Typical soil forms: Dundee; Fernwood; Lamotte and Shepstone (b)Clay soils (often dark), imperfectly drained. Typical soil forms: Rensburg and Willowbrook (c)Soils with a humic top soil containing more than 2% organic carbon. Typical soil forms: Inanda; Kranskop and Magwa

Table 2: Sensitivity of SA soils to changes in hydraulic conductivity induced by SAR levels in irrigation water

Hydraulic conductivity	**Sensitive (1)** (a)Texture contrast soils with a sandy top soil overlying a structured clay horizon (poorly drained). Typical soil forms: Estcourt; Kroonstad and Sterkspruit (b)Clay soils (often dark), imperfectly drained. Typical soil forms: Rensburg and Willowbrook (c)Soils with a blocky structured horizon. Typical soil forms: Swartland and Valsrivier (d)Poorly drained soils. Shallow with a plinthic horizon (especially those containing high silt and sand fractions). Typical soil forms: Cartref; Katspruit; Longlands; Wasbank and Westleigh
	Medium (2) (a)Red and yellow structureless soils with imperfectly drained plinthic horizons (excluding sand textures). Typical soil forms: Avalon; Bainsvlei; Glencoe and Pinedene (b)Weakly structured soils (somewhat poorly drained). Typical soil forms: Oakleaf and Vilafontes
	Tolerant (3) (a)Freely drained, structureless and red structured soils (excluding those with sand and loamy sand textures). Typical soil forms: Clovelly; Hutton and Shortlands (b)Exclusively drained soils (sandy). Typical soil forms: Dundee; Fernwood; Lamotte and Shepstone (c)Soils with a humic top soil containing more than 2% organic carbon. Typical soil forms: Inanda; Kranskop and Magwa

Table 3: Sensitivity of SA soils to hardsetting as induced by SAR levels in irrigation water

Hardsetting	**Sensitive (1)** (a)Soils with a blocky structured horizon. Typical soil forms: Swartland and Valsrivier (b)Texture contrast soils with a sandy top soil overlying a structured clay horizon (poorly drained). Typical soil forms: Estcourt; Kroonstad and Sterkspruit (c)Weakly structured soils (somewhat poorly drained). Typical soil forms: Oakleaf and Vilafontes
	Medium (2) (a)Poorly drained soils. Shallow with a plinthic horizon (especially those containing high silt and sand fractions). Typical soil forms: Cartref; Katspruit; Longlands; Wasbank and Westleigh (b)Freely drained, structureless and red structured soils (excluding those with sand and loamy sand textures). Typical soil forms: Clovelly; Hutton and Shortlands (c)Red and yellow structureless soils with imperfectly drained plinthic horizons (excluding sand textures). Typical soil forms: Avalon; Bainsvlei; Glencoe and Pinedene
	Tolerant (3) (a)Exclusively drained soils (sandy). Typical soil forms: Dundee; Fernwood; Lamotte and Shepstone (b)Clay soils (usually dark), often swelling. Typical soil forms: Arcadia; Bonheim; Inhoek and Tambankulu (c)Clay soils (often dark), imperfectly drained. Typical soil forms: Rensburg and Willowbrook (d)Soils with a humic top soil containing more than 2% organic carbon. Typical soil forms: Inanda; Kranskop and Magwa

Table 4: Effects of SAR on soil physical Conditions (After Department of Water Affairs and Forestry, 1996)

SAR Range	Infiltration Rate	Hydraulic Conductivity	Hardsetting
Target water quality range > or = 1.5	Should ensure an adequate infiltration rate for soils sensitive [See table 1: (1)] to the formation of infiltration rate reducing surface seals under conditions of rainfall during the irrigation season or irrigation with water having an EC < 20 mS/m	No significant reduction in hydraulic conductivity below inherent soil hydraulic conductivity expected in this SAR range for any soil.	No hardsetting above inherent hardsetting expected in any soil in this SAR range
1.5 to 3	Infiltration problems likely to occur in soils sensitive [See table 1: (1)] to the formation of infiltration rate-reducing surface seals under conditions of rainfall during the irrigation season or irrigation with water having EC > 20mS/m. No problems are foreseen at EC> 90, while slight/moderate problems at EC 20-90 mS/m	No significant reduction in hydraulic conductivity below inherent soil hydraulic conductivity expected in this SAR range for any soil.	No hardsetting above inherent hardsetting expected in any soil in this SAR range
3 to 6	Infiltration problems likely to occur in soils sensitive [See table 1: (1)] to the formation of infiltration rate-reducing surface seals under conditions of rainfall during the irrigation season or irrigation with water having EC > 25 mS/m. No problems are expected at EC> 130, while slight/moderate problems at EC 25-130 mS/m	Hydraulic conductivity reduction likely to occur in soils [see table 2: (1)] sensitive to hydraulic conductivity reduction. A low EC may in the soil solution may cause hydraulic conductivity to be irreversibly reduced by 25% for sensitive soils.	Hardsetting increasingly likely to occur in sensitive soils at ECs < 60 mS/m for SAR= 3 and <120 mS/m for SAR= 6
6. To 12	Infiltration problems likely to occur in soils sensitive [See table 1: (1)] to the formation of infiltration rate-reducing surface seals under conditions of rainfall during the irrigation season or irrigation with water having EC > 35 mS/m. No problems are expected at EC> 200 mS/m, while slight/moderate problems at EC 35-200 mS/m	Hydraulic conductivity reduction likely to occur in soils [see table 2: (1)] sensitive to hydraulic conductivity reduction. A low EC may in the soil solution may cause hydraulic conductivity to be irreversibly reduced by >25% for sensitive soils and < 25% in less sensitive soils [see table 2: (2)], depending on the particle size distribution of the soil and the type of clay mineral present in the clay size fraction. Tolerant soils [see table 2: (3)] will show little or no effect. Small and reversible changes in hydraulics occur in sensitive soils [table 2: (1)] when EC is in the range of 100- 200 mS/m.	Hardsetting increasingly likely to occur in sensitive soils [see table 3: (1)] at ECs < 120 mS/m for SAR= 6 and <240 mS/m for SAR= 12

12 to 20	Infiltration problems likely to occur in soils sensitive [See table 1: (1)] to the formation of infiltration rate-reducing surface seals under conditions of rainfall during the irrigation season or irrigation with water having EC< 90 mS/m. No problems are expected at EC> 310, while slight/moderate problems at EC 90-310 mS/m	Hydraulic conductivity reduction likely to occur in soils [see table 2: (1)] sensitive to hydraulic conductivity reduction. A low EC may in the soil solution may cause hydraulic conductivity to be irreversibly reduced by >25% for sensitive soils and < 25% in less sensitive soils [see table 2: (2)], depending on the particle size distribution of the soil and the type of clay mineral present in the clay size fraction. Tolerant soils [see table 2: (3)] will show little or no effect. Small and reversible changes in hydraulics occur in sensitive soils [table 2: (1)] when EC is in the range of 100- 200 mS/m.	Hardsetting increasingly likely to occur in sensitive soils [see table 3: (1)] at EC range 240 mS/m for SAR= 12 and <440 mS/m for SAR= 20
> 20	Infiltration problems likely to occur in soils sensitive [See table 1: (1)] to the formation of infiltration rate-reducing surface seals under conditions of rainfall during the irrigation season or irrigation with water having EC < 180 mS/m. No problems are expected at EC> 560, while slight/moderate problems at EC 180-560 mS/m	Hydraulic conductivity reduction likely to occur in soils [see table 2: (1)] sensitive to hydraulic conductivity reduction. A low EC may in the soil solution may cause hydraulic conductivity to be irreversibly reduced by >25% for sensitive soils and < 25% in less sensitive soils [see table 2: (2)], depending on the particle size distribution of the soil and the type of clay mineral present in the clay size fraction. Tolerant soils [see table 2: (3)] will show little or no effect. Small and reversible changes in hydraulics occur in sensitive soils [table 2: (1)] when EC is in the range of 100- 200 mS/m.	Hardsetting increasingly likely to occur in sensitive soils [see table 3: (1)] at EC range 240 mS/m for SAR= 12 and <440 mS/m for SAR= 20

Source: Department of Water Affairs and Forestry, 1996. South African Water Quality Guidelines, VOL 4, Agricultural Use: Irrigation, second edition, Department of Water Affairs and Forestry, Pretoria, 199 p and Alcock (2002).

2. Shortcomings of the classification of soils in the various levels of tolerance

Several factors influence soil susceptibility to physical deterioration. The data provided above are for general guidance purposes only. The grouping of soil types into the various classes requires modification due to differences in rainfall (the degree of soil weathering) and parent material. For instance, Oakleaf Form soils in the Western Cape are mostly leached of their stabilizing sesquioxides, and are accordingly highly sensitive to infiltration. (Alcock, 2002)

Difficulties are also apparent in deciding where to allocate a given soil type. Clay soils (often dark) and imperfectly drained - such as Rensburg Form soils - are classed as tolerant to infiltration given the deep vertical cracks are dry. The cracks permit the infiltration of large volumes of water. These soils, when already wet, have a slow water intake capacity with a sensitive rate for hydraulic conductivity.

Expert opinion should be obtained when critical decisions are required in terms of soil physical responses to ESP-EC interactions. (Alcock, 2002)

3. Applicability of DWAF irrigation water guidelines to Greywater use

Analyses of greywater samples from various sources i.e. bathwater, dishwater etc. showed a minimum of 1.4 and a maximum of 40. This shows that greywater SAR values are well within the guideline values used for irrigation water guidelines (1996) range and one could apply these to greywater values as measured. However, if greywater SAR values extend beyond that of guideline values, separate guidelines may be required.

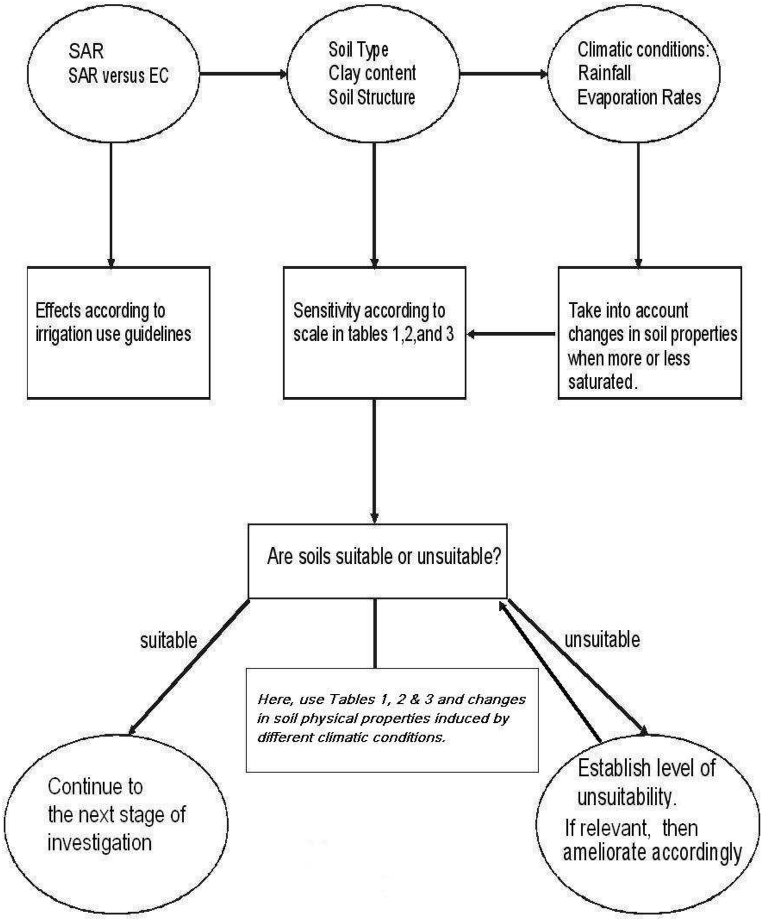
Greywater concentration is to a large extent dependent on the types of additives used during household water usage activities. Detergents in wash water, dishwater, and clothing wash water may increase the sodium content of water considerably and hence the SAR values. With this in mind, issues like dilution, or alternating fresh water and greywater need to be considered for irrigation use, as constant application of high SAR greywater may damage soil physical stability and hence affect crop production.

Optimum soils with respect to irrigation with high SAR, high EC are (from Alcock, 2002 and evident from tables 1, 2, and 3):

the red highly weathered sesquioxic soils (present in high rainfall areas);
moderately permeable calcareous soils in drier areas, and
very sandy soils.

Sesquioxic soils are highly leached and have relatively inert clay fractions, which are iron, aluminium and manganese-rich. Such soils are the most resistant to the dispersive effects of sodium on the cation exchange complex. Many of these highly weathered soils are also able to adsorb anions to some extent (including chlorides and sulphates). Very sandy soils, in turn, have a small clay content and are likewise resistant to dispersion. A disadvantage of the latter soils is that the character and chemical concentrations of the wastewaters, after passing through the soil, may often not be much changed or improved. (Department of Water Affairs and Forestry, 1996; Thompson, 1985)

3.1 Diagrammatic presentation of factors to consider when applying guidelines for irrigation of soils



4. Effects of high sodium concentrations on crop growth / yields and soils

The negative impacts of irrigation with sodium-rich (high SAR) water - and accordingly enhanced soil sodicity (high ESP) – are (After Department of Water Affairs and Forestry, 1996):

reduced crop yields and quality due to sodium uptake through the roots and leaves of sodium-sensitive plants, and

impaired soil physical conditions. Soil deterioration becomes apparent through a reduced soil permeability as a result of a decline in the infiltration rate and/or the soil hydraulic conductivity.

A third effect is an increased tendency for soil hardsetting.

Impacts of high sodium in greywater used for irrigation include the following (After Department of Water Affairs and Forestry, 1996):

High sodium concentrations are toxic to crops on uptake through roots and especially through leaves.

Sodium increases pH of soil: High soil pH has a potential negative effect on growth/health of certain crops.

High sodium concentrations and alkaline irrigation water has negative effect on harvested fruit (e.g. grapes).

High sodium concentrations (specifically high SAR relative to EC) of irrigation water result in reduction in soil infiltration rate and breakdown in soil structure, with consequent impact on plant root systems (less available moisture and reduced soil aeration result in root die-off). Problems can also occur when rainfall is relied upon to leach out sodium ions from "sodic" soils, as rainfall increases the ratio SAR / EC at the soil surface and so reduces its permeability. Also, raindrops mechanically help break down the surface soil structure, forming a sealing affect, and thus causing increased runoff and erosion, with consequent impact on crop growth.

Hardsetting when soil dries out makes it difficult for seedlings to grow.

Mitigation:

Select crops that are more tolerant of sodium and / or high pH.

Increase the leaching fraction (and ensure there is adequate aeration of soils and/or drainage).

Add Ca, Mg and nutrients to irrigation water or to soils.

Add gypsum to irrigation water or to soils.

Add surface mulches and/or compost to soils.

Use drip or subsurface irrigation where feasible. No spray irrigation (Na is toxic to plants when sodium-rich irrigation water is sprayed onto plant leaves).

Lower the Na concentration in irrigation water (Use low-sodium content soaps and detergents in the homes where greywater is reused for irrigation).

(After Department of Water Affairs and Forestry, 1996)

Sensitivity of crops to Na in irrigation water:

The UN FAO indicates (Ayers and Wescott, 1985):

"no problems" in terms of crop toxicity at sodium levels of < 69 mg/L;

"increasing problems" at sodium levels of 69 - 207 mg/L; and "severe problems" at sodium levels of > 207 mg/L)

Crops sensitive to Na (where uptake is through roots only), ordered according to sensitivity, are (Department of Water Affairs and Forestry, 1996):

avocados; deciduous fruits; grapes; nuts; green beans; maize; peas; grapefruit; oranges; peaches; tangerines; mung beans; mash beans; lentils; groundnuts and cowpeas

Less sensitive crops, ordered according to sensitivity, are:

carrots; lettuce; sugar cane; onions; radish; sorghum; spinach; tomatoes and vetch.

For more detailed lists, see Table 5. See Table 6 for approximate volumes of greywater required for irrigating crops.

Table 5: Relative Tolerance Of Selected Crops To Exchangeable Sodium

Sensitive	Semi-tolerant	Tolerant
Avocado Deciduous Fruits Nuts Bean, green Cotton Maize Peas Grapefruit Orange Peach Tangerine Mung Mash Lentil Groundnut (peanut) Gram Cowpeas	Carrot Clover, Ladino Dallisgrass Fescue, tall Lettuce Bajara Sugarcane Berseem Benji Raya Oat Onion Radish Rice Rye Ryegrass, Italian Sorghum Spinach Tomato Vetch Wheat	Alfalfa Barley Beet, garden Beet, sugar Bermuda grass Cotton Paragrass Rhodes grass Wheatgrass, crested Wheatgrass, fairway Wheatgrass, tall Karnal grass

5. Future Research

Guidelines for greywater usage should include a section taking into account the type of grey water; here considering bath water, dish water, clothes washing, etc. and probable composition. Although SAR and soil physical properties are important, guidelines should also consider other chemical parameters e.g. EC, DOC which contribute to the deterioration of soil physical and chemical properties.

Site Specific (local) suitability for grey water use:

Guidelines developed for the Department of Water Affairs could cater for general use when looking at a specific site (see section 3.1). Parameters such as dissolved or solid organic matter in greywater also need to be incorporated before a decision with respect to use is taken. The concentrations of salts (EC) as well as ESP are also important parameters to be considered along with SAR. Site specific conditions like infiltration rate, clay content, soil structural features, parent material and thickness of soil horizons will all contribute to actual effects of greywater irrigation and the extent of deterioration of soil conditions. Chemical parameters such as soil solution (soil extract) chemistry and soil horizon chemistry and may impact on the rate of deterioration of soil properties. A method that takes into account all or most of the parameters mentioned above would result in better site-specific suitability classes for greywater irrigation.

National suitability for greywater use:

Land-type maps developed by the Agricultural Research Council, displaying marked uniformity of terrain, soil pattern and climate is indeed a useful database, which could be incorporated into a national greywater use classification map.

The land type map has records of terrain type, parent material, clay content, descriptions of soil horizons, and a binomial soil classification for each terrain (valley, floodplain etc.). The considerations for climatic zones also further assist the incorporation of changes in soil physical properties under varying saturation in particular soils as highlighted in previous sections. However, it is stated in the land type map introductory document that estimates given of the areas in (ha) are not available for agriculture; that is, the area occupied by towns, roads, dams and pans where these are recorded on the current edition maps.

The greatest challenge for creating a national greywater suitability map is that greywater concentrations vary greatly depending on the sources of greywater or the activities that yield greywater. One could possibly come up with a national greywater suitability index/map based on SAR ranges described in irrigation water guidelines (1996) and the soil types that are sensitive to them (As pointed out in tables 1, 2 and three). This would enable the compiling of a greywater suitability index for the entire country, based on land type, and the sensitivity or tolerance of soils within a specific land-type.

Evaluation of effects of greywater irrigation should be tested for some characteristic soil types as currently described in the guidelines as tolerant, sensitive or of medium sensitivity to high SAR irrigation water so as to verify theoretical prediction of suitability.

Appendix B: Background to potential water resource contamination.

The presence of a substance such as a detergent or solvent promotes suspension of contaminants (e.g. pathogens) in water, and stimulates movement of certain contaminants into the ground. Such substances are known as "carriers". Carriers include detergents and oils in greywater. Carriers promote the ingress of pathogens and certain other contaminants into the soil by binding to them and transporting them into the ground. They also promote the transport of contaminants in surface water channels (e.g. streams, stormwater drains) for long distances.

The effects of modern detergents as carriers are usually short-lived in the environment, as modern detergents are biodegradable. Detergents in greywater have been found to degrade especially rapidly in soils.

Proteins in greywater break down into products that include ammonia, phosphorus and potassium. In suitable oxidising conditions, microbes convert ammonia to nitrates. Nitrates are highly soluble in water and have a low capacity for adsorption onto soil particles, so are very mobile in aerobic soils. Nitrates, phosphates and potassium are plant nutrients, so can save on the requirement for additional fertilizers when greywater is used for irrigating crops.

Unrestricted disposal of organic wastewater to land could present a nitrate contamination risk for groundwater resources (Tredoux, 2004). Generally, nitrates do not degrade in shallow aquifers as the water usually contains free oxygen. Confined aquifers are often anoxic, and usually contain very low concentrations of nitrates. Greywater does not generally represent a significant source of nitrate contamination.

Where there is vegetation cover, nutrients such as nitrates are taken up from the surface soils during the growing season by the roots of plants. In deeper soils, nutrients may be taken up by crops such as maize and sugar cane, and also by most trees, to a depth of two metres. Certain trees can take up nutrients from soil at greater depths. These crops are likely to be most suitable for greywater use where greywater is irrigated using mulch basins or through recommended subsurface methods (provided they are not sensitive to the dissolved salts and high pH of greywater).

Greywater can cause eutrophication if it enters ponded surface water in large enough quantities. Eutrophication means that nutrients are present in the water in sufficient concentration to promote dense growth of algae and other water plants. Given sufficient sunlight and warmth, populations of algae rapidly grow, and then die off, causing the water to smell and taste repulsive. Eutrophic surface water sources are usually considered unfit for drinking.

Faeces contain very high numbers of pathogens, and these may be present in significant quantities in greywater when households include invalids, small children or babies, or when occupants are suffering from diarrhoea. Generally, such greywater should not be used for growing crops unless strictly controlled (Author's Note: Although subsurface irrigation of fruit trees should be considered safe enough).

Pathogens tend not to last long in dry conditions, in sunlight or where there is abundant oxygen. When greywater (or any other water) contaminated by pathogens slowly percolates into the soil surface, the pathogens are usually held back by filtration and adsorption, and when the topsoil dries out, they tend to die off as result of:

aeration and desiccation, and

competition with and predation by aerobic microbes.

Some pathogens on the soil surface are killed by sunlight, while certain pathogens, in the form of spores and eggs, can remain viable with in the soil for several years.

Greywater disposed in large volumes at one point to bare ground can form stagnant puddles or pools in lower-lying areas, where it can infiltrate the ground rapidly under hydraulic pressure, and so can present a contamination risk to groundwater. When greywater is distributed over the soil surface so that it can infiltrate the ground slowly over a large area without forming ponds or puddles, the pathogens in the greywater tend to get trapped in the top soil, and slowly die off. Groundwater contamination risk in the latter case will be significantly reduced.

Using greywater for irrigating crops (with restrictions on crop type, etc.) is preferable to indiscriminate disposal.

When shallow water flows over the soil surface for a short period of time, some of it percolates into the topsoil layer. If this water contains pathogens and other contaminants, these are normally rapidly removed by the aerobic soils.

When greywater is discharged indiscriminately to land, it may collect to form puddles and small pools, and insoluble substances in greywater are deposited here, along with pathogens. These sediments and the stagnant greywater become anoxic, giving off unpleasant odours, and release nutrients such as ammonia, while providing an ideal environment for pathogenic bacteria to proliferate as well as providing a breeding environment for insect pests. The health risk is increased if animals such as pigs and cattle gain access to the water, or if humans have direct contact with it.

The risk of water resources becoming contaminated by greywater disposal to the natural environment is increased under the following conditions:

Greywater is disposed in an area where it can gain easy access to groundwater or surface water resources, such as when disposed in close proximity to, or upslope of, an unprotected well, borehole, spring, sinkhole, mine, quarry, stormwater channel or stream.

High loading. The more concentrated greywater is, or the greater the volume, when disposed to the ground, the greater the contamination risk to groundwater and surface water resources.

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Appendix C: Notes

Notes taken from: Patterson, R.A. 1997 "Domestic Wastewater and the Sodium Factor", *Site Characterization and Design of On-Site Septic Systems, ASTM STP 1324, M.S.* Bedinger, A.I. Johnson, and J.S. Fleming, Eds., American Society for Testing and Materials, 1997 pp 23 - 35.

No incentives are given to householders to improve the domestic wastewater quality before treatment or disposal. While governments address phosphorus reduction programs, the effect of sodium in wastewater is ignored. Many laundry detergents use sodium salts as fillers, adding significant sodium to the wastewater: The fillers in regular, non-concentrated detergents provide no worthwhile contribution to the wash but may provide up to 40% of the sodium salts in the wastewater.

Simply by changing laundry products, a reduction of up to 38% of the current sodium concentrations in domestic wastewater can be achieved at no cost to the consumer with no negative impact on household operations.

In NSW, the average increase in sodium concentration in sewage water as a result of domestic use of water was 63 + 3 mg L-1, The average increase in SAR for reticulation water to sewage water is approx. 2.5, ranging between 1.5 and 3.8 In terms of sodium per wash, 67% of detergents produced more than 35 g of sodium per wash, Only nine samples produced less than 10 g of sodium per wash, of which seven were liquid detergents. In a typical NSW household, 93 % (28/30) of sodium in sewerage water is contributed by soaps and detergents.
Increases in SAR by clothes washwater (per wash) from different detergents ranged from zero to 6.8. Soap powders ranged from 0.5 to 6.8. Liquid soaps ranged from 0 to 2.2 (For NSW) A reduction in the total household sodium load of 38% per wash is easily achievable (Up to 62 % could be achieved) through a choice of a low sodium detergent even where the household is only currently using an average sodium detergent.