Sustainable Use of Greywater in Small-Scale Agriculture and Gardens in South Africa

TECHNICAL REPORT

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Report to the
Water Research Commission

by

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Executive Summary

Introduction

Limited supplies of fresh water are a concern worldwide and especially in South Africa where annual rainfall falls well below the world average. Reuse of greywater offers one means of relieving pressure on fresh water supplies. It is established practice in a significant minority of households, especially in low income settlements where water is difficult to obtain and families are under financial pressure to minimise use of all resources. Use of greywater specifically for irrigation is practised to a lesser extent than for other household uses, but does occur in middle and higher income suburbs in times of drought, and in low income areas to supplement water supplies for food production. Active promotion of greywater use for irrigation in gardens and small-scale agriculture has the potential not only to maximise use of limited water supplies, but also to improve food security in low income settlements. However, before this can be promoted through government structures and local authorities, the legal status of greywater use for irrigation needs to be clarified and guidance needs to be formulated for users so that small-scale irrigation use of greywater is performed in a way that is safe for humans, plants and the environment. The development of such guidance is the purpose of this project.

Aim and objectives

Aim

To develop guidelines for the sustainable use of greywater in small-scale agriculture and gardens in rural villages, peri-urban and urban areas of South Africa.

Objectives

1. Identify and describe the areas where greywater use is an established practice.
2. Refine knowledge on the *status quo* of greywater use (where, who, why, how, quantities and qualities) and needs of actual and potential users of greywater.
3. Review the social and anthropological acceptability of greywater use.
4. Review the current institutional and legal framework for use of greywater in consultation with relevant government departments.
5. Document the available knowledge (including the previous four objectives, other WRC projects and South African and international experience) and other considerations in a Technical Report that records the proposed rationale and associated limits for South African conditions as reflected in the Draft Generic Guidelines.
6. Draft Generic Guidelines for sustainable use of greywater in small-scale agriculture and gardens based on the rationale provided in the Technical Report.
7. Workshop the draft generic guidelines with Water Service Authorities (WSAs), Water Service Providers (WSPs), users and other interested and affected parties (IAPs) to test the feasibility and acceptability thereof.
8. Identify the most important gaps in knowledge that should be addressed to refine the draft guidelines.
9. Conduct a number of case studies designed to fill these gaps in knowledge.
10. Test the draft guidelines against current practice.

11. Update the Technical Report to record the rationale and associated limits for the final set of guidelines.
12. Consult with regulating authorities and potential users of the guidelines about the acceptability of the proposed rationale and associated limits for the guidelines.
13. Identify, document and prioritise the remaining crucial issues relating to greywater use that would need to be investigated in follow-on research.
14. Prepare a final set of final user friendly guidelines for different target groups (*e.g.* sewered *vs.* unsewered; urban *vs.* rural; inland *vs.* coastal, *etc.*) for current and potential use of greywater in small-scale agriculture and gardens in rural villages, peri-urban and urban areas of South Africa.

Approach adopted to address project aim and objectives

The development of a Guidance Report for greywater irrigation and a supporting Technical Report followed the process outlined below:

- Survey of national and international literature (peer-reviewed literature, legislation and guidelines, technical reports and 'grey' literature) to identify existing knowledge and key issues.
- Identification of gaps in knowledge, and initiation of case studies to address these.
- Exploratory workshop with policy-makers and questionnaire surveys of local authorities and of water users in sewered settlements (questionnaire surveys of unsewered settlements were available from previous studies).
- Identification of greywater constituents of interest from existing studies of greywater quality in South Africa.
- Development of preliminary draft greywater quality guidelines for all identified constituents.
- Peer review to reduce number of constituents, refine the draft quality guideline and set the framework for other issues to be covered in the guideline.
- Compilation of complete draft guidelines, containing sections on
  - Managing risks and uncertainty in greywater irrigation,
  - Greywater quality,
  - Greywater quality mitigation, and
  - Greywater quantity.
- Submission of complete draft guideline to peer review.
- Capacity building workshops at municipality level, and consultation with national policy-makers.
- Incorporation of outcomes of the case studies, peer review and consultation into the Guidance Report and the Technical Report.
- Formulation of implementation and research recommendations on the basis of all work conducted, and inclusion thereof in the Technical Report.

Summary of outcomes

Literature review and case studies

Supporting literature was reviewed in the Technical Report. It was noticed that information from South Africa was particularly sparse. Six case studies were conducted to address knowledge gaps identified in the literature and to support development of the Guidance Report. These were:

- Case Study 1: Plant growth, soil characteristics and microbiological quality of vegetable crops irrigated with domestic greywater in eThekwini Municipality
- Case Study 2: Consultative process supporting development of the Guidance Report
- Case Study 3: Identifying greywater quality constituents for inclusion in the Guidance Report
- Case Study 4: Greywater treatment
- Case Study 5: Impact of cleaning products on greywater quality
- Case Study 6: Estimating greywater volumes for irrigation.

Outcomes of literature review and case studies

The most salient points emerging from the literature review and the case studies were collated, as follows.

Greywater quality and quantity

- Kitchen greywater should not be used for irrigation unless it undergoes some form of treatment first.
- It is preferable to use only the rinse water of the laundry greywater fraction for irrigation.
- The greywater constituents identified as being of the greatest relevance to greywater irrigation in South Africa are:
    - Electrical conductivity (EC)
    - Sodium adsorption ratio (SAR)
    - *Escherichia coli*
    - pH
    - Boron
    - Chemical oxygen demand (COD)
    - Oil and grease
    - Suspended solids
    - Total nitrogen
    - Total phosphorus.
- Estimation of greywater quantities for irrigation should be based on the water needs of plants and not on the disposal of greywater.
- Using relatively simplistic methods, it is possible to provide users with an approximate guide to the volumes of greywater that can be applied. While this does not take into account the best that science can offer in terms of irrigation water planning, it takes cognisance of the need for guidance to be simple enough for relatively unsophisticated users to apply.

Health implications

- Sub-surface irrigation provides the best protection from microbial health risks; it can be implemented simply and should be encouraged.
- A multi-barrier approach to limiting human exposure, as advocated by WHO (2006), can reduce risks from even below-ground vegetables to within commonly recognised acceptable limits.
- Personal hygiene is an important exposure barrier in the use of greywater for irrigation.
- Cognisance must be taken of the vulnerability of HIV-positive persons to exposure to potential pathogens.

- Greywater has the potential to improve nutrient intake from home-grown food crops.

Environmental water quality implications
- Greywater must not be allowed to enter surface water bodies.
- Greywater must not be allowed to pond on the surface.
- While the impact of small-scale greywater irrigation on groundwater quality is likely to be minimal, groundwater must be considered when planning greywater irrigation implementations.

Implications for plant growth and yield
- In general, irrigation with mixed domestic greywater improves both growth and yield of crops relative to tap water, although yield appears to be boosted less than growth. It is unclear whether this effect extends to all types of greywater. The effect varies among crops.
- Use of plants tolerant to certain greywater constituents, *e.g.* sodium or boron, can maximise the use of greywater for irrigation.
- Greywater users need to observe their plants for signs of stress and modify their greywater irrigation regime accordingly.

Implications for soil properties
- Sodium from detergents poses the greatest risk to soil properties, particularly in terms of soil salinity and soil sodicity.
- Soil should be leached to minimise the accumulation of salts.
- Steps should be taken to minimise the development of sodic soil conditions, *e.g.* addition of mulch (organic matter) or gypsum to soil.

Greywater treatment
- Greywater treatment systems should be sufficiently simple and robust to function effectively in rural and peri-urban settlements, preferably without power or piped water and with minimal technical expertise required for maintenance.
- Greywater treatment systems should use the simplest and most cost-effective technology required to meet the water quality objectives.
- Greywater treatment systems should be thoroughly tested and proven before being implemented in practice, to avoid user fatigue caused by system failure and on-going changes.
- Wherever possible, treatment systems that have been previously proven to work in South Africa should be considered before introducing new technologies which have yet to be proven under local conditions.

Considerations for implementation of greywater irrigation
Legal issues
- The legal status of greywater use for small-scale irrigation needs to be clarified.

Social issues

- Sewered settlements seem broadly similar in terms of greywater generation characteristics, while unsewered settlements must be evaluated on a case-by-case basis.
- Informal settlements often lack a sense of community and this hampers the development of initiatives seen to be for the greater good or even individual improvement. Greywater irrigation implementations in such environments cannot succeed unless a sense of community can first be fostered.
- In informal settlements, the quality of greywater is generally extremely poor. For greywater to be of a quality fit for irrigation use, greywater needs to be separated from other waste streams at source and the number of uses to which it is put need to be limited. This is contingent on provision of adequate water supplied otherwise users are driven by logistical and economic factors to maximise the use to which water is put before disposal. It is also heavily dependent on the provision of adequate sanitation and solid waste management.
- Commitment of users and managers of greywater irrigation implementations is essential if these are to succeed.

Education

- Local authorities urgently require capacity building in knowledge of greywater issues in general, and of the potential of greywater use for irrigation in particular.
- Potential irrigation users of greywater need to be involved in the planning and implementation of any greywater irrigation implementation, and must be educated on the risks, benefits and proper handling of greywater, of irrigated land and of greywater-irrigated crops.
- Although residents of unsewered and sewered settlements expressed reservations about the use of greywater for irrigation, there is already a culture of using greywater several times before disposal. This could be used as a foundation to promote use of greywater for irrigation.

Greywater use in new developments

- Probably the greatest potential for greywater use for small-scale irrigation is by including it in the planning of new communities or alterations to existing communities. However, it is important to ensure that the greywater technologies introduced have been proven to be sound; that designs are implemented correctly and that housing management and users are committed to using the facilities properly. Failure in any of these areas has been shown to lead to failure of greywater use projects.

Approach adopted for development of the Guidance Report for irrigation use of greywater

Central concepts identified from the literature review and case studies, and deliberations of the project team and the Reference Group, together determined the underlying principles and the structure of the Guidance Report.

Underlying principles
The intended users of the Guidance Report were identified as:

- Municipalities or NGOs who wish to initiate greywater irrigation implementations or wish to support water users in developing and monitoring greywater irrigation implementations.
- Informed members of the public who wish to plan for irrigation use of greywater on their properties or in their settlements, and need guidance in doing so.

The focus of the Guidance Report was defined as:

- Minimisation of risks of *illness* in handlers of greywater and greywater-irrigated produce, or consumers of greywater-irrigated produce.
- Minimisation of risks of *reduction in growth or yield* of plants/crops irrigated with greywater.
- Minimisation of risks of environmental degradation, especially reduction in the *ability of soil irrigated with greywater to support plant growth*.

In addition, the Guidance Report was developed within the following boundary conditions:

- Irrigation use is interpreted as the *beneficial use of greywater to support plant growth within the boundaries of the irrigated property only*. It is important to note that movement of greywater beyond the boundaries of the property is explicitly *excluded*, since this would amount to uncontrolled disposal of greywater to the environment and all the disadvantages and risks associated with that.
- The guidance provided is intended to address irrigation use of greywater only, not to provide a general solution for disposal of greywater. Thus the focus is not on maximising the volume of greywater which can be applied to land, but on minimising risks and on maximising benefits associated *specifically with irrigation use of greywater*.
- The guidance provided is intended to be used within the context of existing knowledge and best practice relating to irrigation, *e.g.* selection of plants, installation and maintenance of irrigation equipment, and adaptation of irrigation schedules to local agroclimatic conditions. The guidelines focus not on providing a catch-all manual for small-scale irrigation implementations, but on *managing the additional risks and challenges* arising out of the use of greywater in such implementations.

Structure of Guidance Report
The structure decided upon for the Guidance Report is as follows:

What is greywater?
Why use greywater for irrigation?
Concerns about the use of greywater for irrigation
    Health considerations
    Plant growth and yield
    Ability of soil to support plant growth
Purpose of the Guidance Report
    Intended users of the Guidance Report

Focus of the Guidance Report
Major sources used
Legislative context of greywater use for irrigation
Special considerations
Guidance for greywater use in small-scale irrigation in South Africa
Guide to managing risks and uncertainty
Greywater quality: Guide to greywater constituents
Greywater quality: Mitigation of greywater quality
Greywater quantity: Guide to irrigation volumes

The core of the Guidance Report is provided by the section "Guidance for Greywater Use in Small-Scale Irrigation in South Africa". In the sub-section on "Managing Risks and Uncertainty in Greywater Irrigation", three categories of greywater use are identified, based on the extent of characterisation of greywater and, by implication, on compliance with quality limits. Use restrictions are identified for each category. The most stringent restrictions apply to greywater used without characterisation. Minimum analysis – comprising pH, electrical conductivity, sodium adsorption ratio and *E. coli* –, and compliance with quality limits on these, are associated with less stringent restrictions. The least restrictions are associated with use of greywater undergoing full analysis (minimum analysis plus boron, chemical oxygen demand, oil and grease, suspended solids, total inorganic nitrogen and total phosphorus). The quality limits in each category are specified in the sub-section on "Greywater Quality: Guide to Greywater Constituents". The section on "Greywater Quality: Mitigation of Greywater Quality" provides means of adjusting to or improving on greywater quality. Two approaches are considered: agricultural practices to mitigate the effect of, predominantly, chemical constituents such as sodium; and treatment to improve, predominantly, the organic and microbiological quality of greywater. The last sub-section, "Greywater Quantity: Guide to Irrigation Volumes" guides users in selecting the volume of greywater to be applied and in adjusting this for site-specific conditions.

Major recommendations

Recommendations for the dissemination of the outputs of the project, implementation of the Guidance Report and further research to address remaining knowledge gaps were formulated, again based on the literature review and the outcomes of the case studies.

Implementation: Dissemination of Guidance Report

- All local authorities, as well as Water Boards, should be informed directly of the imminent release of the Guidance Report, once an approximate release date is known.
- The Water Institute of Southern Africa (WISA) should be used to publicise the release of the Guidance Report to its members.
- Consideration should be given to establishing a Greywater web page on the WRC web site.

Implementation: Capacity building at Local Authority level

- A short educational pamphlet on greywater and greywater irrigation, aimed specifically at local authorities, should be developed and distributed.

- Attendees at a capacity building workshop, held in January 2010 to introduce local authorities to the Guidance Report, requested that the workshop be repeated annually. They requested addition of a practical component during which hands-on experience could be obtained of successful interventions.
- Another request made by attendees at the capacity building workshop referred to above was a forum in which questions could be asked and experiences exchanged on an ongoing basis.

Implementation: Education of greywater users

- Potential greywater users need to be involved in planned greywater implementations from the planning stages, informing them of the benefits and risks of greywater use for irrigation, allowing them to express their views and concerns, and providing a mechanism for them to be involved in decision-making.
- Potential irrigation users of greywater need information to practice greywater irrigation in a safe and sustainable manner. Although this information is provided in the Guidance Report, it would be helpful to provide users with quick reference sheets to support the more comprehensive Document. This could take the use of one-page information sheets.
- Once a greywater implementation has been planned and initiated, greywater users need ongoing monitoring and support. This should be tailored to meet the different information and support needs of low income rural and peri-urban settlements and middle to higher income urban settlements.

Legislation: Recognition of greywater and beneficial greywater use in water and waste legislation

- Current legislation pertaining to disposal and use of water and waste falls short in that a definition of greywater as a separate wastewater stream is lacking. Clarity is needed for the future by explicit definition of greywater and the beneficial uses to which it may be put.

Research: Remaining knowledge gaps

- Suitable indicator micro-organisms for health protection.
- Identification of the greywater quality constituents which most contribute to deterioration in plant growth, crop yield, crop quality and soil characteristics.
- Maximising fertiliser potential of greywater.
- Trialling of 'green' cleaning products to test whether the greywater generated with these does indeed preserve plants, crops and soil relative to greywater generated with conventional cleaning products.
- Cost-effective proven on-site treatment processes that are sufficiently robust for implementation in low income communities.
- Role of different soil types on interaction with greywater.
- The pollution potential of managed greywater irrigation.

In addition, review of the Guidance Report is recommended in one to two years, with updates to be made based on experience in practice.

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Mr N Ahashoni	Department of Water Affairs
Dr J Burgess	WRC
Mr LR Gravelet-Blondin	Department of Water Affairs/Consultant
Dr WR Harding	Consultant
Ms S Harigobin	Department of Water Affairs
Mr JL Harrison	eThekwini Municipality
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Mr L Ramashala	Department of Water Affairs
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Abbreviations and Acronyms

ANOVA	Analysis Of Variance
BCM	Buffalo City Municipality
BOD	Biochemical Oxygen Demand
CF	Crop Factor
CFU	Colony Forming Unit
COD	Chemical Oxygen Demand
DAFF	Department of Agriculture, Forestry and Fisheries
DALY	Disability-Adjusted Life Years
DBP	Disinfection By product
DEA	Department of Environmental Affairs
DoH	Department of Health
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
E_0	Reference Evapotranspiration
EC	Electrical Conductivity
EcoSan	Ecological Sanitation
EDC	Endocrine Disrupting Chemical
ESP	Exchangeable Sodium Percentage
ET	Evapotranspiration
EWU	Estimated Water Use
GA	General Authorisation
GP	Gauteng Province
HA	Area Irrigated
HIV/AIDS	Human Immunodeficiency Virus / Acquired Immune Deficiency Syndrome
IAPs	Interested and Affected Parties
KZN	KwaZulu-Natal
LIM	Limpopo
MDGs	Millennium Development Goals
MP	Mpumalanga
NBR	National Building Regulations
NGO	Non-Governmental Organisation
NWA	National Water Act
PFU	Plaque Forming Unit
PhAC	Pharmaceutically Active Compounds
PRG	Pollution Research Group
QMRA	Quantitative Microbial Risk Assessment
SALGA	South African Local Government Association
SAR	Sodium Adsorption Ratio
SAWQG	South African Water Quality Guidelines
SS	Suspended Solids
TDS	Total Dissolved Solids
TKN	Total Kjeldahl Nitrogen
TOC	Total Organic Carbon
TSS	Total Suspended Solids
UCT	University of Cape Town
UD	Urine Diversion
UN	United Nations

UNESCO	United Nations Education, Scientific and Cultural Organisation
UV	Ultraviolet
WHO	World Health Organisation
WC	Western Cape
WRC	South African Water Research Commission
WSA	Water Services Authority
WSP	Water Services Provider
XOC	Xenobiotic Organic Compound

1 Introduction

1.1 Background

Greywater is untreated household wastewater from baths, showers, kitchen and hand wash basins, and laundry, *i.e*. all non-toilet uses (Morel and Diener, 2006). Many authors exclude water from kitchen sinks and dishwashers in their definition of greywater (Alcock, 2002; Roesner *et al*., 2006). More than half of indoor household water use is normally used for these purposes and can potentially be intercepted by the householder for additional uses. Greywater use is practiced on an informal basis to supplement irrigation water, either in urban gardens in middle to upper income suburbs in times of drought, or in food gardens in lower income informal, peri-urban and rural areas. It holds the potential to contribute significantly to food security in low income settlements by providing a source of both irrigation water and nutrients for crop plants. Where crops are produced in excess of household needs and can be sold or exchanged for other goods or services, it further holds the potential for informal employment.

The long term needs of South African citizens as far as access to water is concerned, have already been spelt out in key government structures, with the targets for the provision of basic water and sanitation set out in the Strategic Framework for Water Services (DWAF, 2003) as well as in the Millennium Development Goals (MDGs) (UNICEF, 2007). Missing from the policy however, are the goals for managing future scarcity caused by climatic change and demographic shifts, as well as the handling of wastewater. In this regard, the management of greywater can contribute both to water conservation and to environmental rejuvenation. The basic strategies for the management of greywater should therefore allow for health improvement, water conservation, reuse (where possible) and environmental protection.

It is possible that greywater could make some contribution to water conservation and to easing the pressure on sources of potable water by replacing this water in various uses, *e.g.* pour-flush toilets, irrigation of gardens, lawns, shrubs and trees, and dust control. This is not advisable in densely-settled areas however, where greywater has minimum reuse value owing to its generally very poor quality. In instances where its quality allows it, however, greywater use for irrigation of gardens and small-scale agriculture holds promise.

There are no formal guidelines for the use of greywater for irrigation in South Africa at present. The WRC therefore has funded, and continues to fund, research into the management of greywater from sewered and unsewered areas, addressing both management of greywater to prevent adverse health and environmental effects, and the potential beneficial uses of greywater. As part of this focus on greywater, the WRC solicited the present project to develop guidance for the use of greywater in small-scale agriculture and gardens.

The use of greywater for irrigation of food crops poses certain health challenges about which not enough is known at present. Projects investigating hazards associated with greywater reuse are reported as part of this project. The results of site surveys conducted in unsewered areas throughout South Africa by Carden *et al.* (2007) have shown that there is some resistance to the use of greywater for food irrigation purposes, based on its poor chemical and bacteriological quality (which are the consequences of the amounts of detergent in the water and the different uses to which the water is put), and also because of observations that certain crops (*e.g.* maize) are not able to tolerate the elevated salt levels and other chemical contaminants in the greywater. Water quality data collected during these surveys of unsewered areas confirmed that this greywater is generally unfit for use except under controlled conditions, but the concept of using certain types of greywater (*e.g.* first-wash or rinse waters) should not be ignored (Carden *et al*., 2007). A scoping study has been undertaken in this regard (Murphy, 2006) to evaluate the fitness-for-use of greywater in urban and peri-urban agriculture. These investigations form the background to the present project which was solicited by the Water Research Commission (WRC) to develop guidance for the sustainable use of greywater in gardens and small-scale agriculture (henceforth referred to collectively as small-scale irrigation).

The use of greywater in agriculture fits in well with the concepts of Ecological Sanitation (EcoSan) which seeks to prevent pollution and disease by managing human urine and faeces as a resource rather than a waste, with recovery and recycling of the nutrients (Winblad *et al*., 2004). The difference between the use of toilet waste (*e.g.* urine and safely composted faecal matter) and greywater (bacteriological issues aside) however, is that toilet waste generally has beneficial levels of nutrients for plant growth without harmful chemical contamination. By contrast, greywater generated in households generally has low levels of nutrients (except for phosphorous, usually in the form of polyphosphates which react in water to become orthophosphates) and often high levels of chemicals from the detergents (salts, metals, *etc*.), which are potentially harmful to plants. In both cases, the management of the recycling practice is crucial and the precautionary principle needs to be applied, particularly with respect to health issues, *e.g.* gastro-intestinal disease and HIV/AIDS management. The over-riding principle is that the reuse of greywater for the irrigation of edible food should not be allowed in unsewered areas without being able to identify and describe the risks involved, preferably quantitatively (Carden *et al*., 2007).

1.2 Project aims and objectives

Overall aim

To develop guidance for the sustainable use of greywater in small-scale agriculture and gardens in rural villages, peri-urban and urban areas of South Africa.

Objectives

1. Identify and describe the areas where greywater use is an established practice.
2. Refine knowledge on the *status quo* of greywater use (where, who, why, how, quantities and qualities) and needs of actual and potential users of greywater.
3. Review the social and anthropological acceptability of greywater use.

4 Review the current institutional and legal framework for use of greywater in consultation with DWA, DoH, DAFF, DEA and other relevant South African government departments.
5 Document the available knowledge (including the previous four objectives, other WRC projects and South African and international experience) and other considerations in a Technical Report that records the proposed rationale and associated limits for South African conditions as reflected in the Draft Generic Guidelines.
6 Develop Draft Generic Guidelines for sustainable use of greywater in small-scale agriculture and gardens based on the rationale provided in the Technical Report.
7 Workshop the draft generic guidelines with Water Service Authorities (WSAs), Water Service Providers (WSPs), users and other interested and affected parties (IAPs) to test the feasibility and acceptability thereof.
8 Identify the most important gaps in knowledge that should be addressed to refine the draft guidelines.
9 Conduct a number of case studies designed to fill these gaps in knowledge.
10 Test the draft guidelines against current practice.
11 Update the Technical Report to record the rationale and associated limits for the final set of guidelines.
12 Consult with regulating authorities and potential users of the guidelines about the acceptability of the proposed rationale and associated limits for the guidelines.
13 Identify, document and prioritise the remaining crucial issues relating to greywater use that would need to be investigated in follow-on research.
14 Prepare a final set of final user friendly guidelines for different target groups (*e.g.* sewered *vs.* unsewered; urban *vs.* rural; inland *vs.* coastal, *etc.*) for current and potential use of greywater in small-scale agriculture and gardens in rural villages, peri-urban and urban areas of South Africa.

1.3 Approach adopted to address project aim and objectives

The steps taken to develop a Guidance Report for the use of greywater in small-scale irrigation and a supporting Technical Report are outlined below. Objectives from Section 1.2 above which were addressed at each stage are indicated in brackets.

- National and international literature was surveyed to identify existing knowledge and key issues relating to standards, guidelines and advice on the use of greywater for irrigation. Existing WRC projects, peer-reviewed literature, legislation and guidelines, technical reports and ‘and ‘grey’ literature were used as sources. A literature review was produced which summarised this information. This is included in the Technical Report, and provided the basis for development of the Guidance Report and for case studies. (Objectives 1, 2, 3, 4, 5)

- Based on the outcome of the literature review, gaps in knowledge were identified, and case studies to address these knowledge gaps were proposed. These included a number of desk studies, surveys of local authorities and potential greywater users, and three experimental studies (plant growth with greywater irrigation; health risks associated with greywater irrigation; and greywater treatment). The outcomes of the case studies were documented for inclusion in the Technical Report. (Objectives 8, 9, 11)

- Consultation was undertaken with policy-makers, local authorities and potential greywater users. Several methods were used. An exploratory workshop was held with policy-makers, while local authorities were surveyed by a questionnaire sent out to all local authorities listed by the South African Local Government Association (SALGA). Existing surveys of greywater generation, use and disposal, from WRC Project 1524 (Carden *et al.*, 2007), were supplemented by surveys of six settlements served either by waterborne sewerage or by dry on-site sanitation. (Objectives 2, 3, 4, 9, 11)

- Beginning with the water quality aspect of guidance for irrigation use of greywater, a preliminary identification of greywater constituents of interest was performed based on existing studies of greywater quality in South Africa. (Objectives 9, 11)

- Draft greywater quality guidance was developed for all identified constituents. This preliminary guidance was submitted for peer review by the Reference Group, with the aim of reducing the number of constituents to a practical short list and of setting the framework for other issues to be addressed in the Guidance Report. (Objectives 6, 10).

- A full draft of the Guidance Report was developed, containing sections on
    - managing risks and uncertainty in greywater irrigation,
    - greywater quality,
    - greywater quality mitigation and
    - greywater quantity.

  (Objective 6)

- The completed Draft Guidance Report was submitted for peer review via the Reference Group. It was also submitted to representatives of policy-makers for comment. (Objectives 10, 12)

- A feedback and capacity building workshop was held for local authorities, in which the Guidance Report was presented and feedback was solicited. Policy-makers were invited to participate in the workshop or otherwise to provide comment on the Document. (Objectives 7, 10, 12)

- The outcomes of the case studies, peer review and consultation were incorporated in the Guidance Report and the Technical Report. (Objectives 11, 14)

- Implementation and research recommendations were formulated on the basis of all work conducted. These were included in the Technical Report. (Objectives 11,13)

1.4 Structure of the Technical Report

This introductory chapter is followed by a literature review in Chapter 2. The nature of greywater is examined, followed by a review of regulations and guidelines pertaining to greywater use in South Africa and beyond. Quality of greywater is described, and specific implications of greywater quality for greywater irrigation are considered. Options for greywater treatment are briefly described, as are the issues surrounding the implementation of a greywater irrigation project.

Chapter 3 presents case studies conducted to support the development of guidance for greywater irrigation in South Africa.

The implications of both the reviewed literature and the case studies for the development of guidance for greywater irrigation are considered in Chapter 4.

The approach to guidance development in South Africa is described in Chapter 5.

The problem of engaging communities in greywater irrigation implementations is considered in Chapter 6, and a case study is presented.

Recommendations for implementation of greywater irrigation and for further research in the field are given in Chapter 7.

2 Literature Review

2.1 What is greywater?

Greywater, graywater, sullage and light wastewater are terms that are used as synonyms. Greywater is commonly defined as all wastewater generated in the household from bathroom sinks, baths, showers, laundry facilities and kitchen wastewater, excluding toilet waste. In various countries greywater definitions sometimes exclude wastewater from the kitchen (Eriksson *et al*., 2002; Dixon *et al*., 1999; Roesner, 2006).

Domestic wastewater is divided into three distinct wastewater forms *viz.* black water, yellow water and greywater. Black water arises from toilet waste and is collected via sewer drainage systems. It is characterised by high concentrations of potentially pathogenic microorganisms, high organic loads, high concentrations of nutrients, is typically dark in colour and is foul-smelling (Al-Jayyousi, 2003). Yellow water is the waste stream which contains urine. It is not usually collected separately from black water except where some form of source separation sanitation (typically in the form of urine diverting systems) is practised. Yellow water contains the highest concentration of the nutrients nitrogen and phosphorus, and should contain the lowest concentrations of micro-organisms. Where systems are suitably designed to accommodate this, it can be collected separately and used in agriculture as a plant nutrient supplement (Winblad *et al*., 2004). Greywater is usually characterised by low to moderate levels of microbial contamination, contains only about 1/10th of the nitrogen (nitrite and nitrate) in mixed domestic waster, its organic content decomposes more rapidly, it is lighter in colour, has less organic load, and a comparatively low nutrient content which makes it easier to treat (Prathapar *et al.,* 2005).

Greywater characteristics depend largely however on *inter alia* the level of water and sanitation service to a settlement, quality of water supply, type of distribution for both drinking and greywater, and activities in the household. The compounds present in greywater vary from source to source, where customs, installation, and use of chemical household products are of importance (Eriksson *et al*., 2002). The most obvious concerns with respect to greywater quality include micro-organisms, nutrients, salts and heavy metals. Increasing concern is being shown about xenobiotic organic compounds (XOC), pharmaceutically-active compounds (PhAC), endocrine disrupting compounds (EDC) and disinfection-by-products (DBP) in wastewater in general, hence also in greywater (Eriksson *et* al., 2002; Toze, 2006). However, little is known about the significance of these in greywater. Presently, most studies characterising greywater are from European and North American countries, with only limited information available on greywater characteristics in low and middle-income countries.

Owing to the fact that greywater has lower strength, and lower concentrations of health-related micro-organisms and nutrients than blackwater, it can also potentially be re-used. One possible form of re-use is for small-scale irrigation of gardens and crops. However, because it remains a waste stream containing potentially significant levels of contaminants, any re-use must be subject to guidelines to protect human users and the environment from possible adverse effects.

Authors writing about greywater in South Africa have distinguished between “light greywater” and “dark greywater”, the latter being typified by the highly polluted greywater emanating from unsewered informal settlements. Dark greywater is characterised by high organic strength, high microbial loads and high content of chemical pollutants. This type of greywater is not suitable for further use without extensive intervention and is probably fit only for disposal to a sewer. Irrigation use is therefore an option only for less strongly polluted, ‘lighter grey’ forms of greywater (Carden *et al*., 2007; Winter *et al*., 2010).

2.2 Review of guidelines worldwide

2.2.1 Standards, guidelines and recommendations pertinent to irrigation use of greywater in South Africa

Legal context for greywater use in South Africa

Although greywater use is presently practised to some extent on an informal basis to supplement irrigation water, either in urban gardens in middle to upper income suburbs in times of drought, or in food gardens in lower income informal, peri-urban and rural areas, there are no formal standards or guidelines for the irrigation use of greywater in South Africa at present.

The National Water Act (NWA) of 1998 is the major piece of legislation addressing the use and disposal of water in South Africa. The Act makes no specific reference to greywater, but refers to “disposal of waste or water containing waste”. This may be considered to apply also to greywater. In terms of the NWA, use of water containing waste for irrigation is considered a “controlled activity”. Discharge or use of water containing waste requires that the use is listed in a General Authorisation (GA) of the Act or alternately requires issue of a licence.

General Authorisations provided under the NWA were revised in 2004 to allow, amongst others, limited use of biodegradable industrial wastewater for irrigation (DWAF, 2004). Although greywater is not mentioned among the types of wastewater considered, this is probably the closest that existing legislation comes to providing guidance for quality of greywater intended for irrigation use. Three categories of wastewater quality are mentioned, linked to the volume irrigated per day (see below). Although irrigation use of wastewater under this revision of the general authorisations does not require a licence, users are required to register such use with a responsible authority.

The Department of Water Affairs (previously Department of Water Affairs and Forestry), the Government department tasked with implementation of the NWA, has indicated that it supports single household use of greywater for irrigation as a water-saving measure, provided this poses no health or pollution hazards. The authorisation for this is considered to be implicitly provided under permitted water uses specified in Schedule 1 of the NWA. Although greywater use for small-scale irrigation is not mentioned specifically, it is considered to be within the spirit of the law. For larger scale use, either the requirements under the GAs apply as mentioned above, or a licence for this use would have to be obtained (Gravele't-Blondin, pers. comm., 2010).

The National Building Regulations (NBR), in terms of the National Building Regulations and Building Standards Act 103 of 1977, recognises only stormwater and sewage (domestic wastewater including toilet waste) as water leaving a property and provides regulations for how each is to be managed. Greywater is not defined separately and would be considered to fall under sewage. In terms of the NBR, there is therefore no provision for the storage and use of greywater on a property (Resolve Consulting, Report to eThekwini Municipality, in preparation).

National policy on water and sanitation defines minimum levels of sanitation and water supply to which all South Africans are entitled, but fails to address the disposal of greywater (DWAF, 1994; DWAF, 2003). Irrigation with wastewater is addressed under national health guidelines (Department of National Health and Population Development, 1978), although these do not make specific reference to greywater.

Some local authorities, *e.g.* Cape Town Municipality, have introduced policies and by-laws (currently in draft form) which provide guidance relevant to the management and use of greywater for irrigation, either explicitly or implicitly (Carden *et al*., 2007). However, the status of such guidance remains in doubt as long as the status of greywater use in terms of the NWA is not clarified.

Thus, existing legislation does not specifically exclude use of greywater for irrigation, but there are inconsistencies which arise from the absence of a clear definition of greywater as a subset of domestic wastewater which differs in character and hazards from blackwater. These need to be resolved to clarify the legal position of use of greywater for irrigation.

South African revised General Authorisations under the National Water Act (DWAF, 2004)

It is worthwhile to visit the revised GAs under the NWA (DWAF, 2004) in a little more detail since, in the absence of greywater-specific guidelines, these may be considered to give guidance for the quality of greywater which is to be discharged or used for irrigation.

The revised GAs allow for irrigation of land with "biodegradable industrial wastewater" arising from a list of industrial activities as specified in the legislation. The quality of the wastewater to be used for irrigation is linked to the volume of water to be used, as shown in

Table **1**. In addition to the quality limits shown, irrigation with wastewater may not impact on a water resource or on the water use of another person, and may not be detrimental to the health and safety of the public in the vicinity (DWAF, 2004). Small-scale irrigation with greywater is most likely to fall into the category specifying irrigation of up to 500 m^3 per day. The extent to which greywater would meet the relevant water quality requirements is arguable, particularly with respect to microbiological quality (faecal coliforms not to exceed 100 000 colony-forming units (CFU) per 100 mℓ) (Murphy, 2006). No licence is required for the use of wastewater for irrigation, within the stated limits, but the irrigation use must be registered with a responsible authority and the general authorisation applies for a maximum of five years (DWAF, 2004).

Table 1 Quality of biodegradable industrial wastewater which may be used for irrigation, according to the revised General Authorizations under the National Water Act (DWAF, 2004).

Maximum volume of wastewater irrigated per day	Wastewater constituent	Limit
2 000 m^3	Faecal coliforms Chemical oxygen demand (COD) pH Ammonia-nitrogen Nitrate/nitrite-nitrogen Free chlorine Suspended solids Electrical conductivity Orthophosphate-phosphorus Fluoride Soap, oil or grease	1 000/100 mℓ 75 mg/ℓ 5.5-9.5 3 mg/ℓ 15 mg/ℓ 0.25 mg/ℓ 25 mg/ℓ Does not exceed 70 mS/m above intake, to a maximum of 150 mS/m 10 mg/ℓ 1 mg/ℓ 2.5 mg/ℓ
500 m^3	Electrical conductivity pH COD Faecal coliforms Sodium adsorption ratio (SAR)	200 mS/m 6-9 400 mg/ℓ after removal of algae 100 000/100 mℓ 5
50 m^3	Electrical conductivity pH COD Faecal coliforms SAR	200 mS/m 6-9 5 000 mg/ℓ after removal of algae 100 000/100 mℓ 5

Limits are also set for the discharge of domestic or industrial wastewater into water resources. These limits could also be considered a guide to the quality of greywater which can be used beneficially, although clearly not as directly applicable to greywater irrigation as the limits for wastewater irrigation, presented above. DWAF (2004) states that up to 2 000 m^3 of wastewater can be discharged per day to a water resource which is not a listed water resource (as listed in the legislation), provided it complies with the general limit values shown in table 1. For listed water resources, the special limit values in Table 2 apply.

Table 2: Wastewater limit values applicable to discharge of wastewater into a water resource (from DWAF, 2004).

Wastewater constituent	General limit	Special limit
Faecal coliforms	1 000/100 mℓ	0
Chemical oxygen demand, after removal of algae	75 mg/ℓ	30 mg/ℓ
pH	5.5-9.5	5.5-7.5
Ammonia (unionised and ionised), as nitrogen	6 mg/ℓ	2 mg/ℓ
Nitrate/nitrite as nitrogen	15 mg/ℓ	1.5 mg/ℓ
Chlorine as free chlorine	0.25 mg/ℓ	0
Suspended solids	25 mg/ℓ	10 mg/ℓ
Electrical conductivity	70 mS/m above intake to a maximum of 150 mS/m	50mS/m above background receiving water to maximum of 100 mS/m
Orthophosphate as phosphorus	10 mg/ℓ	1 (median) 2.5 (maximum)
Fluoride	1 mg/ℓ	1 mg/ℓ
Soap, oil or grease	2.5 mg/ℓ	0
Dissolved arsenic	0.02 mg/ℓ	0.01 mg/ℓ
Dissolved cadmium	0.005 mg/ℓ	0.001 mg/ℓ
Dissolved chromium (VI)	0.05 mg/ℓ	0.02 mg/ℓ
Dissolved copper	0.01 mg/ℓ	0.002 mg/ℓ
Dissolved cyanide	0.02 mg/ℓ	0.01 mg/ℓ
Dissolved iron	0.3 mg/ℓ	0.3 mg/ℓ
Dissolved lead	0.01 mg/ℓ	0.006 mg/ℓ
Dissolved manganese	0.1 mg/ℓ	0.1 mg/ℓ
Mercury and its compounds	0.005 mg/ℓ	0.001 mg/ℓ
Dissolved selenium	0.02 mg/ℓ	0.02 mg/ℓ
Dissolved zinc	0.1 mg/ℓ	0.04 mg/ℓ
Boron	1 mg/ℓ	0.5 mg/ℓ

South African Water Quality Guidelines for irrigation

With specific reference to the irrigation aspect of greywater use for small-scale irrigation, the South African Water Quality Guidelines (SAWQG) (DWAF, 1996) for irrigation use (Volume 4 of the SAWQG) may also be used as an indicator of acceptable water quality. These guidelines are summarised in Table 3. It is evident from inspection that this list contains many water constituents which are unknown, and probably inapplicable, to greywater relative to any other irrigation water, while other constituents which would be expected to be of importance in greywater specifically are not specified, *e.g.* chemical oxygen demand (COD), oil and grease, different nitrogen species, phosphorus, micro-organisms other than faecal or thermotolerant coliforms / *Escherichia coli*.

It should be noted that the rationale of the SAWQG is based on qualitative assessment of risk, the particular type of risk depending on the use to which the guidelines apply. In terms of irrigation, the guidelines consider mainly risk of harm to human consumers, plants, crops and soil, and secondarily risk to irrigation equipment. Additionally, the SAWQG for irrigation apply predominantly to large-scale irrigation use, which differs from the smaller scale for which greywater irrigation is anticipated.

Table 3: Summary of South African Water Quality Guidelines for Irrigation, 2nd edition (summarised from DWAF, 1996).

Irrigation water constituent	**Target range**	**Maximum range, (mostly applicable to fine-textured neutral to alkaline soils)**	**Short-term use on site-specific basis**
Aluminium (mg/ℓ)	Up to 5	5-20	> 20
Arsenic (mg/ℓ)	Up to 0.1	0.1-2.0	> 2.0
Beryllium (mg/ℓ)	Up to 0.1	0.1- 0.5	> 0.5
Boron (mg/ℓ)	Up to 0.5	0.5 to 6.0, depending on crop sensitivity	> 6.0
Cadmium (mg/ℓ)	Up to 0.01	0.01-0.05	> 0.05
Chloride (mg/ℓ)	Up to 100	100-350, depending on crop sensitivity	> 350
Chromium (VI) (mg/ℓ)	Up to 0.1	0.1-1.0	> 1.0
Cobalt (mg/ℓ)	Up to 0.05	0.05 -5.0	> 5.0
Coliforms (faecal) (counts/100 mℓ)	Up to 1	1-1 000	> 1 000, can be used on limited contact crops depending on irrigation system > 50 000, clogging of drip irrigation systems
Copper (mg/ℓ)	Up to 0.2	0.2-0.5	> 0.5
Fluoride (mg/ℓ)	Up to 2.0	2.0-15	> 15
Iron (mg/ℓ)	Up to 5.0	5.0-20	> 20
Lead (mg/ℓ)	Up to 0.2	0.2-2.0	> 2.0
Lithium (mg/ℓ)	Up to 2.5	2.5-5.0, depending on crop sensitivity	
Manganese (mg/ℓ)	Up to 0.02	0.02-10	> 10
Molybdenum (mg/ℓ)	Up to 0.01	0.01-0.05	> 0.05
Nickel (mg/ℓ)	Up to 0.2	0.2- 2.0	> 2.0
Nitrogen (inorganic) (mg/ℓ)	Up to 5	5-30	> 30
pH	6.5-8.4		< 6.5, > 8.4
Scaling / corrosion/hardness (Langelier index, saturation pH of water with respect to calcium carbonate concentration)	-2.0 to +2.0		< -2.0, > +2.0
Selenium (mg/ℓ)	Up to 0.02	0.02-0.05	> 0.05
Sodium Adsorption Ratio, SAR ($[sodium]/\sqrt{[calcium]+[magnesium]}$ All concentrations measured in mmol/ℓ, SAR usually reported without units)	Up to 2.0	2.0-15, depending on sensitivity of crops to sodium	> 15
Sodium (mg/ℓ)	Up to 70	70-460, depending on crop sensitivity	> 460
Suspended solids, SS (mg/ℓ)	Up to 50	50-100, depending on irrigation system	> 100
Total dissolved solids, TDS (mg/ℓ)	Up to 40	40-540, by adjusting leaching fraction	> 540
Uranium (mg/ℓ)	Up to 0.01	0.01-0.10	> 0.10
Vanadium (mg/ℓ)	Up to 0.1	0.1-1.0	> 1.0
Zinc (mg/ℓ)	Up to 1.0	1.0-5.0	> 5.0

Guidelines for greywater management in South Africa

A number of authors have presented recommendations for the management of greywater, specifically in informal settlements (Wood *et al*., 2001; Carden *et al*., 2007), and for irrigation use of greywater (Murphy, 2006; City of Cape Town, quoted in Carden *et al*., 2007). These recommendations have predominantly issued from WRC-sponsored studies on greywater management and use. They provide guidance for minimising the adverse impact of greywater on human users and the environment, for planning greywater irrigation implementations, and for the general operation of greywater irrigation. The guidelines presented by each author are summarised below. Guidelines for greywater management are discussed first, followed by those for planning and, finally, operation of greywater irrigation implementations.

Greywater management in dense informal settlements (Wood et al., 2001)

Wood *et al.* (2001) highlighted that the potential for greywater generation had to be considered and provided for when planning and developing settlements. They concluded that integration of suitable long-term service provision was essential to alleviate the problems of greywater management which they observed in their study of dense informal settlements in South Africa. Guidelines were proposed regarding the planning of greywater systems, as follows:

- Settlements should not be established on steep slopes because of the increased risk of erosion.
- No development should occur in the 1:50 year floodline, and natural drainage channels should be maintained.
- Where water points are located near rock outcrops or where the soil in the area is unsuitable, it may be possible to use surface drains to transport greywater to a more suitable area for disposal.
- Open spaces should be maintained within informal settlements.
- Provision must be made for the collection of greywater and leakage from water standpipes; preferably infiltration beds and soakaways should be provided at the standpipes (or drainage to gravitate the greywater to an appropriate site for handling and disposal) so that ponding of contaminated water is minimised. Standpipes should be no further than 100 m from each household.
- The preferred option for greywater disposal is by gravity to sewer – the collection and treatment of greywater in ponds or wetlands is not a viable option for many high-density settlements owing to the lack of large open spaces, health risks, safety considerations, *etc*.
- Solid waste collection points should be established at regular, convenient points throughout the settlement, and should be protected from wind and stormwater.

Planning greywater use for irrigation (Murphy, 2006)

Murphy (2006) considered the fitness-for-use of greywater in urban and peri-urban agriculture. In presenting his recommendations, he provided a list of steps to be taken when considering greywater use for irrigating garden crops:

- Greywater availability – The available sources of greywater (laundry, bath, wash basin, shower, kitchen rinse water) should be identified. For each source, the volume of greywater produced on a daily or weekly basis should be estimated.

- Land area suitable for irrigating garden plants – The area of land that can be irrigated using each greywater source should be calculated. It would be necessary to 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 – It would be necessary to identify 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 – Greywater should be used by source, in the following order of preference:
  1. bathroom greywater;
  2. laundry greywater (preferably use only rinse-wash water);
  3. kitchen greywater (rinse water only, unless using for composting).

  (Example of a treatment option: Using a sieve at the greywater source for trapping hair, lint and food particles).
- Management measures – The management measures which may be applicable for greywater irrigation from the source in question should be determined (*e.g.* it may be necessary to ameliorate the soil on a regular basis to counteract the negative effects of sodium on soil structure.)
- Regulations – Applicable regulations (*e.g.* municipal by-laws) would need to be determined.
- Health aspects of greywater quality – Greywater should not be used if any member of the household has an infectious disease.

Such basic characterization of the greywater, application site and plants to be irrigated, would need to be combined with an assessment of the quality of the greywater under consideration, which can be expected to vary widely from site to site.

Summary of specific recommendations for greywater use for irrigation (Murphy, 2006)

In addition to outlining the planning requirements for greywater irrigation applications, Murphy (2006) also provided extensive practical recommendations for day-to-day management of greywater irrigation. These are summarised as follows:

- For newly-designed houses, greywater outlet pipes should be kept separate until outside the house.
- Simple gravity-feed greywater irrigation systems should be used wherever possible.
- For greywater from the laundry and kitchen, it would be preferable to use only rinse water for irrigation.
- For laundry greywater to be used for irrigation, it would be preferable to use low sodium-content and zero boron-content detergents and soaps. Fabric softeners and chlorine-based bleaches should not be used.
- Water softeners should not be used.
- For piped irrigation systems, a minimum of a simple filter (*e.g.* a nylon stocking) should be used. It should be possible for irrigation piping to be completely and easily drained. Greywater storage tanks should be covered.

- For piped systems at dwellings connected to sewage systems, there should be a diversion facility to the sewage system at or near the greywater source outlet.
- Greywater should not be allowed to leave the property on which it is generated, except by sewer.
- It should be possible to accommodate surges in the greywater irrigation system (*e.g.* a surge tank or mulch basin).
- Greywater should not be stored for longer than 24 hours.
- Greywater should not be used for spray irrigation.
- Mulch and/or compost should be used on the soil surface and in irrigation trenches to reduce evaporation, to help prevent accidental contact with greywater and to ensure that irrigated soils have adequate sub-surface drainage.
- Greywater should not be applied to one place for long periods of time.
- Greywater should not come into contact with edible parts of crops, and crops should be cooked prior to consumption. Greywater should not be applied to crop foliage.
- Greywater potentially containing particularly infectious pathogens should not be used for irrigation.
- Greywater should be applied only to mature crops. If any signs of plant injury appear, greywater irrigation should be reduced or stopped, and soils should be flushed with fresh water.
- The following precautions should be taken when irrigating with greywater (or other water) which has high concentrations of dissolved salts:
    - Sodium-tolerant, salt-tolerant and high-pH-tolerant plants should be selected.
    - Gypsum should be used to mitigate soil infiltration problems.
    - The leaching fraction should be increased (and adequate aeration of soils and sub-surface drainage should be ensured). Alternately, fresh water should be applied in rotation with greywater to leach out salts. A little gypsum may be applied directly to the surface to stimulate percolation, if necessary.
    - Irrigation water should not be applied to plant leaves.

Greywater management in unsewered settlements (Carden et al., 2007)

Carden *et al.* (2007) surveyed greywater generation and provision for greywater management in unsewered settlements across South Africa. They concluded that the density of a particular settlement, together with the consumption of water per dwelling unit, were the most critical factors in determining whether greywater could be safely disposed on-site (including reuse options). However, they observed that it was behavioural patterns that drove the reality of how greywater was disposed. Although the level of service with respect to water supply to unsewered areas varied widely, only two categories seemed to have any influence on the amounts of water consumed, *viz*. having a tapstand on the property or having to walk to fetch water, irrespective of the distance walked (Carden *et al.*, 2007). A water supply point located on the property (*i.e.* in-house or yard tap) increased water consumption by as much as 2 to 3 times, compared to having to walk to fetch water (Graham, 2003).

Carden *et al.* (2007) developed a relationship to describe the interdependence of dwelling density and average volume of greywater volume generated by each dwelling in influencing greywater quality. They termed this the greywater generation rate, G. The relationship is presented in Equation 1. A mean value of 75% return rate on water consumption was assumed on the basis of on-site surveys of dense informal communities.

This relationship was expressed as follows:

$$G = QD \qquad \textbf{Equation 1}$$

G is the greywater generation rate, ℓ/ha.day
Q is the volume of greywater produced per household (water consumption × 75%), ℓ/dwelling unit (du).day
D is the density of households per hectare, du/ha.

Management guidelines were proposed for different ranges of greywater generation rate, G:

- *Low density greywater generation* was defined as < 500 ℓ/ha.day, which generally equates to dwelling densities of < 10 du/ha and plot sizes of > 800 m^2.
- *Low/medium density greywater generation* was defined as 500-1 500 ℓ/ha.day, equating to dwelling densities of 10-30 du/ha and plot sizes of 300-800 m^2.
- *Medium/high density greywater generation* was defined as 1 500-2 500 ℓ/ha.day, equating to densities of 30-50 du/ha and plot sizes of 130-150 m^2.
- *High density greywater generation* was defined as > 2 500 ℓ/ha.day, equating to densities of > 50 du/ha and plot sizes of < 150 m^2.

Greywater management options could then be determined by way of rule-based flow diagrams which ask relevant questions for each of the criteria identified to determine options for greywater management and disposal. Limits were given for some of these criteria where it was deemed possible to provide recommendations for off-site disposal of greywater, as shown in Figure 1 and Table 4.. Decision trees such as that presented in Figure 1 could help decision-makers to determine quickly whether on- or off-site disposal of greywater should be considered.

Note that the value of 2 500 ℓ/ha/d limit proposed in Table 4 is not intended to be associated with irrigation. The figure proposed as a "threshold limit" in Table 4 is purely aimed at identifying settlements where on-site disposal of greywater *by any means* could have potentially serious deleterious effects on human health and the environment. It aims to ensure that ponding and surface run-off do not occur, and build-up of greywater contaminants in soil is minimised.

In the context of a wide range of unsewered communities monitored in the course of the project, only greywater generated at low density, and possibly low/medium density, was of a quality which could be used for small-scale irrigation with minimal risk to health and the environment. Greywater generated at low/medium and medium/high density might be suitable for irrigation use, subject to a number of site-specific factors and to possible pre-treatment. The project report detailed a number of potential greywater treatment technologies, and emphasised that the simplest technology which achieves the desired end is the best under almost all circumstances. Greywater generated at high density was typically associated with informal settlements, having no or dysfunctional provision for water supply and sanitation (particularly sanitation), had already been reused in the home several times before it was discarded, and was not safe for any form of further use without extensive pre-treatment – which was usually not feasible in terms of insufficient space for treatment facilities and poor upkeep due to poverty and low education status of the user communities. For greywater in the latter category, off-site disposal via sanitation systems was recommended as the only safe disposal method (Carden *et al.*, 2007).

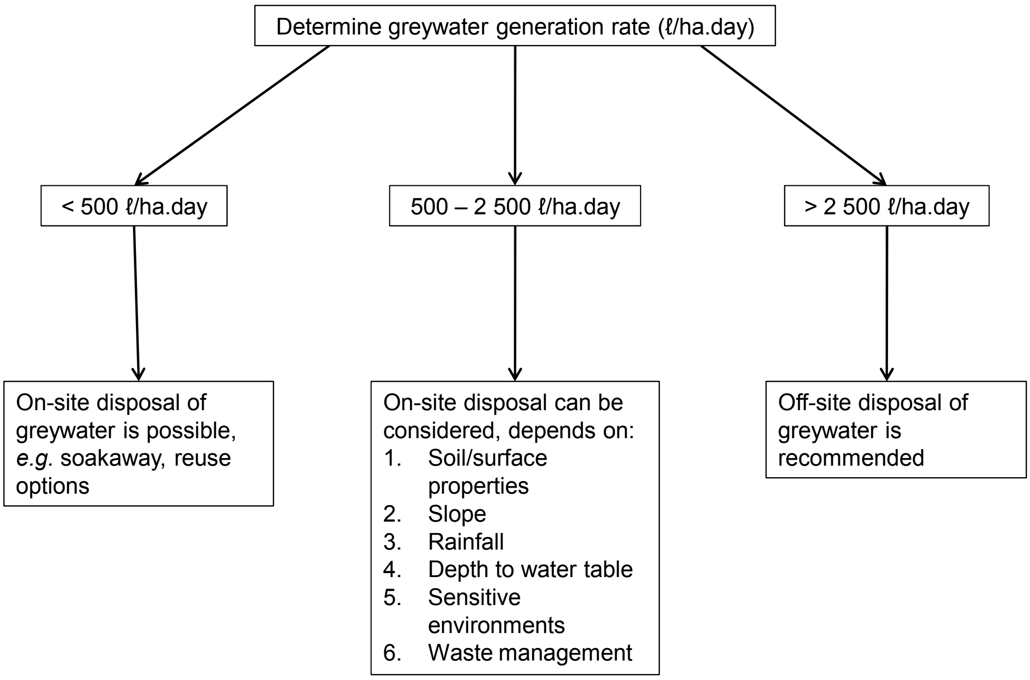

Figure 1: Decision tree for determining appropriate greywater management options, linked to greywater generation rate (from Carden *et al.*, 2007).

Table 4: Recommendations regarding greywater management (from Carden *et al.*, 2007).

Criterion	Off-site disposal of greywater recommended under following limits
Greywater generation rate (ℓ/ha/day)	When greywater generation rate exceeds 2 500 ℓ/ha/day
Soil/surface properties	If surfaces are hard-packed or impervious (*e.g.* heavy clay and rock)
Topography	When slopes are greater than 30%
Depth to water table	If depth to water table is less than 1m
Proximity to sensitive environments	Within floodplains (*e.g.* 1:50 year)

City of Cape Town (Carden et al., 2007)

Carden *et al*. (2007) quote draft guidelines for greywater management in informal settlements, proposed by the City of Cape Town in 2005. In these guidelines, greywater use is considered in terms of the typical components that may be expected of a greywater system (intake, disposal, operation and maintenance). Recommendations are given within the context of each of these components. The guidelines proposed by the City of Cape Town are presented in Table 5.

Table 5: Guidelines for greywater management in informal settlements proposed by the City of Cape Town (from Carden *et al*., 2007)

Greywater irrigation guidelines per system component
Intake • Greywater intakes must be located close to where the water is used (maximum distance from dwelling to disposal point of 25 m). • Where communal washing facilities are provided, sediment and fat traps are required before disposal of greywater (unless to sewer). • For new standpipes, greywater intakes with galvanised gratings should be provided, with sediment and fat traps. • Sediment and fat traps should be located close to greywater intakes (< 3 m) and no more than five intakes should be served by one sediment and fat trap. • Conveyance to sewer/soakaway/stormwater system can be done using small bore gravity pipeline where slopes permit.
Disposal • Gravity connection to sewer is preferred option. • Soakaways can only be provided in areas where soil is permeable and water table is low. Sediment and fat traps should always be provided. • Further treatment is required before discharge into the stormwater system, through the use of, for example, artificial wetlands.
Operation and maintenance • Communities provided with greywater disposal systems should be educated in terms of their purpose and correct use, *i.e*. greywater systems may not be used for the disposal of blackwater or night soil. • The maintenance of sediment and fat traps should be programmed to take place on a regular cycle, depending on capacity and usage of system.

2.2.2 *Beyond South Africa*

Unlike numeric limits for specific water quality variables, there is an increasing wealth of information obtainable on the Internet, from water authorities, from non-governmental organisations (NGOs), from manufacturers of greywater treatment systems, and from professionals in the field, regarding precautions to be taken in the application of greywater for irrigation.

The most comprehensive guidelines, albeit restricted primarily to the health perspective, are provided by the World Health Organisation (WHO). These are based on rigorous research and review by international panels, and are highly regarded worldwide as a basis for setting regional guidelines. Because of their prominence, these guidelines are reviewed separately in the following section.

A number of cities, states and countries have produced guidelines, specifying practical measures to be applied in the use of greywater for household use and particularly for irrigation. Mostly, these guidelines appear to be founded on a combination of common sense and derivation from wastewater reuse guidelines. The States of Arizona and California (USA) and of Victoria (Australia) are generally acknowledged to be among the leaders in providing regulations and guidelines for the domestic use of greywater. These are presented briefly in the remainder of this section.

State of Victoria, Australia

In the State of Victoria, Australia, household-level reuse of greywater is permitted without approval, either by carrying greywater in a bucket or by installing a diversion system leading greywater directly from the point of generation to the point of use. Such diversion systems do not require prior approval, but must be installed by a licensed plumber. However, if a permanent on-site treatment system is to be installed, then local council approval is required. Reuse of kitchen greywater is discouraged. A set of simple greywater irrigation guidelines is provided in an easily accessible pamphlet, distributed by the Victoria Environmental Protection Agency (EPA Victoria, 2008). The guidelines are presented in Table 6.

Table 6: Guidelines for use of untreated greywater (“Greywater Dos and Don’ts”) in the State of Victoria, Australia (from EPA Victoria, 2008).

Greywater Dos
✓ Reuse wastewater from baths, showers, hand basins and washing machines (preferably the final rinse water). ✓ Only apply as much greywater on the garden as the soil can absorb and rotate the areas you irrigate. ✓ Wash your hands after watering with greywater. ✓ Use environmentally friendly shampoos, detergents and cleaning products to better protect your soil and plants. ✓ Stop using greywater if plants appear to become unhealthy or odours are generated.
Greywater Don’ts
✗ Water vegetable gardens if the crop is to be eaten raw or uncooked. ✗ Use kitchen wastewater (including from dishwashers), due to the high concentration of food wastes and chemicals that are not readily broken down by soil organisms. ✗ Let children or pets drink or play with greywater. ✗ Use greywater that has faecal contamination, such as from washing nappies or soiled sheets. ✗ Store greywater for more than 24 hours, or store in rainwater tanks. ✗ Allow greywater to flow from your property or enter stormwater drains.

State of Arizona, USA

Greywater legislation in Arizona, USA, uses a three-tier approach based on the volume of greywater generated. The lowest tier, and that which covers household use of greywater, applies to greywater flows of 400 gallons (1 500 ℓ) per day and less. For this tier, no registration, licence or treatment requirements apply, termed a Type 1 General Permit. The permit eligibility criteria are given as follows (Arizona Department of Environmental Quality, 2001):

- The general permit is meant for private residential use only. Greywater must be used on the site where it is generated and cannot be accessed by the public.
- Greywater can be used only for irrigation, not for any other use.
- Greywater flow must be less than 400 gallons (1 500 ℓ) per day.

For the purposes of the Arizona legislation, greywater is defined as household wastewater which is collected separately from a sewage flow and which originates from a clothes washer, bathtub, shower or sink. Wastewater from a kitchen sink, dishwasher or toilet is excluded (Roesner *et al*., 2006).

A list of 13 “best management practices” is defined, to which all users of greywater under the General Permit must adhere. These were developed to protect public health and water quality (Arizona Department of Environmental Quality, 2001). The criteria for General Permit use of greywater, and the associated best management practices, are made available to potential greywater users in an easily accessible pamphlet. The best management practices are presented in table 7..

Qualitative guidelines for greywater use, such as the “greywater dos and don’ts” of the State of Victoria and the “best management practices” of the State of Arizona, lend themselves well to adaptation to the South African situation.

Table 7: Best management practices applicable to greywater irrigation under a Type 1 General Permit (greywater flow less than 1 500 ℓ per day) in Arizona, USA (from Arizona Department of Environmental Quality, 2001).

Type 1 General Permit Best Management Practices
• First and foremost, avoid human contact with greywater. • You may use greywater for household gardening, composting, and lawn and landscape irrigation, but it should not run off your property. • Do not surface irrigate plants that produce food, except for citrus and nut trees. • Use only flood or drip irrigation to water lawns. Spraying greywater is prohibited. • When determining the location for your greywater irrigation, remember that it cannot be in a wash or drainage way. • Greywater may only be used in locations where groundwater is at least five feet (1.5 m) below the surface. • Label pipes carrying greywater under pressure if confusion between greywater and drinking water pipes is possible. • Cover, seal and secure storage tanks to restrict access by small rodents and to control disease-causing insects. • Hazardous chemicals, such as antifreeze, mothballs and solvents, cannot be in greywater. Do not include wash water from greasy or oily rags in your greywater. • Greywater from washing diapers (nappies) or other infectious garments must be discharged to a residential sewer or other wastewater facility, or it can be disinfected prior to use. • Surface accumulation of greywater must be kept to a minimum. • Should a backup occur, greywater must be disposed into your normal wastewater drain system. To avoid such a backup, consider using a filtration system to reduce plugging and extend the system's lifetime. • If you have a septic tank or other on-site wastewater disposal system, your greywater use does not change that system's design requirements.

State of California, USA

Greywater irrigation regulations in California are considerably more restrictive than those in Arizona. Only reuse of greywater from washing machines is permitted without a construction permit for the greywater irrigation and/or disposal system, and simple bucket-type reuse of water from any source other than washing machines is not provided for. Permitting requirements are shown in Table 8. For irrigation use of greywater from washing machines without a permit, a number of conditions apply (Table 9) and users must comply with these. Regulations for the construction, inspecting and testing of all greywater systems requiring a construction permit are provided in detail in the legislation (California Building Standards Commission, 2010). These are sufficiently restrictive to provide a significant barrier to household-level greywater use in compliance with the regulations and are unlikely to prove useful as a model for greywater irrigation guidelines in South Africa.

Table 8: Construction permitting requirements for greywater disposal and irrigation systems in California, USA (from California Building Standards Commission, 2010).

Type of system	Permit requirements
Clothes washer system: a greywater system utilising only a single domestic clothes washing machine in one- or two-family dwelling.	No construction permit required if conditions in Table 9 are met.
Simple system: a greywater system serving a one-or two-family dwelling with a discharge of 250 gallons (950 ℓ) per day or less.	Permit and plans required.
Complex system: a greywater system that discharges in excess of 250 gallons (950 ℓ) per day.	Permit and plans required.
Treated greywater: non-potable water collected and treated on-site suitable for direct beneficial use.	Permit and plans required. Treatment must be equivalent to tertiary treatment of wastewater.

Table 9: Conditions with which users must comply for reuse of washing machine greywater in California, USA (from California Building Standards Commission, 2010).

Conditions applying to greywater disposal or use from a clothes washer system
• The greywater system shall not be connected to any potable water system without an air gap or other physical device which prevents backflow, and shall not cause ponding or runoff of greywater • The type of system shall be determined by the location, discharge capacity, soil type and groundwater level. The system shall be designed to handle greywater discharged from the building and may include tanks or other devices necessary to ensure proper function of the system. • No greywater system or part thereof shall be located on any lot other than the lot that is the site of the building or structure that discharges the greywater. Minimum distances of greywater systems from structures are provided in the legislation. • Where there is insufficient lot area or inappropriate soil conditions to prevent ponding or runoff of the greywater, no greywater system shall be allowed. • All greywater systems shall be designed to allow the user to direct the flow to either the irrigation or disposal field (*i.e.* the intended destination of the greywater in the receiving landscape) or the building sewer. The means of changing the direction of the greywater shall be clearly labelled and readily accessible to the user. • Water used to wash diapers (nappies) or similarly soiled infectious garments or other prohibited contents shall be diverted by the user to the building sewer. • Greywater shall not be used in spray irrigation, allowed to pond or run off, and shall not be discharged directly into or reach any storm sewer system or any surface body of water. • Human contact with greywater or the soil irrigated with greywater shall be minimised and avoided, except as required to maintain the greywater system. The discharge point of any greywater irrigation or disposal field shall be covered with at least two inches (50 mm) of mulch, rock, soil or solid shield to minimise the possibility of human contact. • Greywater shall not be used to irrigate root crops or edible parts of food crops that touch the soil.

2.2.3 World Health Organisation Guidelines for reuse of wastewater, excreta and greywater in agriculture and aquaculture (WHO, 2006)

A major advance in the development of health-based guidelines for waste which respond to the specific requirements of each reuse project or site was the publication of revised WHO guidelines for the reuse of wastewater, excreta and greywater in agriculture and aquaculture. The document describes the use of a risk assessment approach, combined with reduction of risk through a variety of potential treatment steps and/or exposure barriers, to protect users of domestic waste in producing crops. The underlying risk assessment principles are encapsulated in a methodology termed the Stockholm Framework, which is described below. The components of the

Stockholm Framework are discussed in greater detail in the sections which follow thereafter.

The Stockholm Framework

The Stockholm Framework comprises a harmonised framework for the development of health-based guidelines and standards for water- and sanitation-related hazards. It was first published in 2001, following an expert meeting in Stockholm, Sweden. The basic principles of the Stockholm Framework provide for the setting of health-based targets and the development of guideline values, defining basic controls and evaluating the impact of these combined approaches on public health (WHO, 2006). This process is summarised in diagrammatic form in Figure 2. The Framework does not provide specific targets, but rather presents a means of developing guideline values which take into account the local social, cultural, economic and environmental circumstances, and to compare health risks associated with, *e.g.* greywater use, to risks associated with microbial exposures through other routes. In so doing, the Framework explicitly recognises that guideline values which may be desirable and achievable in developed countries may be unattainable in developing countries. It also recognises that an unattainable guideline may be worse than no guideline at all, since users and legislators would probably abandon any attempts to operate within safe limits.

In making health targets comparable across microbial (or chemical) hazards, and across different water and sanitation applications, disease outcomes are compared in terms of a common measure, most usually disability-adjusted life years (DALYs). DALYs are a measure of the health burden of a population due to a specific disease or risk factor. They represent an attempt to measure the time lost because of a disability or disease, compared with a long life lived in the absence of disease or disability. Their importance as a measure of health outcomes lies in the ability to compare long-term chronic effects (*e.g.* cancer) with short-term, often self-limiting effects (*e.g.* giardiasis, watery diarrhoea). Thus comparisons can be conducted on a common basis across very different types of health effects when guidelines values are developed. The United Nations Education, Scientific and Cultural Organisation (UNESCO) definition and description of DALYs is given in Table 10.

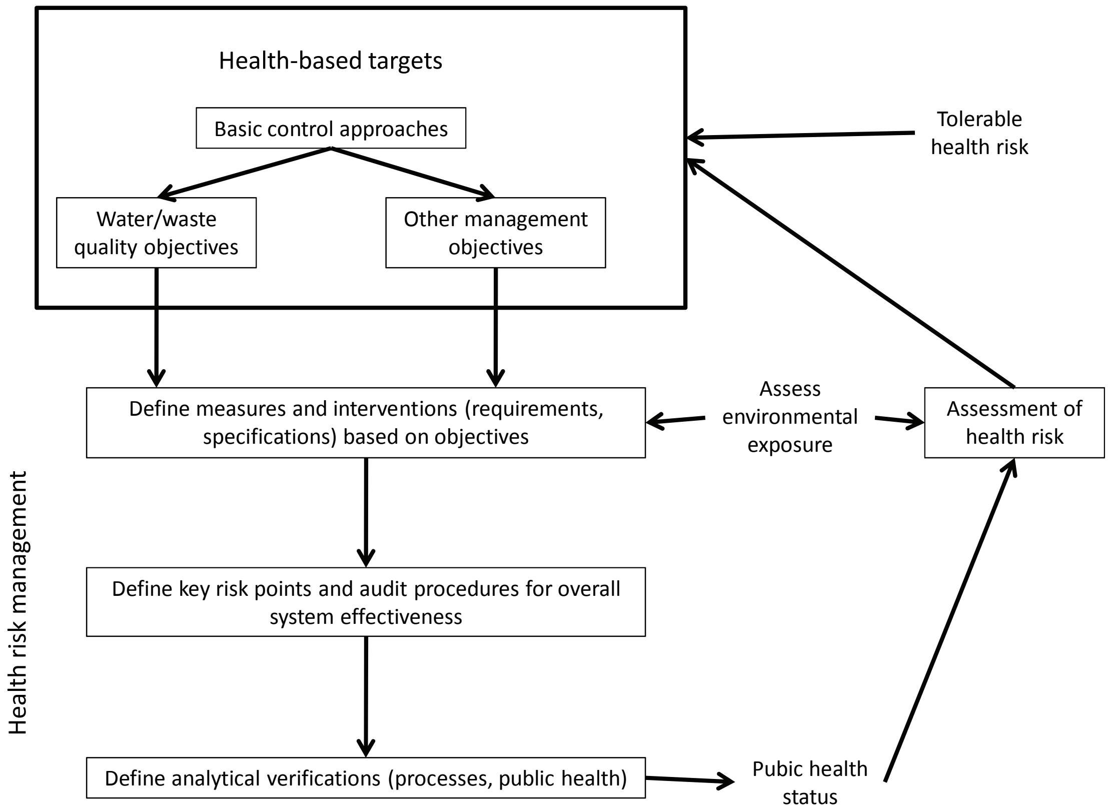

Figure 2: The Stockholm Framework for developing guidelines for the management of water-related infectious diseases (adapted from WHO, 2006).

The concept of health risk

A specific pathogenic organism represents a *hazard* which is capable of causing disease. However, for a hazard to represent a *risk* to health (*i.e.* a probability that someone will contract the disease associated with the infectious hazard), it is necessary that the person, or group of persons, is *exposed* to the hazard. Without exposure to a susceptible host, the hazard does not represent a risk. Thus, the *assessment of exposure* is an important input to both risk assessment and risk management, and guidelines based on health risk aim to control risk via controlling exposure to a hazard. This means that information (preferably quantitative information) is needed both about the characteristics of the hazard and the nature of the exposure.

Table 10: Definition and description of the concept of DALYs (disability-adjusted life years), as given by UNESCO[1].

DALY (Disability-Adjusted Life Year)	
Prepared by	World Health Organisation
Rationale	The Disability-Adjusted Life Year (DALY) is a summary measure of population health, integrating mortality and disability information in a single unit. DALYs show the relative importance of health problems and can be combined with data on costs and effectiveness of interventions to establish which public health interventions would be the most cost-effective. The DALY is the measure of choice to monitor the burden of disease in relation to improvements in water supply and sanitation.
Definition	One DALY represents the loss of one healthy year of life. For each disease DALYs are calculated as the sum of years lost to premature mortality and the years of productive life lost due to disability for incident cases of the ill-health condition in question.
Underlying definitions and concepts	DALY estimates depend on availability of data of sufficient quality and on assigning a certain class of severity of disability to each disease, which is based on expert opinion.
Specifications of determinants needed	The DALY is an indicator of the time lived with a disability and the time lost due to premature mortality. To measure the time lived with a disability in manner that can be meaningfully compared with the time lost due to premature mortality, there is a need for the following data: (1) age- and gender-specific information on the incidence of disease, (2) the proportion of disease incidence leading to a disabling outcome, (3) the average age of disability onset, the duration of disability, and (4) the distribution of disability across the six classes of disability severity. In most cases these data are unavailable and researchers are forced to rely on estimates, many of which are uncertain.
Computation	The duration of time lost due to premature mortality is calculated using standard expected years of life lost with model life-tables. The reduction in physical capacity due to morbidity is measured using disability weights. The value of time lived at different ages has been calculated using an exponential function which reflects the dependence of the young and the elderly on the adults. Because incidence data are rarely available, the Global Burden of Disease study uses a mathematical model to convert prevalence data to incidence data.
Units of measure	The DALY
Data sources, availability and quality	WHO Global Burden of Disease database: http://www.who.int/evidence/bod; annexes of the annual World Health Report. Cause of death patterns by age and gender are needed to calculate the years of life lost to premature death. Worldwide, only about 30-35% of all deaths are captured by vital registration. For the remainder, cause of death structure as a function of the level of mortality can provide broad cause-of-death groups. Such methods are generally unreliable for more specific causes.
Scale of application	Global, by age, gender and 14 epidemiological regions
Geographical coverage	Global
Interpretation	There are uncertainties in estimates of disease incidence, duration, severity and disability weighting.
Alternative methods and definitions	It has been stated that the value choices in the DALY on disability weighting, age-weighting and discounting, tend to underestimate the disease burden attributed to young populations and communicable disorders.

[1] http://www.unesco.org/water/wwap/wwdr/wwdr2/indicators/pdf/Ch06-IPSFinalEdits.pdf)

Health risk assessment

The assessment of risks associated with exposure to particular environmental hazards (in this case, hazardous agents present in household greywater) is central in preventive public health. It can be carried out directly via *epidemiological studies* or indirectly through *quantitative microbial risk assessment (QMRA)*. Epidemiological studies are preferred, since the amount of uncertainty surrounding the causal link between exposure to the hazard and a particular disease outcome is much reduced, but there are very few epidemiological studies on greywater.

In the absence of reliable epidemiological studies, risk is more usually assessed indirectly by QMRA. Risk assessment is commonly recognised as having four components: hazard identification, hazard characterisation (also called dose-response assessment), exposure assessment and risk characterisation (Haas *et al.,* 1999; WHO, 2006).

In *hazard identification*, the microbial hazard, its associated health effects and likely exposure routes are described. The goals of the risk assessment are established, and may be located within a specific policy or regulatory framework.

The goal of *hazard characterisation (dose-response assessment)* is to develop a model of the interaction of the hazard with the exposed population in order to cause infections. In the case of microbial hazards, this relationship is most usually determined from human volunteer feeding studies (unlike chemical dose-response assessments, which are usually based on the response of animal models to challenge with the hazardous substance). In order to extrapolate experimental data to the exposed human population, one of two quantitative probabilistic models is typically used. The difference between the models relates to the underlying assumptions:

(i) If random distribution and probability of infection for an organism are assumed, a one-hit exponential model (Equation 2) is used.

$$P_{inf} = 1 - e^{(-rDose)} \qquad \textbf{Equation 2}$$

P_{inf} is the probability of infection (not necessarily clinical disease)
r is the dose-response parameter determined by fit to the experimental data.

(ii) If the probability of exposure is affected by heterogeneity of interactions among host and hazard (pathogen), then the probability of infection is better described by a β-Poisson distribution (Equation 3).

$$P_{inf} = 1 - (1 + Dose/\beta)^{-\alpha} \qquad \textbf{Equation 3}$$

P_{inf} is the probability of infection
α, β are model parameters describing the relationship between host and the exposed population.

Where data are available, risk to susceptible sub-populations like children, the aged, HIV-positive persons and the disabled, can be modelled separately or suitable adjustments can be made to the calculated risk.

Exposure assessment aims to describe the specific exposure routes for the population under consideration. The amount of microbial hazard to which an individual is exposed via various routes (*e.g.* direct exposure to greywater or exposure to greywater-irrigated produce) is quantified, with a description of the variability of distribution of the microbe within the medium (*e.g.* water, crop), where possible. The quantity and frequency of exposure are also quantified (*e.g.* amount of greywater-irrigated produce consumed per portion, and how often that product is consumed). The exposure dose is calculated by multiplying the amount of microbe in the product consumed by the amount ingested in a single exposure.

Risk characterisation combines the outcomes of hazard characterisation (dose-response assessment) and exposure assessment to describe the risk of the exposed population, usually within the context of a particular population or geographic region. Where possible, risk is calculated stochastically, using Monte Carlo simulation to sample distributions of exposure repeatedly. This yields a distribution of risk values, which provides more information about the variability of the risk than does a single risk estimate (point estimate of risk).

Tolerable risk and health-based targets

Risk assessment provides the link between potential health hazards on the one hand, and tolerable risk levels and health-based targets on the other. Tolerable risk levels are set at national level, and historically were derived for chemical hazards for endpoints such as cancer. For carcinogenic chemicals in drinking water, guideline values have been set at 10^{-5} upper-bound of risk (equivalent to one excess case of cancer per 100 000 population ingesting drinking water). The lifetime disease burden associated with this level of risk is approximately 1×10^{-6} DALY. For milder, but more frequent, illnesses, such as mild diarrhoea with an annual risk of mortality of 10^{-3} (1 in 1 000), the lifetime disease burden is also 1×10^{-6} DALY.

Presently, in South Africa, insufficient familiarity with the concept of quantitative health risk assessment and insufficient data prevent guidelines being developed on the basis of DALYs. However, the concept is highlighted here since development of risk assessment and DALY-based guidelines in the future would allow for maximum comparison with international knowledge, especially that made available through international health agencies such as the WHO.

The link between tolerable risk and health-based targets is that the tolerable risk of disease forms the baseline to set specific performance targets (health-based targets) aimed at reducing the actual risk of disease to the tolerable risk level. This clearly involves reducing either exposure to, or concentrations of, pathogens. Health-based targets can be specified in terms of one or more intervention methods. Examples include:

- Health outcomes – measured by epidemiological studies, public health surveillance or QMRA.
- Greywater quality – measured as levels of specific pathogens, *e.g.* intestinal nematode eggs or counts of *E. coli.*
- Performance – measurements can take the form of performance targets for removal of pathogens through combinations of treatment processes, handling practices, storage time, temperature, *etc.*

- Specified technology – specified treatment processes with anticipated removal of pathogens or other greywater components.

Risk management
Health-based targets relate to basic control approaches which permit reduction of risk. Risk management requires assessment of health risks at key points of greywater use processes. Risk management strategies address factors which allow risk of infection to be controlled. These include:

- Behaviours (*e.g.* hand washing with soap).
- Treatment technologies (the simpler the better).
- Operational processes (*e.g.* application methods, operation and maintenance of facilities).
- Protective action (*e.g.* wearing protective clothing during greywater application, cooking food properly before consumption, *etc.*).

Multiple strategies, implemented as several barriers to exposure, are likely to yield the best effect in terms of reduction of overall transmission of disease. Examples of multiple barriers, which may be implemented in combination, include:

- On-site storage and treatment to reduce pathogens.
- Off-site additional treatment for further pathogen reduction.
- Restriction of crops to those that either are not eaten or that are processed (*e.g.* cooking) prior to consumption.
- Application techniques that reduce exposure of workers and contamination of crops (*e.g.* drip irrigation, sub-surface application).
- Exposure control methods, including limiting access to greywater-irrigated area, protective clothing for workers, and disinfecting and/or cooking food prior to consumption.

This concept is illustrated in Figure 3. The target reduction in log numbers of pathogens is shown on the y-axis. Bars A to H indicate that this reduction to a tolerable number of presumed pathogens (or tolerable risk) need not be achieved through one single intervention, *e.g.* an expensive full treatment process capable of achieving a 7 log reduction in microbial numbers. Instead, a range of combinations of barriers may be used to achieve the same end result. These include treatment of the wastewater / greywater, irrigation practices, crop choices and food-related human behaviours.

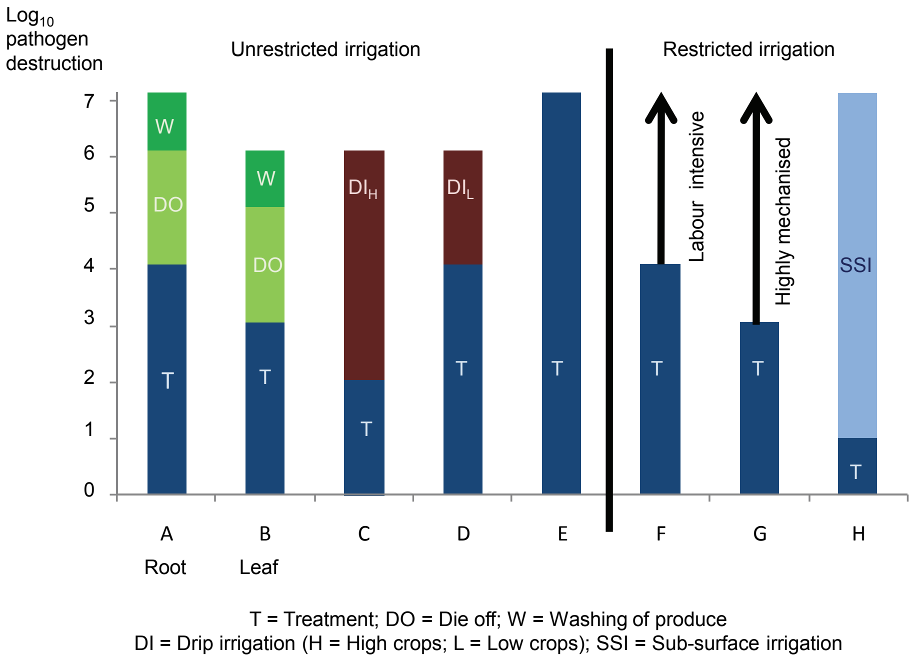

Figure 3: Illustration of principle of managing microbial risk associated with wastewater / greywater irrigation by reducing exposure to potential pathogens through different exposure barriers (adapted from WHO, 2006, Vol. 1).

To determine the efficacy of risk management strategies, knowledge of the baseline health status of the affected population is needed. Similarly, the tolerable risk and health-based targets cannot be set without some knowledge of the characteristics of disease incidence and transmission in the population. Various sources can be used to derive such information. Information on susceptible sub-population, seasonal fluctuations in disease incidence, and treatment process efficiency is of significance.

Once risk management strategies have been designed and implemented, their success must be monitored. Key risk points in greywater use systems need to be identified, and audit procedures need to be instituted to ensure that risk management is achieving its aim. Monitoring of population health status is also required to determine whether risk management strategies are achieving health targets.

Special considerations for small-scale vs. large-scale systems
The latest WHO guidelines for greywater (WHO, 2006), based on the Stockholm framework, include some numeric limits on microbiological constituents of greywater. However, compliance with these is only feasible in large-scale treatment systems. For small-scale treatment systems, non-technical risk management options, and relatively simple primary and secondary treatment to prevent clogging are strongly recommended by WHO. Non-technical risk management options include hygiene education, mosquito breeding control measures, crop restrictions, proper irrigation method, exposure control and chemotherapeutic interventions (WHO, 2006).

The latest guidelines for waste treatment for agricultural use in large-scale treatment systems are described in Table 11. These provide numerical goals which even small-scale systems should strive to achieve for the protection of health of consumers, in the case of greywater-irrigated produce. However, in small-scale systems (unlike large-scale ones), these goals should be seen as the end result of a combination of achievable management practices, not simply as the minimum requirements for treatment.

Table 11: Guideline values for verification monitoring in large-scale treatment systems of greywater, excreta and faecal sludge for use in agriculture (from WHO, 2006).

	Helminth ova	***E. coli***
Treated faeces and faecal sludge	< 1/g total solids	< 1000 /g total solids
Greywater for use in restricted irrigation	< 1/ℓ	< 10^5/100 mℓ Relaxed to < 10^6/100 mℓ when exposure is limited or regrowth is likely
Greywater for use in unrestricted irrigation of crops eaten raw	< 1/ℓ	< 10^3/100 mℓ Relaxed to <10^4/100 mℓ for high-growing leaf crops or drip irrigation

Stockholm Framework and guidelines for greywater use in South Africa

Relating the Stockholm Framework to the proposals for greywater management in South Africa (Carden *et al.*, 2007), it can be seen that the decision tree presented in Figure 1 can be placed in a health context by linking each greywater generation rate with a risk assessment of the associated health impacts. This can further be linked to health-based targets for different greywater use applications. Clearly, the lower greywater generation rates would qualify for more potential applications. Risk management strategies can be designed to minimise the impact of higher greywater generation rates. By implementing strategies to reduce hazardous greywater components, it may be possible to allocate technologies to minimise the health risks associated with on-site or off-site disposal, or possibly even upgrade the greywater quality to a level allowing for some form of beneficial use. Both this document and Carden *et al.* (2007) make reference to some of the available greywater treatment technologies which could be applied in this context
.

2.3 Greywater generation

2.3.1 Greywater quantities

The amount of greywater generated per household varies greatly. The variation is affected by factors such as dynamics of the family, water usage patterns, age distribution of occupants and lifestyle characteristics. Greywater generated in low-income, unsewered areas can be as low as 20-30 ℓ per person per day and about 90-120 ℓ per person per day in sewered houses. In general, in sewered areas greywater represents about 65% of the total wastewater stream whereas in unsewered areas the production of greywater could reach 100% (Morel and Diener, 2006). Greywater production volumes in selected countries are shown in Table 12 (for varying types of water supply) and Table 13 (for a typical Western-style home with in-house water supply and waterborne sewerage). Greywater volumes and estimated greywater generation (Carden *et al.*, 2007; see Equation 1, Section 2.2.1) for dense informal settlements in South Africa are presented in Table 14. All reflect overall higher water use in houses with in-house taps and more affluent lifestyles. Additionally, Table 14 demonstrates that high housing density in unsewered settlements generally corresponds to a high overall greywater generation rate in the settlement, even when the volume of water used per dwelling is relatively low.

Table 12: Domestic greywater volumes generated by day in selected countries (adapted from Morel and Diener, 2006).

	Vietnam ℓ/p/d	Mali ℓ/p/d	South Africa ℓ/p/d	Jordan ℓ/p/d	Israel ℓ/p/d	Nepal ℓ/p/d	Switzerland ℓ/p/d	Australia ℓ/p/d	Malaysia ℓ/p/d
Total	80-110	30	20	50	98	72	110	113	225
Kitchen	15-20	-	-	-	30	-	28	17	-
Shower, bath	30-60	-	-	-	55	-	52	62	-
Laundry	15-30	-	-	-	13	-	30	34	-
Water source	In-house taps	Single tap	Community tap/well	In-house taps	In-house taps	In-house taps	In-house taps	In-house taps	In-house taps
Note: These figures do not reflect national averages but relate to specific cases with specific settings. Type of water supply and living standards appear to be more decisive than the location.									

Table 13: Mean daily water consumption and greywater production according to household use type for a typical Western-style household (adapted from Murphy, 2006).

Plumbing fixture	**Mean percentage volume used and percentage range**	**Mean daily per-person consumption and range (ℓ)[1]**	**Greywater production: mean daily per person volume produced (ℓ)[1]**
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**

[1] Data in the three columns originate from different studies, which is why the greywater volumes in the last column exceed the total water consumption in the middle column.

Table 14: Greywater use and greywater generation in unsewered settlements in provinces of South Africa (adapted from Carden *et al.*, 2007).

Name of Settlement	Province	Density du/ha	Average water use ℓ/du.day	Greywater generation. rate[1] ℓ/ha.day
Clanwilliam	Western Cape	12	65	585
Redhill	Western Cape	11	80	660
Lingelethu	Western Cape	29	55	1196
Fairyland	Western Cape	34	75	1913
Kleinmond	Western Cape	25	105	1969
Masiphumelele	Western Cape	29	100	2175
Khayelitsha	Western Cape	67	55	2764
Sweet Home	Western Cape	60	70	3150
Masakhane	Mpumalanga	6	115	518
Doornkop	Mpumalanga	15	120	1350
Mashati	Limpopo	3	140	315
Manapyane	Limpopo	3	150	338
Tlhalampye	Limpopo	4	125	375
Leeufontein	Limpopo	5	150	563
Jane Furse	Limpopo	5	180	675
Winnie Park	Limpopo	8	130	780
Seshego Z5	Limpopo	10	115	863
Mahwelereng	Limpopo	10	145	1088
Doornkraal	Limpopo	15	135	1519
Pietersburg	Limpopo	18	130	1755
Mothlakaneng	Limpopo	25	140	2625
Emahobeni	Eastern Cape	10	45	338
Mputhi	Eastern Cape	8	75	450
Phakamisa	Eastern Cape	8	80	480
Bongweni	Eastern Cape	5	160	600
New Payne	Eastern Cape	10	80	600
Silvertown	Eastern Cape	20	70	1050
Orange Grove	Eastern Cape	30	60	1350
KwaShange	KwaZulu-Natal	3	100	225
Emambedwini	KwaZulu	4	80	240
Emaqedini	KwaZulu	5	100	375
Boboyi	KwaZulu	5	110	413
Zolani	KwaZulu	20	85	1275
Cato Manor	KwaZulu	25	95	1781
Barcelona	Gauteng	25	95	1781
Mayfield Ext	Gauteng	32	95	2280
Freedom Sq	Gauteng	162	110	13365
Average		**20**	**104**	**1385**

[1] See Equation 1, Section 2.2.1

2.3.2 Sources of greywater

Greywater is sourced from three streams: kitchen, bathroom and laundry. Studies have revealed that kitchen greywater has the greatest negative impact on the quality of greywater (Rose *et al.,* 1991).

Kitchen greywater

Greywater originating from the kitchen makes up to 11% (estimates vary) of the total wastewater volume produced in a typical household. Kitchen greywater contains food particles, high amounts of fats and oils, and dishwashing detergents. It can also contain drain cleaners and grease. It is typically high in nutrients and suspended solids, and may contain bacteria (including potentially pathogenic bacteria) originating from washing of food. Dishwasher greywater may have high pH and high concentrations of suspended solids and salts. Therefore, kitchen greywater could be harmful to soils by altering its characteristics in the longer term and it is sometimes excluded from greywater stream unless treated (Ng, 2004; Morel and Diener, 2006; Roesner *et al.*, 2006).

Bathroom greywater

The bathroom (hand basin, shower, and bath) generates approximately 55% (estimates vary) of the total greywater volume produced by a typical household and is considered to be the least contaminated of the greywater streams. It contains soaps, shampoos, toothpaste and other personal cleaning products, and lint. In addition, it also contains body wastes such as shaving waste, skin, hair, body fats and traces of blood, faeces and urine. Thermotolerant (or faecal) coliform concentrations have been assessed in both shower and bath greywater, indicating that pathogenic micro-organisms may also be present (Ng, 2004; Morel and Diener, 2006; Roesner *et al.*, 2006).

Laundry greywater

Laundry greywater makes up approximately 34% (estimates vary) of the household wastewater. It contains high concentrations of chemicals from soap powders (including sodium, phosphorus, nitrogen, boron and surfactants), bleaches, suspended solids, non-biodegradable fibres from clothing, and possibly oils, paints and solvents. The chemical oxygen demand (COD) is often high. It also typically contains indicator bacteria, including thermotolerant coliforms, hence may contain faecal pathogens. These vary with the nature of the items washed. The microbial load is particularly high when soiled nappies are washed (Ng, 2004; Morel and Diener, 2006; Roesner *et al.*, 2006).

2.4 Greywater use within the household

In middle to upper income households, it is usual for greywater to be disposed to sewer, although greywater use does occur, especially in times of drought when water restrictions are imposed. Then the cleaner fractions of the greywater, *e.g.* bathwater, may be used for car washing or watering the garden. In the USA, a trend of increasing acceptance of reuse of greywater has been noted, with some 7% of households practicing some form of reuse in 2006. Most households used greywater from the washing machine for garden irrigation (Roesner *et al.*, 2006).

On the lower end of the middle income scale and into the lower income range, cost saving becomes a motivator for minimising water consumption. In low income groups in South Africa dependent on the free basic potable water supply of 200-300 ℓ/day or on standpipes situated beyond the boundaries of the properties, shortage of water drives minimisation of water uses other than drinking and cooking. In these groups it is usual for greywater to be used several times before it is discarded. For example, water used to bath adults may thereafter be used to bath children, wash clothes and finally wash the floors. Clearly, greywater generated under these conditions is likely to be far more concentrated, have higher microbial loads and be less suitable for any form of reuse without prior treatment. At the extreme end of the scale, as may be encountered in dense informal settlements with minimal, dysfunctional or non-existent waste services of any kind, it is quite possible that greywater joins other uncontained waste streams in the environment and becomes suitable only for off-site disposal (Carden *et al.*, 2007).

2.5 Greywater characteristics

The focus of this section is on the characteristics of greywater at the point of disposal, after any re-use that may have occurred within the household, but prior to any potential further beneficial use on the property, such as irrigation use.

The major contaminants of greywater are lint, solids and particulates, nutrients, hydrogen ion concentration (pH) and alkaline salts, other salts, hypochlorite and heavy metals. Food particles, raw animal fluids from kitchen sinks, turbidity, soil particles, hair, and fibres from laundry wastewater are the various sources of solid material which could induce clogging of soil and piping used for transportation of greywater (Weston, 1998; Eriksson *et al.,* 2002). Measurements of turbidity and total suspended solids indicate the content of particles and colloids that could induce clogging (Eriksson *et al.,* 2002). Organics in greywater are traditionally measured by biological oxygen demand (BOD), COD and total organic carbon (TOC). These are important parameters for indicating the risk of oxygen depletion due to degradation of organic matter, biofilm formation, aesthetic problems and negative effects on plant and soils. Alkalinity, pH and hardness in greywater are largely determined by the quality of drinking water and chemicals added during the use of water. Detergent use also affects pH. High levels of pH, hardness and alkalinity indicate risks of clogging, which could have negative effects on plant growth and soil quality. Phosphorus and nitrogen are essential nutrients for plant growth but they are also responsible for excessive plant growth, eutrophication of surface waters and nitrate contamination of groundwater. Excessive salts cause soil permeability problems and damage plants. Specific ions, including chloride, sodium and boron, are toxic to some plants at high concentrations, where ‘high’ is defined as concentrations greater than those beneficial to plants (Weston, 1998; Morel and Diener, 2006; Roesner *et al*., 2006; Jefferson, 2008). Excessive amounts of free available chlorine cause damage to plants and also pose potential ground water contamination. Other constituents of possible concern in the reuse of greywater include heavy metals (aluminium, iron, manganese, cadmium, copper, lead, mercury, nickel, chromium), hypochlorite, xenobiotic organic compounds (XOCs), endocrine-disrupting chemicals and pharmaceutically active compounds (Eriksson *et al*., 2002).

To give an overview of representative greywater quality, example concentrations of various greywater constituents from different household sources and from composite greywater worldwide are shown in Table 15. Characteristics of greywater sampled from unsewered settlements in South Africa are presented in Table 16.

Table 15: Physical, chemical and microbiological characteristics of greywater of composite greywater and various greywater fractions, as reported by various investigators (from Roesner *et al*., 2006).

Reference	**Eriksson *et al*., 2003**	**Rose *et al*., 1991**				**Cassanova *et al*., 2001**
Source	**Composite**	**Shower**	**Laundry wash**	**Laundry rinse**	**Composite**	**Composite**
Concentration (mg/ℓ unless otherwise stated)	**Range**	**Range**				**Range**
Temperature (^{0}C)	21.6- 28.2					
pH	7.6-8.6				6.54	7.47
COD	77-240				76.3	
BOD	26-120				0.74	64.85
TSS	7-207				0.98	35.09
Turbidity (NTU)		28-96	39-296	14-29	1.7	43
NH4-N	0.02-0.42	0.11-0.37	0.1-0.37	0.06-0.33	9.3	
NO3-N	<0.02-0.25					
Total-N	3.6-6.4				22.9	
PO4-P					9	
Tot-P	0.28-0.779				144	
Sulphate					158	59.59
Chloride						20.54
Hardness						
Alkalinity						
Ca	99-100					
Mg	20.8-23					
K	5.9-7.4					
Na	44.7-98.5					
Total bacterial pop. (CFU/100ml)	4.0×10^7-1.5×10^8	1.0×10^7-1.0×10^8	1.0×10^7-1.0×10^8	1.0×10^7-1.0×10^8	6.1×10^8	
Total coliforms (CFU/100ml)	6.0×10^3-3.2×10^5	1.0×10^5	199	56	2.8×10^8	8.03×10^7
Faecal coliforms (CFU/100ml)		6.0×10^3	126	25	1.82×10^4-7.98×10^8	5.63×10^5
Faecal Streptococci (Enterococci) (CFU/100ml)						2.38×10^2
E. coli (CFU/1100ml)	<100-2800					

Table 16: Greywater quality for unsewered settlements surveyed in provinces of South Africa (adapted from Carden *et al.*, 2007).

Name of settlement	Province	Average values for wash water samples					
		COD mg/ℓ	**NH_3 mg/ℓ**	**TKN mg/ℓ**	**Total P mg/ℓ**	**Oil & Grease mg/ℓ**	**EC mS/m**
Clanwilliam	Western Cape	-	-	-	-	-	-
Redhill	Western Cape	1470	-	20	27	176	155
Lingelethu	Western Cape	6190	-	-	-	-	-
Fairyland	Western Cape	2320	-	60	88	30	-
Kleinmond	Western Cape	3510	-	110	146	29	-
Masiphumelele	Western Cape	7850	-	130	98	242	-
Khayelitsha	Western Cape	3580	-	-	-	-	-
Sweet Home	Western Cape	8490	-	172	144	307	-
Masakhane*	Mpumalanga	-	3+	-	5+	-	1040
Doornkop*	Mpumalanga	-	3+	-	5+	-	126
Mashati*	Limpopo	-	3+	-	5+	-	289
Manapyane*	Limpopo	-	3	-	5	-	112
Tlhalampye*	Limpopo	-	3+	-	5+		461
Leeufontein*	Limpopo	-	-	-	-	-	770
Jane Furse*	Limpopo	-	2.9	-	1.6	-	389
Winnie Park*	Limpopo	-	3+	-	5+	-	234
Seshego Z5*	Limpopo	-	3+	-	5+	-	140
Mahwelereng*	Limpopo	-	0.5	-	5+	-	90
Doornkraal*	Limpopo	-	3+	-	5+	-	489
Pietersburg*	Limpopo	-	3+	-	5+	-	1530
Mothlakaneng*	Limpopo	-	3+	-	5+	-	196
Emahobeni*	Eastern Cape	-	3+	-	2.9	-	381
Mputhi*	Eastern Cape	-	2	-	1.3	-	783
Phakamisa*	Eastern Cape	-	3+	-	1.9	-	514
Bongweni*	Eastern Cape	-	3	-	3.5	-	916
New Payne*	Eastern Cape	-	2.6	-	4.5	-	113
Silvertown*	Eastern Cape	-	3+	-	5+	-	189
Orange Grove*	Eastern Cape	-	2.2	-	5+	-	764
KwaShange	KwaZulu-Natal	-	12.5	56	57.4	730	59
Emambedwini	KwaZulu-Natal	-	8.5	39	112.4	1365	567
Emaqedini	KwaZulu-Natal	-	5.7	7	15.6	397	70
Boboyi	KwaZulu-Natal	-	3.0	20	34.4	1948	128
Zolani	KwaZulu-Natal	-	3+	45	37.6	1947	199
Cato Manor	KwaZulu-Natal	-	7.6	164	7.5	108	54
Barcelona	Gauteng	-	-	-	-	-	-
Mayfield Ext	Gauteng	-	21.8	43	240.0	1484	653
Freedom Sq	Gauteng	-	-	-	-	-	-
Average		**4770**	**-**	**72**	**-**	**730**	**366**

Notes: 1. * indicates sites where analyses were conducted with field test kits only
2. + indicates reading beyond extent of measurement range for field instrument

2.5.1 Microbiological quality of greywater

Indicator bacteria

Toilet waste is not included in greywater, but micro-organisms including pathogenic viruses, bacteria, protozoa and helminths originating from faecal contamination can be introduced into greywater by handwashing after toilet use, washing of nappies and soiled clothes, anal cleansing, showers and from uncooked vegetables (Ottosson, 2003). The microbial quality of greywater is historically measured by the presence of indicator microorganisms. These are organisms which are typically not themselves pathogens, which are easy to enumerate and the presence of which indicates the possible presence of pathogens from various sources. No indicator fulfils all the criteria perfectly, and different indicators suit different pollution sources or treatment scenarios. Common indicator organisms are total coliforms, thermotolerant coliforms, enterococci and *E. coli*. They can be distinguished by their properties in culture. Total coliforms are not solely enteric bacteria and can be found naturally in water, plant and soil samples. Their presence therefore is an indication of the general environmental sanitary nature of a sample and does not necessarily infer faecal pollution. Thermotolerant coliforms can be distinguished from total coliforms by their growth at higher temperature in culture and are generally found in the gastro-intestinal tract of warm-blooded animals. They are therefore a more reliable indicator of specifically faecal pollution, and hence of the possible presence of enteric pathogens. *E. coli* and enterococci are yet more specific to faecal pollution, enterococci being the more resistant to environmental conditions, particularly saline environments. *E. coli* or enterococci are often the preferred indicators of the possible presence of faecal pathogens. However, coliforms and *E. coli* have been shown to re-grow in warm, nutrient-rich environments (such as stored greywater), which casts doubt on their reliability as indicators of faecal pathogens in such circumstances (DWAF, 1996; Roesner, 2006; Jefferson, 2008). Examples of indicator counts in different greywater fractions are shown in Table 17. The numbers of indicator organisms present in greywater is highly variable and can reach numbers comparable to those in wastewater. Greywater from households with children tends to contain higher concentrations of microorganisms than greywater from households without children. A comprehensive survey of published studies showed that the highest numbers of total coliforms were found in greywater from showers, wash basins and laundry (Jefferson, 2008).

Pathogens

It is important to note that indicator bacteria are only pollution indicators, not hazards in themselves, and are only relevant predominantly as indicators of bacterial pathogens. Protozoan pathogens such as *Giardia*, *Acanthamoeba* and *Crystosporidium* sometimes occur in water where coliforms are absent. Occasionally, pathogenic bacteria such as *Salmonella* and *Campylobacter* can be introduced by food handling in the kitchen (Ottosson, 2003). Parasites like roundworms, parasitic protozoa and helminths, and viruses like hepatitis virus and enteroviruses are all possible non-bacterial greywater contaminants and are not necessarily well indicated by bacterial indicator organisms. Although urine is not regarded as a constituent of greywater, traces of urine have been noticed in bathroom greywater which could introduce three principal urine-transmitted infections, *viz.* schistosomiasis (*Schistosoma haematobium*), typhoid (*Salmonella typhi*) and leptospirosis (*Leptospira*) (Eriksson *et al.,* 2002; Ottosson, 2003).

Table 17: **Representative counts of microbiological indicator bacteria in different greywater sources (adapted from Ottosson, 2003).**

Greywater origin	Numbers of indicator bacteria (log_{10} numbers/100 mℓ)			
	Total coliforms	**Thermotolerant coliforms**	***E. coli***	**Enterococci**
Bath, hand basin			4.4	1.0-5.4
Laundry	3.4-5.5	2.0-3.0		1.4-3.5
Shower, hand basin	2.7-7.4	2.2-3.5		1.9-3.4
Shower, bath	1.8-3.9	0-3.7		0-4.8
Laundry, wash	1.9-5.9	1.0-4.2		1.5-3.9
Laundry, rinse	2.3-5.2	0-5.4		0-6.1
Hand basin, kitchen sink		5.0		4.6
Kitchen sink		7.6	7.4	7.7
Greywater, 79% shower	7.4	4.3-6.9		
Greywater (results from several studies)	7.9 7.2-8.8	5.8 5.8	 5.4	2.4 4.6

An important determinant of whether a microbial pathogen is likely to cause disease is the number of organisms which must be ingested in order to cause disease, *i.e.* the infectious dose. The lower the infectious dose of a pathogen, the greater the risk of disease resulting from its presence in greywater. Infectious doses of representative pathogens are shown in Table 18.

Table 18: Infective doses of waterborne pathogens (from Crook *et al*., 1994).

Pathogen	**Infective dose (cells)**
Escherichia coli	10^6-10^{10}
Salmonella typhi	10^4-10^7
Vibrio cholerae	10^3-10^7
Shigella flexneri 2A	180
Entamoeba histolytica	20
Shigella dysenteriae	10
Giardia lamblia	<10
Cryptosporidium spp.	1-10
Viruses	1-10

Bacteria

Health risks arising from microbiological contamination of reused water are considered to be greater than those associated with chemical compounds in reused wastewater (Mara and Cairncross, 1989). The microbial content of greywater depends on the source of the wastewater. The presence of total and faecal coliforms in greywater indicating faecal contamination and possible presence of intestinal pathogens leads to concerns over possible public health effects. These intestinal pathogens can cause diseases like dysentery, typhoid, and cholera. If greywater is used for irrigation, human exposure to microorganisms can occur from eating irrigated plants, contact with irrigated soils, contact with greywater that has ponded on the soil surface, aerosols, sprinkler irrigation, and contaminated surfaces from greywater run-off (WHO, 2006).

Protozoa
There are several protozoan pathogens which have been isolated from wastewater and recycled water sources. The most common protozoan pathogens detected in recycled water are *Entamoeba histolytica, Giardia intestinalis* and *Cryptosporidium parvum* (Toze, 2006. All these three forms of protozoan pathogens can infect their host through consumption of food or water contaminated by oocysts or by person-to-person contact.

Helminths
The major sources of helminth infection around the world are through reuse of untreated or partially treated wastewater and sludge for the irrigation of food crops that are eaten raw. These are common intestinal parasites, which are transmitted through the faecal-oral route. The most common helminth parasites detected in wastewater include the round worm (*Ascaris lumbricoides*), the hookworm (*Ancylostoma duodenale or Necator americanus),* and whip worm (*Trichuris trichiura*) (Toze, 2006). Infection via greywater has not yet been reported.

Viruses
Viruses are usually excreted in high numbers, persist in the environment and have low infectious doses. The majority of enteric viruses are commonly detected in faecal contaminated water. The enteric viruses are the smallest of the pathogens found in water. Viruses lack the ability to self-replicate, therefore are present in water as inactive particles. Most enteric viruses have a narrow host range meaning that most viruses in recycled water only infect humans.

Diseases other than those transmitted by the faecal-oral route
It is important to note that where direct contact occurs between irrigator and greywater, a number of infections other than faecal-orally transmitted ones are possible. Examples are shown in Table 19.

Table 19: Examples of organisms causing non-gastrointestinal illnesses associated with recreational or casual contact with water (from Carden *et al.*, 2007).

Health problem	Examples of Causes
Skin diseases	*Pseudomonas aeruginosa* Atypical mycobacteria *Staphylococcus epidermidis*
Respiratory diseases	Viruses, especially adenovirus Environmental mycobacteria, especially *Mycobacterium avium* complex (causing lung disease, particularly in immuno-compromised persons) *Klebsiella pneumonia*
Ear infections	*Pseudomonas aeruginosa* *Staphylococcus aureus*
Liver or kidney diseases	*Leptospira* species Various hepatitis viruses
Eye infections	*Pseudomonas aeruginosa* *Acanthamoeba* species

The role of HIV in microbial risks of greywater use in Africa
In considering the possibilities for greywater reuse in Africa in general, and in South Africa in particular, the impact of HIV infection, especially in rural and low-income settlements, must be kept in mind. In 2007, nearly 40% of women in South Africa between the ages of 25 and 29 years were HIV-positive and this proportion is likely to have increased since then. It is these women who bear the bulk of responsibility for child-rearing and household chores, including subsistence farming. They are thus the people most likely to come into contact with infectious agents, including those in greywater, to which their HIV status makes them vulnerable. Greywater poses a much greater risk to those people than to the generally healthy, well-fed population of a first world country where much of existing experience of greywater use originates. The advantages which can be brought by greywater use to improve food security must therefore be balanced against the risks of infection in vulnerable persons such as malnourished children and HIV-positive persons, particularly HIV-positive home keepers and child carers (J. Barnes, in Carden, 2007).

2.5.2 Physical characteristics of greywater

Temperature
Greywater temperatures vary within the range 18-30°C. High temperatures in greywater are attributed to the use of warm water for personal hygiene and discharge of cooking water. Although high greywater temperatures are not critical for biological treatment processes, high temperatures favour increased microbiological growth and decreased $CaCO_3$ solubility, which may result in precipitation in storage tanks or piping systems (Eriksson *et al.,* 2002; Morel and Diener, 2006).

Turbidity
Turbidity of greywater generated from sources other than laundry greywater is generally in the range 15.3-240 NTU. Turbidity values obtained from laundry greywater vary greatly, with high turbidity values during the wash cycle compared to the rinse cycle; 39-296 and 14-29 NTU respectively having been reported (Eriksson *et al.,* 2002). High turbidity values indicate high levels of suspended matter which could cause clogging of both soils and greywater systems (Weston, 1998). In general, laundry greywater has the highest turbidity among greywater sources (Jefferson, 2008).

Suspended solids (SS)
Food, oil and soil particles from kitchen greywater, hair or fibres from clothing, and residues from powdered detergents and soaps from laundry greywater can lead to a high suspended solids content of greywater, which in turn could lead to clogging of pipes, filters and pumps used in greywater treatment processes. The concentration of suspended solids (SS) in greywater depends on the water source and is usually in the range 50-300 mg/ℓ, reaching 1 500 mg/ℓ in isolated cases (Morel and Diener, 2006). The highest SS concentration originates from laundry and kitchen greywater (Jefferson, 2008). Suspended solids also provide surface area to which micro-organisms can attach, especially in the case of organic solids such as food particles.

2.5.3 Chemical characteristics of greywater
Chemical parameters of relevance to greywater use include pH, alkalinity, electrical conductivity, sodium adsorption ratio (SAR), BOD, COD, nutrient content (nitrogen,

phosphorus), potassium, calcium, magnesium, sulphur, sodium, zinc, copper, cadmium, manganese, iron, aluminium, boron, heavy metals, detergents, bleach and surfactants.

Alkalinity and pH

The optimal pH range for irrigation water is 6.5-8.4, to avoid negative impacts for both soil and plants. However, the pH of greywater that originates from laundry is generally in the range 9.3-10, while other sources of greywater have lower pH values, ranging from 5-8.7 (Christova-Boal *et al.,* 1996). High pH of laundry greywater is the result of high concentrations of powdered detergents, soaps and softeners. A change in soil pH influences several soil properties, which directly affects plant growth, soil bacteria and the availability of nutrients. Most plants grow best in soils with pH ranging between 5 and 7. Plant nutrients are mostly available in the pH range 5.5 to 6.5, which is also a good range for beneficial soil bacteria (CSBE, 2003). When the soil pH is 5 or lower, nitrates, phosphates and potassium become less available to plants and soil bacteria become less active (Crook *et al*., 1994). When the soil pH is 8 or higher, iron and zinc become less available to plants, which result in development of chlorotic leaves. Salt burn from sodium and boron may also occur (CSBE, 2003).

Greywater alkalinity is usually in the range 20-340 mg/ℓ, with highest concentrations found in both kitchen and laundry greywater. High concentrations of total dissolved solids (TDS), alkalinity and electrical conductivity (EC) in irrigation water induce salt accumulation in soils, which reduces water uptake by plants, thereby reducing plant productivity.

Biological and chemical oxygen demand (COD and BOD)

Biological and chemical oxygen demand are parameters that are used to measure organic pollution in water in terms of the amount of oxygen required to oxidise all oxidisable compounds in water. The BOD fraction represents the fraction of organic matter in water which can be readily metabolised by microorganisms in the water, while the COD is the fraction which can be chemically oxidised. The BOD and COD concentration of greywater depends largely on the amount of water used and the household cleaning products. Levels of BOD and COD observed in greywater are typically in the region of 8 000 mg/ℓ and in the range 5-1 460 mg/ℓ, respectively. There are differences in both COD and BOD between various sources of greywater. Bathroom greywater levels are usually reported to lie in the range 184-633 mg/ℓ COD and 76-300 mg/ℓ BOD; laundry 725-1 815 mg/ℓ COD and 48-472 mg/ℓ BOD; and kitchen 26-1 380 mg/ℓ COD and 5-1 460 mg/ℓ BOD (Nolde, 1999; Eriksson *et al.,* 2002). Jefferson (2008) also identified laundry greywater as the greatest contributor to the BOD and COD of the greywater fraction. Thus laundry greywater is the highest in both COD and BOD. Concentrations of both COD and BOD in greywater are derived from household chemicals such as dishwashing and laundry detergents, food waste from the kitchen sinks, and body dirt in the bathtub and laundry. Although organics vary in their sorption, volatility and persistence in soil, if greywater is released to soil, high removal of organics is expected with an overall removal of ≥ 90% (Weston, 1998).

The BOD/COD ratio is an indicator of greywater biodegradability. Greywater is regarded as easily biodegradable with a BOD/COD ratio of 2.9-3.6 (Morel and

Diener, 2006). There are a number of factors that influence the rate and extent of biodegradation, including the structure and concentration of the compounds present, the nature of microorganisms to which the compound is exposed, the environmental conditions of exposure and history of exposure (Unkovich *et al*., 2004).

Electrical conductivity (EC) and Sodium Adsorption Ratio (SAR)
Electrical conductivity measures the concentration of dissolved salts, both positively and negatively charged ions. The most common sources of salts in greywater are sodium-based soaps, found in detergents and powdered soaps. Thus electrical conductivity is a means of measuring the TDS in water, including greywater intended for irrigation. The TDS in water indicates the potential for irrigation water to cause soil salinity. Sodium ions, along with potassium, calcium, magnesium and chloride ions, are the major ions contributing to soil salinity. Electrical conductivity is directly proportional to TDS and is easier to measure. Thus EC provides a measure of the salinity of the irrigation water and of soil. If soil is watered continuously with water of high EC and if insufficient leaching occurs, salts will accumulate through the soil profile and the soil will become saline. Salinity increases with depth in the root zone. Saline soil adversely affects plant growth and productivity, and some plants will not grow at all in saline soils. The concentration of electrical conductivity in greywater has been found to be in the range 30 to 150 mS/m and sometimes can be as high as 270 mS/m (DWAF, 1996; Morel and Diener, 2006).

The SAR is defined as the potential of a given irrigation water to induce sodic conditions in the irrigation soil, where sodicity is the percentage of the soil cation exchange capacity that is occupied by sodium (DWAF, 1996). It is calculated from the concentrations (in mmol/ℓ) of sodium, magnesium and calcium ions in the water, as in Equation 4 below (DWAF, 1996):

$$\mathbf{SAR = [Na^+]/\sqrt{([Ca^{2+}]+[Mg^{2+}]/2)}} \qquad \textbf{Equation 4}$$

$[Na^+]$, $[Ca^{2+}]$, and $[Mg^{2+}]$ are the concentrations of sodium, calcium and magnesium (mmol/ℓ)

The effects of SAR are predominantly those of sodium. Irrigation water of high SAR causes deterioration in plant growth and crop quality, but its significance in the use of greywater for irrigation lies primarily in its usefulness for predicting adverse effects on soil. The most important of these is reduction in soil permeability. This occurs through reduction in either infiltration or hydraulic conductivity of soil, although both may also be affected. Reduction in infiltration of soil is caused by formation of a crust at the soil surface, making it difficult for water to penetrate beyond the surface. This is related to peak SAR. Hydraulic conductivity refers to the permeability of soil layers. Reduction in hydraulic conductivity means that water flow through the soil profile is reduced. It can be associated with formation of a temporary water table, reduction in the soil volume available for plant growth and anaerobic soil conditions. The risks of SAR-induced reduction in hydraulic conductivity tend to be long-term, and are not markedly impacted by isolated peaks in SAR (DWAF, 1996).

High SAR irrigation water can also cause hard-setting of soil, causing the soil surface to be dry and compacted. This makes soil difficult to cultivate and causes poor tilth (meaning the soil is slippery when wet or hard when dry). Hardsetting also causes high runoff. Soil structure becomes more dense, causing soils to compact (DWAF, 1996).

The SAR levels in greywater are within the ranges of 2-10 depending on the source of greywater. High EC and SAR in irrigation water induce salt accumulation in soils, which reduces water uptake by plants by lowering osmotic potential and reducing plant productivity (Morel and Diener, 2006).

Major ions

While EC measures the total dissolved salts in greywater, the properties of the individual ions are also of importance. The average concentrations of sodium, calcium, magnesium, chlorides, and sulphate ions are used to characterize salts in greywater. Typical concentrations of the major ions reported in greywater are as follows: sodium 45-1 090 mg/ℓ; calcium 16-824 mg/ℓ; magnesium 2-225 mg/ℓ; chlorides 6-141 mg/ℓ; and sulphates 0.3-40 mg/ℓ. When any water is applied to soils, changes in the concentrations of soluble salts in the soil depend on four factors. These are the concentration effect of evapotranspiration, precipitation of certain constituents of water in soil, alteration of the extent of dissolution of soluble salts from soil weathering and the extent of salt transport in the soil due to rainfall (Surapaneni and Olsson, 2002). Salts in greywater undergo the same processes in soil. Accumulation of salts in soil is also influenced by soil type and climatic conditions. Salt accumulation is problematic especially in arid and semi-arid regions, during germination and seedling development (Weston, 1998).

Sodium is probably the ion of greatest significance when reusing wastewater (including greywater) because it affects the cation exchange capacity of soil by reducing the number of cation binding sites available for cations other than sodium. It can also be taken up by plant roots and foliage and cause toxic effects at elevated concentrations. The presence of sodium sulphate, sodium carbonate, sodium tripolyphosphates, sodium citrate, sodium silicate, sodium perborate and sodium hypochlorite salts, particularly from laundry detergents, increases the concentration of salts in greywater. If soil has been irrigated with greywater for an extended period of time, accumulation of salts in soil is expected to occur (DWAF, 2006; Morel and Diener, 2006). The recommended guideline levels for sodium ion (Na^+) in the irrigation water, from several sources, are as follows: < 69 mg/ℓ indicates no problems, 69-207 mg/ℓ indicate an increasing problem and > 207 mg/ℓ indicates severe problems (Witney *et al.,* 2002; Morel and Diener, 2006). Limits for sodium in irrigation water, as per the South African Water Quality Guidelines, are similar (DWAF, 2006). High levels of sodium can also be detected by a pH test of the soil. A pH of >7.5 indicates that the soil has become overloaded with sodium (Morel and Diener, 2006).

Chlorine, as chloride (Cl^-) is a plant micro-nutrient which is relatively non-toxic when present in excess of nutrient levels. Although it is not normally detected in domestic wastewater, chloride can be present at elevated concentrations in greywater, and can severely damage plants if such water touches the plant foliage. One of the symptoms of chlorine-induced damage is the tendency for new expanding leaves to appear bleached. It is also of concern because it is highly soluble and can accumulate in the environment, particularly in groundwater. Chlorides are largely unaffected by ion exchange reactions in soil and leach freely. Plants take up chloride via both roots and foliage. Chlorides also accumulate in consumable plant parts (DWAF, 1996; CSBE, 2003).

The presence of sulphate (SO_4^-) in greywater is essential for plant growth. However, under anaerobic conditions, sulphates can be reduced to hydrogen sulphide resulting in increased toxicity, odour and corrosion (Weston, 1998).

Boron

Boron is a naturally-occurring element found in soils, but it is also found in detergents, laundry powders, soaps and water softeners containing ingredients such as sodium perborate and borax. Irrigation with greywater can therefore potentially increase the boron concentration in soil. In soil solution, boron occurs as undissociated boric acid except in highly alkaline soils (pH >8.5) where it is in the form of boric acid. It adsorbs to soil by both physical and chemical processes (Unkovich *et al.*, 2004; Bond, 1998). Excess boron is very toxic to plants and first shows up as burning of leaf edges. Other symptoms of excess boron include leaf tip and margin burns, leaf cupping, chlorosis, branch dieback, premature leaf drop and reduced growth (CSBE, 2003; Morel and Diener, 2006). Concentrations of boron in greywater typically range between 0.2 and 0.7 mg /ℓ when kitchen greywater is excluded (Ng, 2004; Weston, 1998).

Nutrients

Greywater is regarded as a low nutrient wastewater when compared to black water. It does however typically contain elevated concentrations of micronutrients (sodium, chloride, iron, manganese, copper, zinc, molybdenum) and macronutrients (nitrogen, phosphorus, magnesium, potassium, calcium and sulphur). It can therefore be considered as a nutrient source for plant growth and this can enhance the value of greywater for irrigation. However, concerns have also been raised about leaching of nitrate to groundwater (as nitrate), about excessive plant growth and about excessive algal growth in surface waters (eutrophication). This concern probably applies more to the effects of phosphorus than of nitrogen, since greywater is recognised as being low in nitrogen relative to other wastewater fractions (most of the nitrogen in wastewater comes from urine). Crops vary in their nutritive demands, requiring macronutrients in greater amounts than micronutrients (Morel and Diener, 2006). Laundry water has been identified as the greatest source of ammonia-nitrogen and phosphate-phosphorus among greywater streams, although shower and kitchen water are similar to laundry water in terms of ammonia-nitrogen (Jefferson, 2008). Another common nutrient in wastewater, including greywater, is dissolved organic carbon, which can also influence the bioavailability of other nutrients. The addition of carbon to soil by irrigation with recycled water can help to ameliorate this, by stimulating the activity of soil-microorganisms and increasing soil biomass (Roesner *et al*., 2006).

Nutrients in any type of reclaimed water need to be monitored in order to prevent over-supply. Over-fertilisation through wastewater irrigation – while less likely with greywater – has been shown to affect the yield and maturation of perennial crops, and to reduce the fruit size and quality (Hamilton *et al.,* 2005).

Oil and grease

Kitchen greywater may contain significant amounts of oil and grease originating mainly from kitchen sinks and dishwashers. The levels of oil and grease in kitchen greywater strongly depend on the cooking and waste disposal of the household. Few data on the concentration of oils and grease in greywater has been reported (Morel and Diener, 2006). Oil and grease concentrations in the ranges 37-78 mg/ℓ and 8-37 mg/ℓ have been reported in bathroom and laundry greywater, respectively (Christova-Boal *et al*., 1996). Microbial degradation in the soil removes oils and grease from greywater, but soil overloading and consequent clogging can occur if levels are high (Morel and Diener, 2006). Studies with greywater-irrigated soil have shown that oil and grease accumulates in soil and adversely affects the passage of water through soil (Travis *et al*., 2008). Pretreatment of greywater prior to irrigation can mitigate this effect (Travis *et al*., 2010). To avoid problems with treatment and disposal systems, and to avoid undesirable effects on soils, the concentration of oils and grease in greywater to be used for irrigation or disposed to the environment should be minimised. This can be achieved by passing greywater through, at minimum, a grease and grit trap (Morel and Diener, 2006) and possibly subjecting it to further biological treatment (Travis *et al*., 2010).

Laundry detergents

Laundry detergents are major contributors to the characteristics of greywater, especially laundry greywater. They contain a variety of ingredients, including surfactants, builders, bleaches, enzymes and fabric whiteners. An overview of common laundry detergent components is given in Table 20.

Table 20: Components present in laundry detergents and their approximate concentrations (from Roesner *et al*., 2006).

Component	Liquid detergent (weight percent)	Powdered detergent (weight percent)
Surfactants		
Anionic	15-30	15-25
Non-ionic	0-15	0-5
Builders		
Zeolite (H)[1]	-	20-30
Citrate (H,S,P)[1]	0-10	0-5
Polycarboxylate polymers (S)	-	0-3
Carbonate (H,P)	-	8-25
Sodium silicate (H)	-	1-3
Sodium sulphate	-	10-25
Enzymes	0-1.5	0-3
Fabric whiteners	0-0.5	0.1-0.5
Bleach		
Perborate	-	0-5
Acitivator	-	0-5

[1] H – Hardness control; S – Soil dispersant; P – pH control

Surfactants are classified as either ionic or non-ionic. The major anionic surfactants used are linear alkyl benzene sulphates, alcohol sulphonates, alkyl sulphates, alcohol ether sulphates or alkyl ethoxy sulphates. The main non-ionic surfactants are alcohol ethoxylates. There is a range of compounds in each class, differing in the length of their alkyl or ethoxy chains and in the position of functional groupings. In comparison with older detergents, surfactants used now are generally biodegradable, with half lives under aerobic conditions lasting from days to weeks (Roesner *et al*., 2006).

Builders comprise a variety of organic and inorganic compounds with functions including pH control, and binding hardness cations which would otherwise interfere with the function of surfactants. In many countries, phosphate builders have been (or soon will be) replaced with inorganic substances such as zeolites, carbonate salts and silicate salts. These are typically added as sodium salts which exchange sodium for calcium in the laundry water (Roesner *et al*., 2006).

The remaining components are present in low concentrations only. Enzymes are proteins which break large molecules into smaller, more soluble ones. They include proteases, amylases, lipases and cellulases. Of the chemicals added to whiten fabrics, the most common are fluorescent derivatives of diaminostilbene disulphonic acid. Other compounds are added to bind dyes and soils, to prevent their re-deposition on fabrics. Bleaches are now predominantly oxygen-based rather than chlorine-based. Perborates and percarbonates are the most common, with perborates requiring an added activator at lower wash temperatures (Roesner *et al.*, 2006).

Fabric softeners and anti-static agents are optionally added at the end of the wash cycle. These typically comprise cationic surfactants, mainly quaternary ammonium compounds including dialkyldimethylammonium chlorides and diethyl ester dimethylammonium chloride. Biodegradation of these compounds depends on their tendency to adsorb to soil and on the length of the alkyl chain, with sorption and long chains decreasing biodegradability (Roesner *et al*., 2006).

Surfactants have been shown to be associated with increased hydrophobicity in soil irrigated with raw greywater (Wiel-Shafran *et al.*, 2006; Travis *et al*., 2010). Treatment of greywater prior to irrigation removed this impact (Travis *et al*., 2010).

Heavy metals and metalloids
Heavy metals are not found in high enough concentrations in greywater and other types of recycled waters to be a direct threat to human health, although they may accumulate in soil and crops (Eriksson *et al.,* 2002; Hamilton, 2005; Unkovich, 2004). In greywater, heavy metals usually originate from plumbing and fixtures (Roesner *et al*., 2006). Negative effects of metals from long-term use of wastewaters, including accumulation of heavy metals on plants and in the environment, should be borne in mind as they could affect the long-term sustainability of irrigation implementations (Madyiwa *et al*., 2004). The chemicals of most concern with respect to produce quality and food standards are heavy metals such as lead, cadmium, mercury, arsenic, and possibly trace organic compounds. Cadmium and mercury are commonly found in untreated wastewater and, relative to most other metals, are more available to plants. They can occur at concentrations in harvestable portions of the crops that could be harmful to humans, but show no toxic signs to the plant. Lead contamination is usually due to aerial contamination of the produce, either through dust contamination, or uptake of atmospheric lead derived from automobile or industrial sources not from recycled water, thus is unlikely to be

of concern in greywater. Arsenic is strongly retained by soil and is generally not regarded as a high risk for food chain contamination (Unkovich *et al.,* 2004).

Monitoring of heavy metals is not recommended at present, but water quality managers and greywater users are advised to keep informed of the latest information in this regard.

Endocrine-disrupting chemicals (EDCs)

Endocrine-disrupting chemicals are defined as compounds originating outside an organism which can impact on the structure and function of the endocrine system, causing effects on the organism or its progeny. Common EDCs that are found in wastewater and the environment include the estradiol compounds commonly found in the contraceptive pill, phytoestrogens, pesticides, industrial chemicals such as bisphenol A and nonyl phenol, and heavy metals (Lim *et al.,* 2000). Household detergent ingredients, body fluids, and urine from bathroom greywater could also be sources for these compounds, but to date they have mostly been found in sewage effluent rather than in any other recycled water. Endocrine-disrupting chemicals represent a group of contaminants which needs to be borne in mind for possible future research and monitoring.

Xenobiotic organic compounds (XOCs)

Xenobiotic compounds originate from chemical products used in the household such as detergents, soaps, shampoo, perfumes, preservatives, dyes and cleaners (Eriksson *et al.,* 2002). Most of these compounds occur in kitchen and laundry greywater. Kitchen greywater contains lipids (fats and oils), tea, coffee, soluble starch, dairy products and glucose while laundry contains detergents, bleaches, perfumes and softeners. Eriksson *et al.* (2002) identified 900 xenobiotic organic compounds in greywater, from shower creams to powder laundry detergents. The XOCs detected were divided into 14 groups depending on their form and function in the chemical products (Table 21). The significance of XOCs in greywater is as yet unclear. They, too, represent a group of chemicals which needs to be borne in mind for possible future research and monitoring.

Table 21: Groups of compounds found in common household chemicals in Denmark (from Eriksson *et al.*, 2002).

Compound group	Number of substances in the group
Amphoteric detergents	20
Anionic detergents	73
Cationic detergents	34
Non-ionic detergents	65
Bleaches	16
Dyes	26
Emulsifiers	28
Enzymes	4
Fragrances and flavours	197
Preservatives	79
Softeners	29
Solvents	67
UV filters	23
Miscellaneous	238

By-products and degradation products
By-products are formed when different chemicals in greywater react with each other. Noteworthy among these are the by-products of disinfection (Eriksson *et al.,* 2002). Processes like oxidation and microbiological activities also lead to production of degradation products that have other properties. However, these products tend to be present at very low doses in treated wastewater and it would require ingestion of large doses over long periods of time for any clinical effect to be caused (Toze, 2006).

Pharmaceutically-Active Compounds (PhACs)
Most of the PhACs that are commonly found in environmental waters and wastewaters are drugs used for a variety of therapeutic uses for both humans and animals. These compounds include analgesics such as ibuprofen, caffeine, anti-epileptics, cholesterol-reducing drugs such as atorvastatin, antibiotics and antidepressants. The most common route for exposure to these compounds is through treated and untreated wastewater (Toze, 2006). Like with endocrine disrupting chemicals, PhACs are mostly found in sewage effluent rather than in recycled water, which means that chances of the presence of these compounds in greywater are minimal. They represent another group of chemicals of possible future relevance in terms of research and monitoring.

2.6 Implications of greywater quality for greywater use in small-scale irrigation

General considerations of greywater quality have been presented in the preceding section. This section focuses specifically on the potential for use of greywater for small-scale irrigation, and considers strategies for avoiding potential undesirable consequences associated with greywater quality variables.

The majority of available literature refers to large-scale irrigation applications and to experience with wastewater reuse, rather than to small-scale applications or to greywater. Not all the risks associated with wastewater reuse that are mentioned in the following section, are associated with greywater. However, lessons from this literature are presented because they provide pointers for the precautions that should be considered for irrigation use of greywater.

2.6.1 Health implications of greywater quality
Health risks can be reduced by minimising human exposure to greywater, including contact with greywater during handling of water and produce, and by the types of irrigation used.

Minimising human exposure
Groups of people who are at risk from wastewater (greywater) reuse include wastewater users, farm workers and their families, crop handlers and consumers, as well as those living near wastewater-irrigated areas. The approach required to minimise exposure depends largely on the target groups. For example, farm workers, their families and crop handlers are more susceptible to helminth infections. For their protection, health authorities encourage the use of shoes and gloves, while field workers would require potable water for drinking and hygiene. It is ineffectual to

protect the crops in the field if they are exposed to contamination in the market, therefore produce vendors should use safe water for washing and rinsing the produce. Consumers are encouraged to wash and cook vegetables thoroughly and maintain good hygiene practices. However, this option cannot minimise risks of infections alone; it also needs a comprehensive health and hygiene education campaign aimed at all stakeholders by public health departments (WHO, 1989).

Irrigation practices

Irrigation practices also contribute strongly to the health implications of the use of greywater for irrigation. For lawn and garden watering, separation of greywater from human contact may be achieved by safe irrigation methods in which wastewater (greywater) does not travel through the air to reach the ground surface. Irrigation techniques used can influence both the degree of plant contamination and the types of precautions greywater users should take. In general, health risks are greatest when either spray or sprinkler methods are used as both of these methods distribute contamination over the surface of the crop and expose nearby populations to aerosols containing bacteria and viruses (WHO, 1989). Aerosols are defined as particles ranging from 0.01-50 μm in diameter that are suspended in air and in which most viruses and pathogenic bacteria can be transferred. Studies have shown that under optimum conditions high concentrations of coliform bacteria can travel 90-130 m with a wind velocity of 1.5 m/s (Jeppesen, 1996).

Localized irrigation systems, including subsurface drip, trickle and bubbler irrigation, can give the greatest degree of health protection by reducing exposure of users. Numerous studies on irrigation methods conclude that sub-surface drip irrigation can be up to 60% more efficient than conventional surface spray. This is because 70% of plant water and nutrition uptake occurs in the upper 50% of the root zone, which is in the top 300-600 mm of soil for most plants (Jeppesen, 1996). Moreover, the assumption is that most pathogens are unlikely to survive if greywater is applied in the top 300 mm of soil, as the upper levels of the soil are most aerobic and the natural microbial populations which compete with pathogens are more prominent.

Another important safety measure is a period of cessation of irrigating with wastewater (greywater) before harvest. The 1989 WHO guidelines for wastewater irrigation (updated in 2006) recommend that wastewater irrigation should be ceased two weeks before harvest time, or two to three days before harvest if there is no alternate water resource, to allow die- off of pathogenic microorganisms.

During the hot season it is highly recommended that irrigation be carried out in the afternoon or at night in order to minimise water loss by evaporation. It is also important that greywater be applied no faster than the soil can absorb it, to avoid saturation and pooling of greywater. Another negative effect of reusing greywater for irrigation is the danger of clogging the irrigation water distribution system and soil. Clogging could be eliminated either by removing solid particles from water (by filtering or sedimentation) or by increasing the diameter of the irrigation pipes. Build-up of algal growth in irrigation systems has been reported by various sources due to the natural presence of nutrients in greywater. Algal growth does not pose any risks to either plants or humans but it could be removed by periodic chlorination of greywater (CBSE, 2003).

Aside from health considerations, it should be borne in mind that some water quality constituents – in particular pH and alkalinity – will adversely affect some types of irrigation equipment. Choice of irrigation systems should therefore:

- Minimise health impacts.
- Be as simple as possible to achieve the desired quality.
- Be robust to the effects of the greywater to which it is exposed.

Crop restriction

Crop restriction alone is not effective to control health risks and is impractical, but it works better if practiced in conjunction with other measures such as methodical public awareness and user education programmes. It can also be used effectively where a public body controls the use of wastewater, and laws providing for crop restrictions are strictly enforced (WHO, 1989).

If greywater is reused for irrigation of food plants, the following measures should be followed:

- Greywater should only be used on well-established plants and not on seedlings, as they are more sensitive to the impurities.
- Greywater should never be applied to root or leafy vegetables that will be eaten raw.
- Greywater should not come into contact with edible portions of fruit and vegetables.
- Greywater application should be restricted to the soil surface around plants of which only the above-ground part is eaten (CSBE, 2003).

Chemotherapeutic intervention

Another potential solution is medical treatment for wastewater users and crop consumers, especially for helminth infections. Treatment of children every four to six months is recommended to prevent infection reaching pre-treatment intensities (WHO, 1998). Regular chemotherapy programmes, human exposure restriction, hygiene promotion and public education should all be considered as health risk control measures in cases where wastewater is used without treatment.

2.6.2 Environmental water quality implications

Water quality variables which are likely to have an impact on the environment surrounding the irrigated area include:

- Total coliforms
- COD
- pH
- Total nitrogen
- Nitrite/nitrate
- Ammonia
- Total phosphorus
- Dissolved oxygen.

The environmental processes most likely to be affected by greywater quality are:

- Surface ponding
- Proximity to sensitive aquatic environments and other surface water bodies
- Percolation to groundwater.

Surface ponding
Bacterial contamination of surface-ponded water (mostly indicated by total coliforms) represents a health hazard to anyone who comes in contact with the water, especially children who tend to play in such water. High levels of nutrients (different forms of nitrogen and phosphorus) will cause the growth of bacteria and algae, further dropping the dissolved oxygen in the water, causing slimy growth and bad odours. Such conditions also attract flies and mosquitoes, and since ponding would likely occur in depressions in the ground, these are likely to co-occur with solid waste which provides a breeding ground for nuisance organisms and disease vectors. Thus greywater used for irrigation should never be allowed to form stagnant pools or ponds on the irrigated surface or in its vicinity.

Proximity to sensitive aquatic environments and other surface water bodies
Discharging of nutrient-rich (particularly rich in nitrogen and phosphorus) recycled water to the environment has the potential to exacerbate eutrophication of river systems, and to contribute to frequent and large blooms of toxic blue-green algae which create anaerobic conditions that lead to aquatic problems and pollution of both ground and surface water. Overgrowth of undesirable organisms resulting from high nutrient levels will cause further decreases in dissolved oxygen, resulting in death of higher organisms such as fish and in decreased biodiversity. Other contaminants present in recycled water include industrial hydrocarbons, detergents, metals, metalloids and heavy metals which could also contaminate surface waters through run-offs, but nutrients are the most significant. For all these reasons, entry of greywater used for irrigation in to surface water bodies should be rigorously avoided.

Percolation to groundwater
Although leaching is essential to prevent salinisation of soils irrigated with recycled water, movement of salts and nutrient-laden water (especially nitrate) from the root-zone to groundwater is an inevitable consequence. Depending on the source of reused water, contaminants such as heavy metals, toxic organic chemicals, and pathogens may accumulate in the soil, resulting in possible increased risks of runoff of these contaminants into surface water and possible leaching to groundwater. Bond (1998) argues that changes in the quality of groundwater may occur in any wastewater irrigation practice, but the impact of change could be minimal based on the following range of factors:

- The depth to the water table will affect the time delay before the effects of recycled water are seen at the water table.
- The quality of groundwater prior to irrigation will determine whether or not the salt or nitrates reaching the groundwater will have a detrimental impact.
- On reaching the groundwater, salt and nitrate will be subject to dilution. The extent of dilution will depend on the rate of recharge and the rate of flow of groundwater beneath the recycled water irrigation site, which in turn depends on aquifer permeability and hydraulic gradient.
- The amount of dilution will also depend on the size of the recycled water irrigation area; a large area will have a greater effect on down-gradient groundwater quality than a small area because there will be less dilution of the salts and nitrates coming from the larger area.

This last consideration is important in small-scale greywater irrigation. Because projects are likely to be of limited area and widely dispersed, it is unlikely that small-scale greywater irrigation will significantly impact groundwater quality provided the water table is not unreasonably high. Nonetheless, monitoring of groundwater remains an important management issue.

2.6.3 Implications for plant growth and yield

Greywater quality variables which are likely to impact on plant growth and yield include:

- Plant macronutrients (predominantly nitrogen and phosphorus)
- Boron
- Chloride
- Sodium.

Macronutrients and micronutrients in greywater

The macro- and micronutrients required for plant growth are shown in Table 22. Of the various waste fractions arising from domestic wastewater, greywater has the lowest levels of useful plant nutrients (usually considered in terms of nitrogen and phosphorus), and the highest level of potentially harmful contaminants (sodium, boron, chloride, heavy metals, suspended solids, oil and grease). However, it does hold fertiliser potential (Alcock, 2002). In fact, for small-scale irrigation use of greywater, particularly among low income users who cannot afford chemical fertilisers, greywater may represent the only source of nutrients that can be applied. In this context, the low nutrient concentrations in greywater make it a *de facto* low-grade fertiliser, and this needs to be recognised in any guidance provided for greywater irrigation in South Africa.

Optimum levels of macronutrients are often expressed in terms of the ratios of nitrogen (N), phosphorus (P) and potassium (K), known as the N:P:K ratio and sometimes N:P:K:S, including sulphur (S). Optimum levels of this ratio vary among crops. It tends to be higher in nitrogen for leaf crops, higher in phosphorus for root crops, and higher in potassium for many fruits (Unkovich *et al.,* 2004). The N:P:K ratio provides an adequate basis for deciding on a fertiliser application regime. The average concentrations of nitrogen, potassium and phosphorus in greywater range between 0.6 and 74 mg/ℓ for nitrogen, and 6 and 23 mg/ℓ for phosphorus (Rose *et al.*, 1991). High nitrogen and phosphate concentrations are found in greywater originating from washing and cleaning detergents. High concentrations of phosphorus between 6 and 23 mg/ℓ can be found where phosphorus detergents are used, while concentrations of 4 to 14 mg/ℓ are found where non-phosphorus detergents are used (Morel and Diener, 2006). Typically, greywater contains excess amounts of sulphur relative to the other nutrients, leading to possible acidification of the soil and formation of sulphides under anaerobic conditions (Palmquist and Jönsson, 2003).

Table 22: Elements for essential plant growth, approximate concentrations in plant tissue and general roles in plant metabolism (adapted from Unkovich *et al.*, 2004).

Element	Symbol	Approximate concentration	Mobility	Roles
Macronutrients (% dry matter)				
Nitrogen	N	2.5	Mobile	Central component of proteins, nucleic acids
Potassium	K	1.0	Mobile	Remains in ionic form, osmotic adjustment, enzyme activation
Magnesium	Mg	0.2	Variable	Remains in ionic form, osmotic adjustment, enzyme activation
Phosphorus	P	0.2	Mobile	Component of some lipids, cell membranes, nucleic acids
Calcium	Ca	0.2	Immobile	Remains in ionic form, osmotic adjustment, enzyme activation
Sulphur	S	0.1	Variable	Component of proteins
Micronutrients (mg/kg dry matter)				
Sodium	Na	500	Mobile	Remains in ionic form, osmotic adjustment, enzyme activation
Chlorine	Cl	100	Mobile	Remains in ionic form, osmotic adjustment, enzyme activation
Iron	Fe	100	Immobile	
Boron	B	12	Immobile	Cell wall maintenance, unknown
Manganese	Mn	20	Immobile	
Zinc	Zn	20	Variable	Component of some enzymes, coenzymes
Copper	Cu	3	Variable	
Nickel	Ni	0.1	Mobile	
Molybdenum	Mo	0.1	variable	

Boron

Although boron concentrations are not often reported in greywater and any other reclaimed water, greywater may have higher levels of boron than other irrigation waters. Some soils also have naturally elevated levels of boron and low concentrations of boron added to these soils can lead to a toxic response presenting itself in sensitive crops in reclaimed water irrigation systems (Morel and Diener, 2006; Roesner *et al.*, 2006). Boron is an essential plant nutrient in the µg/mℓ range, but becomes toxic in the mg/mℓ range. The effects of boron at various concentrations in irrigation water are listed in **Table 23**.

The effect of boron concentrations in soil and plants is significant in the longer term rather than in the short term. Free boron in the soil water is dependent on the sorption and desorption properties of boron to soil particles. This means that it may take several irrigation seasons for the effects of boron to become apparent. Boron toxicity shows first in older leaves, although sensitive crops may show effects before leave symptoms are noticed (**Table 23**). The usual amelioration is excess irrigation to leach ions out of the top soil. An alternate approach is to grow boron-tolerant plants (DWAF, 1996). Boron tolerant plants are listed in Appendix 3 to the Guidance Report produced on the basis of this Technical Report.

Table 23: **Effects of boron on crop yield and appearance. The Target Water Quality Range is the optimum boron concentration for irrigation water, as identified in the South African Water Quality Guidelines for irrigation (from DWAF, 1996).**

Concentration range (mg/ℓ)	Crop yield and appearance
Target water quality range <0.5	**Should prevent the accumulation of boron to toxic levels (through root uptake) in all but the most sensitive plants.**
0.5-1.0	Crops very sensitive to boron accumulate toxic levels (through root uptake). They start to display symptoms of foliar injury and/or yield decreases.
1.0-2.0	Crops sensitive to boron accumulate toxic levels (through root uptake). They start to display symptoms of foliar injury and/or yield decreases.
2.0-4.0	Crops moderately sensitive to boron accumulate toxic levels (through root uptake). They start to display symptoms of foliar injury and/or yield decreases.
4.0-6.0	Crops moderately tolerant to boron accumulate toxic levels (through root uptake). They start to display symptoms of foliar injury and/or yield decreases.
6.0-15.0	Crops tolerant to boron accumulate toxic levels (through root uptake). They start to display symptoms of foliar injury and/or yield decreases.
<15.0	Crops very tolerant to boron accumulate toxic levels (through root uptake). They start to display symptoms of foliar injury and/or yield decreases.

Chloride

Chlorides are considered to be largely unaffected by soil ion exchange reactions and leach freely. Chloride ions from irrigation water are taken up by plants via roots and foliage. Since foliage suffers leaf burn at elevated sodium concentrations, irrigation methods which do not wet leaves should be used. Chlorides also accumulate in consumable plant parts (DWAF, 1996). The effect of chloride on crops at various concentrations is shown in **Table 24**.

Table 24: The effect of chloride in irrigation water on crops. The Target Water Quality Range is the optimum chloride concentration for irrigation water, as identified in the South African Water Quality Guidelines for irrigation (from DWAF, 1996).

Concentration range (mg/ℓ)	Crop yield and appearance
Target water quality range <100	**Should prevent the accumulation of chloride to toxic levels in all but the most sensitive plants, even when chloride uptake is through foliar absorption, *i.e.* crop foliage is wetted.**
<140	Should prevent the accumulation of chloride to toxic levels in all but the most sensitive plants when chloride uptake is through root absorption, *i.e.* water is applied to the soil thereby excluding wetting of foliage.
140-175 100-175	Only slight problems with accumulation of chloride to levels toxic to crops can be expected when chloride uptake is through root absorption, *i.e.* water is applied to the soil thereby excluding wetting of foliage. Crops sensitive to foliar absorption accumulate toxic levels of chloride when crop foliage is wetted. They display foliar injury and yield decreases.
175-350	Some problems with accumulation of chloride to levels toxic to moderately sensitive crops can be expected when chloride uptake is through root absorption, *i.e.* water is applied to the soil thereby excluding wetting of foliage. Crops moderately sensitive to foliar absorption accumulate toxic levels of chloride when crop foliage is wetted. They display foliar injury and yield decreases.
350-700	All moderately sensitive crops and most moderately tolerant crops accumulate chloride to levels toxic to crops can be expected when chloride uptake is through root absorption, *i.e.* water is applied to the soil thereby excluding wetting of foliage. Crops moderately tolerant to foliar absorption accumulate toxic levels of chloride when crop foliage is wetted. They display foliar injury and yield decreases.
>700	Increasing problems with the accumulations of chloride to levels toxic to crops can be expected when chloride uptake is through root absorption, *i.e.* water is applied to the soil thereby excluding wetting of foliage. Crops tolerant to foliar absorption increasingly accumulate injury and yield decreases.

Sodium

Sodium is not an essential plant nutrient, although low levels can be beneficial to the growth of plants. The use of sodium-based salts as fillers in detergents and washing powders means that greywater typically has relatively high levels of ionised sodium (the same applies for ionised forms of boron and for chloride, from the same source). Sodium is taken up by plants through both the leaves and the roots. Sodium toxicity shows up first as sodium burn along the edges of leaves, moving inwards towards the veins. Crop productivity may also be reduced. Table 25 shows the concentrations of sodium typically associated with crop effects.

Sodium uptake by plants can be minimised by avoiding sprinkler irrigation (DWAF, 1996). Another possible mitigation measure is to choose sodium-tolerant plants.

Examples of sodium tolerant plants are presented in Appendix 3 of the Guidance Report.

Table 25: Concentrations of sodium associated with adverse effects on plant growth and yield. The Target Water Quality Range is the optimum sodium concentration for irrigation water, as identified in the South African Water Quality Guidelines for irrigation (from DWAF, 1996).

Concentration range (mg/ℓ)	Crop yield and appearance
Target water quality range <70	**Should prevent the accumulation of sodium in all but the most sensitive plants, even when crop foliage is wet.**
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 decreases.
115-230	Crops moderately sensitive to foliar absorption accumulate toxic levels of sodium when crop foliage is wetted. They display symptoms of foliar injury and yield decreases.
230-460	Crops moderately tolerant to foliar absorption accumulate toxic levels of sodium when crop foliage is wetted. They display symptoms of foliar injury and yield decreases.
>460	Crops tolerant to foliar absorption accumulate toxic levels of sodium when crop foliage is wetted. They display symptoms of foliar injury and yield decreases.

2.6.4 Implications for soil properties

Greywater quality variables which are likely to impact on soil structure and on the ability of soil to support plant growth include:

- pH
- Electrical conductivity
- Sodium Adsorption Ratio (SAR)
- Oil and grease
- Total suspended solids

pH

The pH of irrigation water and of soil is probably the single most important determinant of reactions occurring in these media. Many micro- and macronutrients are unavailable to plants at high pH and become available (some to toxic levels) at low pH. Soil is far more strongly buffered against changes in pH than is water, therefore pH changes are expected to change slowly over a long period of time. Thus, although the pH of greywater is more alkaline than most irrigation waters, it is probable that corrective action for other soil, crop or water quality concerns will be required before they need to be considered for soil pH (DWAF, 1996).

Electrical conductivity

Electrical conductivity (EC) provides a measure of the salinity of the irrigation water and of soil. If soil is watered continuously with water of high EC and if insufficient leaching occurs, salts will accumulate through the soil profile and the soil will become saline. Salinity increases with depth in the root zone. Saline soil adversely affects plant growth and productivity, and some plants will not grow at all in saline soils (Table 26). One way of managing salinity in irrigation water is to grow salt-tolerant crop species. Another is to apply water more frequently in lower quantities as is common with drip irrigation, but which can also be imitated through manual applications. These are probably the only options available to small-scale agriculture, where low cost and low technology are the driving factors in the choice of management options for water quality problems (DWAF, 1996). Salt-tolerant species of a range of commercially-relevant crops are listed in Appendix 3 of the Guidance Report. Pinto *et al*. (2010) reported that, while continuous irrigation with greywater resulted in increased soil pH and EC, alternating irrigation with greywater and with fresh water did not affect these soil properties. Thus it is possible to counteract or manage salt accumulation as a result of greywater irrigation by a number of measures.

Table 26: The effect of salinity (measured as electrical conductivity) on crop yield. The Target Water Quality Range is the optimum electrical conductivity for irrigation water, as identified in the South African Water Quality Guidelines for irrigation (from DWAF, 1996).

Electrical conductivity Range (mS/m)	Crop yield and appearance
Target water quality range <40 mS/m	**Should ensure that all 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.**
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 should be avoided.
90-270	A 90% relative of moderately salt-tolerant 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 should be avoided.
270-540	An 80% relative yield of moderately salt-tolerant crops can be maintained provided that a high frequency irrigation system is used. A leaching fraction of up to 0.2 may be required and wetting of foliage should be avoided.
>540	These waters can still be used for irrigation of selected crops provided sound irrigation management is practiced and yield decreases are acceptable. However, the management and soil requirements become increasingly restrictive and the likelihood of sustainable irrigation decreases rapidly.

[1] The leaching fraction is the total water application that is leached to below the root zone. A high leaching fraction results in a lower EC in the drainage water and in the overlying soil profile than does a lower leaching fraction.

Sodium adsorption ratio (SAR)

The greatest effects of SAR are on soil structure, via reduction in either infiltration rate or hydraulic conductivity, and sometimes in both.

The reduction in infiltration rate caused by surface sealing (formation of a surface crust under the impact of rain drops) can be mitigated by:

- Surface application of gypsum to increase the salt content of the infiltrating water.
- Application of surface mulch (organic matter) to reduce drop impact energy.

- Application of large quantities of organic matter to the soil surface.
- Application of soil stabilisers on their own or in combination with each other and with easily dissolvable gypsum (DWAF, 1996).

Hardsetting and reduced soil hydraulic conductivity can be ameliorated by:
- Gypsum application calculated to reduce the exchangeable sodium percentage (ESP) of the soil to acceptable levels by mixing it to the desired level with affected soil.
- Application of large amounts of organic matter.
- Increasing the EC or TDS of the greywater used for irrigation without increasing the SAR (although this may have other negative effects).
- Increasing leaching to reduce the ESP of lower soil layers.
- Refraining from cultivation when soil is wet to prevent further hardsetting (DWAF, 1996).

The SAR ranges at which adverse effects on soil properties can be expected are shown in Table 27.

Table 27: SAR ranges at which infiltration rate and hydraulic conductivity of soil are adversely affected. The Target Water Quality Range is the optimum SAR for irrigation water, as identified in the South African Water Quality Guidelines for irrigation (from DWAF, 1996).

Sodium adsorption ratio range (mS/m)	Infiltration rate	Hydraulic conductivity and hardsetting
Target water quality range <1.5	**Should ensure an adequate infiltration rate for soils sensitive to the formation of infiltration rate-reducing surface seals under conditions of rainfall during the irrigation season or irrigation with water having electrical conductivity (EC) <20 mS/m.**	**No significant reduction in hydraulic conductivity expected in this SAR range for any soil; no hardsetting above inherent hardsetting expected in any soil in this SAR range.**
1.5-3.0	Infiltration problems likely to occur in soils sensitive 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 problem is expected with irrigation waters having EC > 90 mS/m; slight to moderate problems can be expected at EC in the range 20-90 mS/m.	No significant reduction in hydraulic conductivity expected in this SAR range for any soil; no hardsetting above inherent hardsetting expected in any soil in this SAR range.
3.0-6.0	Infiltration problems likely to occur in soils sensitive to the formation of infiltration rate-reducing surface seals when irrigated with water having EC < 25 mS/m; no problem is expected with irrigation water having EC > 130 mS/m; slight to moderate problems can be expected at EC in the range 25-130 mS/m.	Hydraulic conductivity reduction likely to occur in soils sensitive to hydraulic conductivity reduction. A low EC in the soil solution may cause hydraulic conductivity to be irreversibly reduced by up to 25% for sensitive soils. Hardsetting is increasingly likely to occur in sensitive soils at EC<60 mS/m for SAR=3 and <120 mS/m for SAR=6.

Sodium adsorption ratio range (mS/m)	Infiltration rate	Hydraulic conductivity and hardsetting
6.0-12.0	Infiltration problems likely to occur in soils sensitive to the formation of infiltration rate-reducing surface seals when irrigated with waters having EC < 35 mS/m; no problem is expected with irrigation water having EC > 200 mS/m; slight to moderate problems can be expected at EC in the range 35-200 mS/m.	Hydraulic conductivity reduction likely to occur in soils sensitive to hydraulic conductivity reduction. A low EC in the soil solution may cause hydraulic conductivity to be irreversibly reduced by >25% for sensitive soils and by <25% in less sensitive soils, depending on the particle size distribution of the soil and the type of clay mineral present in the clay size fraction. Tolerant soils will show little or no effect.
12.0-20.0	Infiltration problems likely to occur in soils sensitive to the formation of infiltration rate-reducing surface seals when irrigated with waters having EC < 90 mS/m; no problem is expected with irrigation water having EC > 310 mS/m; slight to moderate problems can be expected at EC in the range 90-310 mS/m.	Hydraulic conductivity reduction likely to occur in soils sensitive to hydraulic conductivity reduction. A low EC in the soil solution may cause hydraulic conductivity to be irreversibly reduced by >25% for sensitive soils and by <25% for less sensitive soils, depending on the particle size distribution of the soil and the type of clay mineral present in the clay size fraction. Tolerant soils will show little or no effect. Small and reversible changes in hydraulics occur in sensitive soils where EC is in the range 100-200 mS/m. Hardsetting is likely to occur in sensitive soils at EC<240 mS/m for SAR=12 and for EC<400 mS/m for SAR=20.
>20.0	Infiltration problems likely to occur in soils sensitive to the formation of infiltration rate-reducing surface seals when irrigated with waters having EC < 180 mS/m; no problem is expected with irrigation water having EC > 560 mS/m; slight to moderate problems can be expected at EC in the range 180-560 mS/m.	Hydraulic conductivity reduction likely to occur in soils sensitive to hydraulic conductivity reduction. A low EC in the soil solution may cause hydraulic conductivity to be irreversibly reduced by >25% for sensitive soils and by <25% for less sensitive soils, depending on the particle size distribution of the soil and the type of clay mineral present in the clay size fraction. Tolerant soils will show little or no effect. Small and reversible changes in hydraulics occur in sensitive soils when EC is in the range 100-200 mS/m.

Oil and grease; Total suspended solids (TSS)

The main adverse effect expected from high levels of oil, grease and suspended solids is clogging of the soil structure. This affects infiltration of water into the soil and reduces the amount of water available to lower layers of the soil horizon in the root zone. Oil, grease and suspended solids can be minimised in greywater used for irrigation by excluding untreated kitchen greywater and/or by passing greywater through a grease and grit trap prior to use (Morel and Diener, 2006).

2.7 Greywater treatment and disposal

The quality of greywater for irrigation use can be influenced by three processes, *viz.* storage, source control and treatment. Although storage and source control are not strictly treatment processes, they alter the quality of greywater which can be used for irrigation, and are therefore included in this section.

2.7.1 Storage of greywater

Storage of greywater promotes either generation of offensive odours or the growth of microorganisms. Direct greywater reuse without any storage minimises the growth of microorganisms, offensive odours and health risks with contact. Although extended retention of greywater before use can compromise overall system performance, storage is acceptable if treatment can control odours at non-offensive levels for reuse in watering lawns and gardens.

Conflicting opinions with regard to storage of greywater exist. Some greywater use recommendations state that greywater should not be stored for more than 24 hours (Murphy, 2006; EPA Victoria, 2008). Guidelines in the UK, based on comprehensive research, recommend that greywater should not be stored beyond 48 hours before reuse (Dixon *et al*., 2000). Birks *et al.* (2004) observed strains of *Legionella* in stored greywater samples, showing stored greywater to be a potential source of pathogens. Other specialists argue that the process of digestion in the form of anaerobic reactions which occur during storage results in greywater that contains less organic material and is cleaner. The only side effect would be unpleasant odours that could be controlled by venting the greywater storage tank away from the places where odour would be a nuisance (CSBE, 2003).

2.7.2 Source control

Pollution load on greywater treatment and management systems can be minimised by active participation of all household members in reducing undesirable substances entering the greywater streams. Source control should aim to (Morel and Diener, 2006):

- Minimise water usage.
- Optimise and minimise use of cleaning products.
- Avoid discharge of substances which cause problems in treatment and irrigation, *e.g.* oils, fats, bleach, solvents.
- Substitute hazardous or harmful products with environmentally friendly ones.

Minimising water use is an option in scenarios where there is high water consumption and a relative abundance of water. In settlements which are not adequately supplied with water, or in areas where water is scarce as a result of climatic conditions, water consumption has usually already been reduced as far as possible and possibilities for further reduction are limited (Morel and Diener, 2006).

Reduction in the use of personal cleaning products and household cleaners, and careful choice of products, can contribute significantly to reducing the pollution load in greywater. Hard soaps and most washing powders contain sodium salts that contribute to sodium toxicity to plants and to soil degradation. Wherever possible, sodium-based products should be substituted with potassium-based ones, or with liquid soaps that contain less sodium. Disinfectant use, particularly of chlorine bleaches, should be minimised because of their detrimental effect on treatment systems and soil organisms. Soaps and cleaning products containing bleaches, softeners, whitening agents, non-biodegradable surfactants or heavy metals such as boron should be avoided wherever possible. There is an increasing range of environmentally friendly household products available on the market that avoid such components. Water outlets (*e.g.* sinks, drains) should be equipped with screens to prevent entry of solids into the greywater. Fats and grease should not be disposed of into the kitchen sink. These measures all require provision of adequate information to, and co-operation from, household members contributing to the greywater stream (Morel and Diener, 2006).

2.7.3 Low-cost greywater treatment systems

A wide variety of technologies has been developed and tested for greywater treatment, mostly on an *ad hoc* basis. Treatment systems are divided into primary, secondary and tertiary systems. In the case of greywater treatment at household level, tertiary treatment is uncommon.

Present information indicates that most households using greywater are not using any form of treatment (Weston, 1998). Primary greywater systems use untreated greywater directly, with little or no treatment apart from coarse screen filters, which remove lint, hair and food particles, and also do not allow any greywater storage (Jeppsen, 1996). These are only designed to convey greywater from the source to garden watering or irrigation applications. Secondary and tertiary treatment technologies offer a variety of improvements in treated greywater quality, usually including some form of biological treatment (Wiltshire, 2005). The selection of an appropriate technology is dependent on many factors including characteristics of the greywater, the required effluent quality, the cost of the selected treatment option, scale of operation, end use of the water, socio-economic factors relating to the cost of water, and household customs and practices (Jefferson *et al.*, 2004).

For the scope of this study, only simple treatment technologies are explored, since these are the most likely to be effective at household level, in terms of gaining user co-operation in the installation and maintenance thereof. Examples are presented of simple treatment systems for greywater which have been trialled in South Africa.

2.7.4 Primary treatment systems

Primary treatment is characterised by removal of pollutants from greywater by physical processes (Morel and Diener, 2006).

Simple gravity diversion systems

This type of treatment is best described as a diversion system for greywater and is the most economical, but provides very little in the form of treatment. Most of these simple plumbing systems are designed to cope with fouling material such as hair, lint, and food particles. The system is gravity-fed throughout in order to eliminate the need for external energy, therefore is reliant upon favourable topographic conditions, building and plumbing designs. The transportation pipes are usually oversized (about

50 mm) and distribution holes are at least 5 mm in diameter to reduce the risk of clogging, hence filtering is not required. Simple gravity systems allow soil to treat greywater and therefore the type and depth of the soil available to complete treatment without compromising the environment are important (CSBE, 2003). A potential problem is that relatively low flows from greywater sources could cause incomplete drainage within the pipes and lead to fouling, anaerobic conditions, and microbiological contamination.

Filtration

Filtration is regarded as simple greywater treatment, to remove solid material such as hair, lint and food particles from entering the greywater systems. Moreover, filtration reduces organic loads and solid levels which could induce microbial growth in greywater systems (Al-Jayyousi, 2003). In its simplest form, anything from a sock or stocking, net wire, sand, gravel, small stones, leaves, tree bark, *etc.* could be used for filtration. A sock or stocking attached to the inlet pipe could therefore function as a filter.

Coarse filtration

Coarse filtration systems mainly prevent fouling. Geo-textile, nylon sock-type or mesh-type filters are the most efficient and require only low maintenance. These coarse filters are usually installed in the greywater drain line when discharging into the surge tank prior to pumping (Wiltshire, 2005). Sock filters maintain adequate flow as they expand when filled up with filtered material and require replacing or cleaning only fortnightly on average (Christova-Boal *et al.,* 1996). Removing and installing new filters need not pose any health risks if performed responsibly.

Other coarse filter types include disc or mesh filters, which can be installed with automatic back-washing systems. These filters are very effective at removing finer particles that easily foul treatment systems. However, these coarse filters utilise more external energy and have high initial capital costs, which make them unfavourable for rural and peri-urban areas. These filters are cleaned or self-clean once a week; an automatic filter cleaning process lessens the chances of human exposure and simplifies operator maintenance (Christova-Boal *et al.,* 1996).

Slow sand filters

Slow sand filters include shallow layers of stone, medium gravel, and pea-sized gravel beneath a deep layer of sand. Multi-media filters which are filled with a variety of media in order of increasing size are more comprehensive, yet still low cost and simple, greywater treatment systems. More natural forms of slow sand filtration include soil boxes, infiltration beds and vertical reed beds or constructed wetlands, although these all include an element of biological treatment. It has been reported that about 90% of organic matter, 98-100% of SS, 90-99% of BOD, 100% of COD, 87-100% phosphate and 40-100% nitrogen from domestic wastewater and greywater can be removed by such treatment systems. Clogging of soil due to constituents such as grease, lint, hair, particulates collecting at the soil interface and biofilms from nutrients can limit the effectiveness of soil treatment (CSBE, 2003; Morel and Diener, 2006).

The most efficient technique of reusing greywater for irrigation is one that utilises drip sub-surface irrigation system, which is incorporated with a sand filter as the fine filtration treatment step. The disadvantages associated with slow sand filters include potentially very slow percolation rates, the need for regular cleaning and replacement of the top layer of media (CSBE, 2003; Morel and Diener, 2006).

Settlement and flotation
Settling tanks are sometimes regarded as means of removing solids from greywater. Substances denser than water will fall out of suspension to the bottom of the tank while grease, oil, and other small particles will float to form a surface scum and the remaining liquid can be reused (CSBE, 2003). A settling tank has the added advantage of allowing cooling of hot water before reuse. This form of treatment is easy to maintain. In its simplest form, this combination of physical processes is provided by a grease and grit trap, while septic tank systems form the other end of the spectrum. Morel and Diener (2006) recommend the inclusion of a grease and grit trap as a primary treatment step in most greywater treatment and management systems.

2.7.5 Secondary treatment systems
These are systems which cannot be categorised as primary treatment systems as they typically allow some form of storage of treated greywater before use or disposal. Systems that store greywater seek to maximise subsequent use. Secondary treatment follows after the physical removal mechanisms of primary treatment and therefore aims to remove dissolved organic matter and SS which are not removed by primary treatment. Biological treatment, *i.e.* improvement in the quality of greywater as a result of removal of organic matter through the biochemical reactions of microorganisms, usually forms part of a secondary treatment system. These systems are more complex, more expensive, and require more maintenance than primary treatment systems, making them less suitable for rural, informal and peri-urban areas. Nonetheless, there are examples worldwide of biological treatment systems that have worked well in these settings (Morel and Diener, 2006; Jefferson, 2008).

Morel and Diener (2006) identify the following secondary treatment systems as being suitable for greywater treatment in low and middle income countries.

Anaerobic filtration
As with many biological treatment systems, anaerobic filtration systems depend on the action of an attached biofilm, also termed fixed-film reactors. In such a system, bacteria colonise the surfaces of a solid medium, such as gravel, rocks, cinder or specially formed plastic pieces, and remove organic material from the wastewater as it flows over this medium. The layer of bacteria in a coating of extracellular mucilaginous matter which forms on the solid media is termed a biofilm. An anaerobic filter consists of a watertight tank containing several layers of submerged solid media. Greywater is introduced at the bottom of the tank and flows upward, passing over the attached biofilm. The treated greywater is drawn off at the top of the tank, with the media layers remaining submerged, hence anaerobic, at all times. Anaerobic filters provide good removal of SS and BOD, but only limited removal of nutrients, as is typical of anaerobic systems (Morel and Diener, 2006).

Vertical and horizontal filters
Both vertical and horizontal filters also depend on the removal of organic material from greywater by the action of microorganisms in attached biofilms. Vertical filters

are aerobic systems in which water is applied intermittently and evenly over the filter surface to ensure oxygen supply to the filter medium. In horizontal filters, the greywater is applied to the filter from below. As a result parts of the filter operate anaerobically (in the absence of oxygen and nitrogen), while others operate anoxically (in the absence of oxygen but the presence of nitrogen) or aerobically. Because there is at least an element of aerobic treatment in both systems, removal of nutrients occurs in addition to removal of dissolved and suspended solids (Morel and Diener, 2006; Jefferson, 2008).

Planted filters, also termed sub-surface flow, constructed wetlands, artificial wetlands, reed beds, root zone method, gravel bed hydroponic filters or vegetated submerged beds, are vertical or horizontal filters planted with vegetation on the upper surface. The root zone of the plants provides the necessary attachment sites and conditions for the development of microorganisms and other organisms which are efficient at nutrient removal. The plants themselves provide only limited nutrient removal (Morel and Diener, 2006).

2.7.6 *Tertiary treatment*

Greywater treatment or management systems which allow for storage of greywater may provide some form of disinfection to minimise bacterial contamination or bacterial regrowth during storage.

Disinfection of greywater seeks to reduce bacterial contamination provided that solid or organic material has been previously removed by primary treatment systems. It usually takes place before storage of greywater in order to reduce the risks of anaerobic reactions, which increase contamination levels. Disinfection includes addition of chlorine or iodine tablets, or use of Ultraviolet (UV) light. Ultraviolet light disinfection does not require a long contact time and therefore is a favourable technology for the treatment of greywater. On the other hand, it requires low turbidity and SS in order to prevent shadowing of pathogens when greywater passes over the UV lamp and the lamps themselves are prone to fouling (Wiltshire, 2005). Therefore this type of disinfection is more effective when coupled with pre-filtration.

Chlorine or bromide disinfection changes the characteristics of greywater and requires at least twenty minutes contact time. Moreover, chlorine or bromide may react with certain waste products in greywater and form potentially toxic by-products (Christova-Boal *et al*., 1996; Eriksson *et al*., 2002). Given that doses of chlorine are very difficult to maintain, overdosing would negatively affect both plant and soils. Therefore, disinfection with chlorine should be left at least overnight to allow chlorine to volatilise. Other forms of disinfection such as ozone and chlorine dioxide are more complex and more expensive and are therefore not considered here.

2.7.7 Treatment systems tested in pilot studies in South Africa

The processes described below are examples of treatment systems that have been tested in pilot studies in South Africa. They represent combinations of primary and secondary treatment processes, either separate from irrigation or integrated with sub-surface root zone irrigation. The treatment systems shown aim to lower levels of SS, oil and grease, COD and health-related microorganisms. Some removal of nutrients (nitrogen, phosphorus) may also occur, although this is of lesser concern where the treated greywater is going to be used for irrigation.

Mulch tower and resorption bed

A treatment system combining primary and secondary treatment was piloted in the Hull Street Project, Kimberley (Ridderstolpe, 2007), and the Scenery Park Development, Buffalo City Municipality (BCM) (Whittington-Jones, 2007). The system comprises an above-ground mulch tower and a sub-surface resorption bed. The two trial implementations are similar and were designed by Peter Ridderstolpe, under the auspices of the Stockholm Environment Institute, for implementation in low-cost ecological housing developments incorporating greywater treatment and reuse. Mulch towers in keeping with Ridderstolpe's design have been tested by Tandlich and co-workers (Zuma *et al.*, 2009; Tandlich *et al*., 2009). The combination of mulch tower and resorption bed, as per the BCM design, has been tested by Naicker (Naicker, 2008; Naicker *et al.*, 2009; Appendix 1).

A mulch tower is the minimum treatment required for use of kitchen greywater identified in the Guidance Report. It is primarily a primary treatment process, aimed at removal of SS, oil and grease, with some secondary biological degradation of COD. A variety of packing material can be used, but the design according to Ridderstolpe (2007) provides for an organic substrate (*e.g.* coconut fibres, wood chips) over layers of different sizes of gravel and, possibly, coarse sand. The support material acts as a sieve for suspended particles, while macro- and micro-organisms in the organic layer and in the biofilm which forms on the inert layer (gravel, sand) break down organic matter. The mulch layer needs replacing periodically, the interval between replacements depending on how heavily the mulch filter is loaded. Although in this treatment system the mulch tower is part of a larger treatment system, it can also be used on its own as a low-cost, low-technology household-based treatment system. Two studies testing the performance of mulch towers have shown that this treatment process significantly improves greywater quality (Naicker, 2008 and Appendix 1; Zuma *et al.*, 2009). An implementation of a mulch filter in Buffalo City Municipality is shown in Figure 4.

A **B**

Figure 4: Mulch tower situated at the outlet of kitchen sink (A), and view of mulch tower from above (B), showing organic filtering material (mulch).

The combination of mulch tower and resorption bed represents a combination of primary and secondary treatment. The mulch tower provides mainly primary treatment, while secondary treatment is performed by a subsurface resorption bed with embedded infiltration zone (termed “Infiltra” in the design and henceforth referred to by that term). Effluent from the mulch tower drains into the resorption bed with Infiltra, which is the below-ground secondary treatment stage. The Infiltra consists of stone chips encapsulated within a geotextile and lies within the resorption bed (Figure 5). The resorption bed also consists of stone chips, and is lined with and enclosed in geotextile. Biofilm in the Infiltra serves as a site for removal of COD and BOD, and facilitates even distribution of the influent on the resorption bed. The base of the resorption bed also allows for biofilm development, which is expected to remove the bulk of COD and to contribute to removal of nutrients and waste-derived microorganisms (Ridderstolpe, 2007). Water travelling through the resorption bed permeates through the geotextile lining of the resorption bed and enters the soil environment. The design allows for sampling pipes through which samples of water in the Infiltra and the resorption bed can be withdrawn, to determine the extent to which this treatment process has improved the quality of greywater. The resorption bed was designed primarily as a disposal system, with greywater infiltrating into the surrounding soil. However, relatively simple additions (*e.g.* lining with an impermeable liner and draining the resorption bed into an agricultural drain; planting around or over the resorption bed) would allow the system to be adapted to the use of treated greywater for plant irrigation. A combination of mulch filter and resorption bed, constructed at the University of KwaZulu-Natal (Durban), is shown in Figure 5.

Figure 5: Combination of mulch tower and sub-surface resorption bed, including embedded infiltration zone and surrounding gravel filter. Projecting pipes are access points for sampling.

Testing to date has indicated that the bulk of treatment occurs in the mulch tower, with a smaller proportion performed by the Infiltra and resorption bed (Naicker, 2008; Naicker *et al.*, 2009; Appendix 1). However, this may have been the result of limitations in experimental design. Observational studies in Kimberley suggest that the combination of mulch tower and resorption bed successfully treats household greywater (Ridderstolpe, 2007).

Tower gardens and "Agritubes"

Tower gardens and variations thereof represent combinations of physical primary treatment by filtration through stones/sand, and biological secondary process by the action of microorganisms in an attached biofilm and/or in soil.

Variations on the concept of tower gardens for use of greywater in irrigating vegetables have been applied on a small-scale in various places throughout the developing world. The implementation described here was developed by communal water use consultant Chris Stimie after observing tower gardens in Kenya, and has been implemented in the Eastern Cape and Limpopo provinces (Stimie, pers. comm., 2009). The "tower" comprises a column of soil contained within supporting material and surrounding a central core of stones. Holes are made in the supporting material and plants planted in these. Greywater is poured onto the stone core, which serves as a biofilter and as a means of distributing the greywater. To account for the often-soapy greywater, pouring two buckets of clean water into the column each week clears the system. This system favours the growth of leafy vegetables such as spinach (Crosby, 2005; Morel and Diener, 2006). In this case, the tower garden is simultaneously a means of treating greywater (as it moves through the stones which become coated in biofilm, and as it moves through the soil) and of sub-surface irrigation of plants growing on the outside surface of the tower. The liner of the tower represents an additional barrier between the soil and the above-ground parts of the irrigated plants. Implementations of tower gardens are shown in Figure 6.

A B

Figure 6: Tower gardens, (A) shortly after construction and planting, (B) obscured by spinach growing on the outer wall of the tower garden and tomato plants growing on the upper surface of the tower garden (from Crosby, 2005, used with permission).

Growing tubes, or "Agritubes", are a similar concept, designed by Khanyisa Projects and recently piloted in informal settlements in eThekwini Municipality (Alcock, pers. comm., 2009; Gounden, pers. comm., 2009). As with the tower gardens, Agritubes are supported cylinders filled with soil in which holes can be cut to plant vegetables. In this case, the central core of stones is absent, greywater being distributed instead via a slotted pipe inserted into the centre of the column. Since the core is narrower, the entire column is also narrower. The base of the column is supported by a tyre. An outlet pipe can be added for collection of overflow greywater, though it would be preferable to adjust the loading of the Agritube such that overflow does not occur. The soil used in pilot growing tubes was composted sludge from a sewage treatment works. As with tower gardens, treatment is integrated with sub-surface irrigation. An example of a pilot implementation in eThekwini Municipality is shown in Figure 7.

A **B**

Figure 7: Growing tubes (Agritubes), (A) as tested by eThekwini Municipality for growing plants with greywater, and (B) in use for greywater irrigation of food crops in an informal settlement in eThekwini Municipality. (From Nick Alcock, Khanyisa Projects; used with permission)

2.7.8 Commercial greywater treatment systems available in South Africa

Commercially available systems for household-level treatment of greywater were reviewed comprehensively in Appendix B of Carden *et al.* (2007). In the interests of collating the available irrigation-related information in a single document, the content of that Appendix is largely repeated in Appendix 2 of this document. The relevant websites were checked and any products no longer listed were removed.

Two commercial systems which are available in South Africa are briefly presented below.

Water Rhapsody *(http://www.waterrhapsody.co.za)*

In this system greywater from the bath, basins, shower and washing machine is collected directly at the outflow. The combined greywater is passed through a filter and then to a pump chamber, from where it is sprinkled onto the garden (Figure 8). An advantage of this system is that there is no storage of the greywater as the pump switches on as soon as there is any flow into the tank. A disadvantage is that water is irrigated by sprinkler which is not appropriate for greywater because of the dispersal of aerosols and droplets onto plant leaves and to the surrounding atmosphere (Carden *et al.*, 2007).

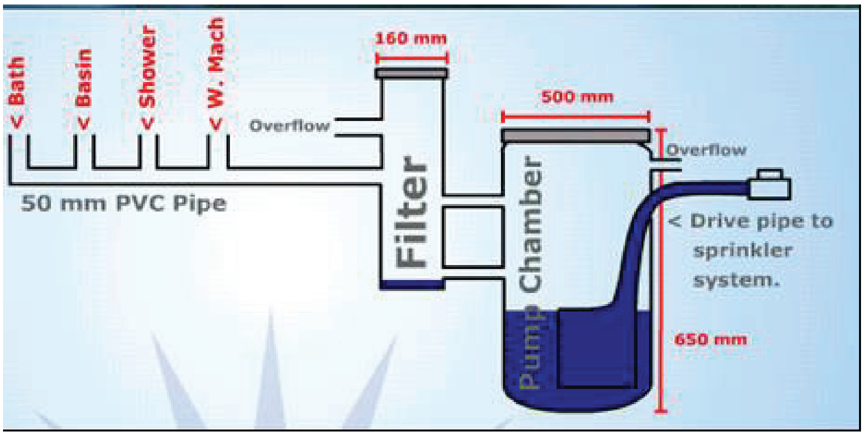

Figure 8: Schematic illustration of the Water Rhapsody greywater system (from http://www.waterrhapsody.co.za).

Garden Res-Q *(http://www.greywater.co.za)*

The Garden Res-Q unit is similar in concept to the Water Rhapsody system. It also uses greywater to irrigate a small to medium-sized garden. The unit is connected directly to the outlet pipes of the bath or shower or washing machine. The greywater is collected and filtered of hair and lint. A low-pressure pump is activated to pump the water through a normal 20 mm garden hose as soon as the sump starts filling with the greywater. Once the shower has been turned off or the bath emptied, the pump automatically switches off and ceases the irrigation process until the flow of greywater is resumed. A return to sewer mechanism / overflow has been included in the design of the system, and a small percentage of greywater is automatically diverted to sewer during each session, thereby assisting with solid waste removal and keeping rubber seals wet and lubricated. The self-contained unit provided is shown in Figure 9.

Figure 9: The Garden Res-Q greywater system (from http://www.greywater.co.za).

2.8 Greywater quantity to be irrigated

Any guidance for the use of greywater in small-scale irrigation is incomplete if it does not also address the amount of greywater which can be used. Roesner *et al*. (2006) concluded that a household of two to three people in a house of approximately 230 m^2 produces sufficient greywater to irrigate the non-grassed areas (flower beds and shrubs) of a garden of approximately 1 010 m^2 (0.1 ha), assuming half the area is grassed. By extension, this equates to a food garden of approximately 500 m^2. It should be borne in mind that this estimate was derived for North American households which typically have high water consumption.

There are two possible philosophical approaches to deciding how available greywater should be applied in small-scale irrigation:

1) Using greywater disposal as the point of departure, the maximum possible volume of greywater is applied that can be absorbed by the soil. This approach is based on soil properties and on the area of land required to dispose of the available greywater.

2) Using the beneficial use of greywater for irrigation as the point of departure, the water requirements of the plants, and other environmental variables impacting on this, are the driving factors.

Murphy (2006), in reviewing the fitness-for-use of greywater for irrigation in South Africa, presents examples of both approaches.

Using the first approach, Murphy (2006) estimated greywater production volumes in South African urban and peri-urban areas based on Census data, annual water consumption data, and an assumption of 90% greywater return in unserviced households and 50% in serviced households. An approximate crop irrigation requirement of 10 ℓ/m^2/day was used, together with the estimated greywater production per community category, to estimate the average area of land per dwelling required for irrigating garden crops during dry summers in semi-arid / arid areas. The assumed value for crop irrigation requirement was high to allow for a conservative estimate of the potential area required. This compensated for the need to apply additional water to prevent salt accumulation in the soil, to be sufficient for periods when evapotranspiration (crop water use) would be highest, and to compensate for the fact that not all the available greywater would be suitable for use on all crops and soils.

Given these considerations of greywater generation and irrigation water requirements, two categories of land required for irrigation were proposed by Murphy (2006):

- For communities required to get their water from a community stand or a tap in the yard, an area of approximately 17 m^2 per dwelling was estimated.
- For communities with piped water directly to their homes, an area of approximately 35 m^2 per dwelling was estimated.

According to this philosophical approach to estimating greywater irrigation volumes, the amount of greywater which can be used to replace clean water for irrigation purposes (or, viewed alternately, which can be disposed of by irrigation, given that water quality is fit for irrigation use) is therefore linked to land availability for irrigation (Murphy, 2006).

Approaching the estimation of greywater irrigation volumes from the second perspective, *viz*. meeting plant water requirements, Murphy (2006) showed a table originally presented by Bennet (1995) in which estimates of irrigation volumes were given for a range of assumed agroclimatic conditions. The volumes were based on values of estimated water use (EWU) of plants in California, based on the assumed crop water use. Murphy (2006) converted the information in the table to metric units from the original US units, but did not further adapt the information in the table to South African conditions. While this represented only a limited attempt to estimate irrigation volumes for South Africa on the basis of plant water requirements, it illustrates the second philosophical approach that can be taken to estimating greywater irrigation volumes.

It is an underlying principle of the present project that the guidance given should be based on the *beneficial use of greywater for small-scale irrigation* and *not* on disposal of greywater (for more details, see Section 5). Therefore further consideration of methods for estimating greywater volumes for irrigation will be based on the water requirements of the irrigated plants.

2.8.1 Estimating plant water requirements

Calculating estimated water use (EWU)

Both nationally and internationally, for irrigation of landscapes and, nationally, of crops, irrigation volumes have been calculated using Equation 5 or minor variations thereof (Green, 1985; Bennet; 1995; University of California, 2009). In the context of landscape irrigation, this equation applies particularly to low volume irrigation systems supplying water with high efficiency at the soil surface or below it, which corresponds to the most appropriate means of applying greywater. This removes the need to apply a correction for irrigation efficiency (Bennet, 1995).

$$\mathbf{EWU = E_0 \times PF \times HA} \qquad \textbf{Equation 5}$$

EWU = estimated water use
E_0 = reference evapotranspiration
PF = plant factor (in South Africa, crop factor, CF)
HA = area irrigated.

This represents the optimal, or maximum, amount of water to be applied to meet the water needs of the plant.

In Equation 5, the reference evapotranspiration, E_0, has different meanings in South Africa relative to other parts of the world. Elsewhere, and particular in the USA, E_0 is the evapotranspiration demand, or water use, of a reference crop, typically a short lawn or turf grass, sometimes also termed ET_0 (Allen *et al*., 1998). In South Africa, E_0 is typically measured by pan evaporation, specifically evaporation from an American Class A evaporation pan (Green, 1985; SAPWAT, 2009). The value of E_0 in either interpretation is largely a meteorological measure, depending on factors such as solar irradiation, temperature, wind speed and similar factors. Values for E_0 vary with location, time of year and stage of plant development.

Also, in South Africa, crop factors (CF) are used rather than plant factors, *i.e*. PF in Equation 5. Crop factors are conceptually the same as plant factors, being defined as the ratio of actual evapotranspiration for the crop / plant species to E_0 for a particular location and time of year. The difference is that, in South Africa, E_0 is the value for pan evaporation rather than evaporation from turf grass.

Thus, for application in South Africa, Equation 5 for maximum estimated water use is more accurately expressed as in Equation 6.

$$\mathbf{EWU = E_{0,\ pan\ evaporation} \times CF \times HA} \qquad \textbf{Equation 6}$$

EWU = estimated water use
E_0 is measured by pan evaporation
CF = crop factor
HA = area irrigated.

Tabulated values of CF are given for a variety of crops and seasons in Green (1985), commonly known as the Green Book.

The Penman-Monteith equation
After worldwide concern of the variation in measurement of E_0, or ET_0 using grass as the reference crop, a wide-ranging study was performed under the auspices of the United Nations Food and Agriculture Organisation (FAO) to compare comprehensively the methods in use at the time. The results were published as the FAO Irrigation and Drainage Paper No. 56 (Allen *et al*., 1998) which were widely accepted as the basis for estimating E_0 (or ET_0) in a manner that was minimally affected by variation in local conditions. Use of grass as a reference crop was endorsed, and the Penman-Monteith equation was identified as the most reliable function for determining ET_0.

Application of the Penman-Monteith equation for calculation of ET_0 and use of short grass reference evaporation have been limited in South Africa because of perceived limitations in data availability (SAPWAT, 2009).

The SAPWAT model
The SAPWAT model for irrigation planning in South Africa was developed by Crosby and Crosby (1999). In the original model, crop factors based on pan evaporation were converted to a short grass reference by use of a conversion factor. A major shortcoming of earlier methods, which was improved upon in SAPWAT, was to create means for making crop factors responsive to regional conditions and to the crop development stage. Instead of a single factor per crop which was applied countrywide, single-value crop factors were replaced by crop factor files in which crop factors were allowed to vary in response to region and to crop development stage. The country was divided into seven agro-climatic regions and default crop factors were developed for each region. Default planting dates were developed for each region and each crop. Where planting date had a significant influence on crop development stages, different crop factor files were developed by region and crop.

Where crop variety had a significant impact, the different varieties were treated as different crops. This yielded a wide variety of crop factor files which were responsive to regional planting regimes and to the development of the crop. Crop factor files are continually authenticated and can also be manipulated manually. The model also uses separate evaluations of soil evaporation and plant evapotranspiration (SAPWAT, 2009).

The SAPWAT model provides a far more comprehensive, physiologically and meteorologically responsive means of estimating crop irrigation than a single point estimate of EWU, as in Equation 6. However, estimation of EWU by the simpler means presented in Equation 6 still occurs (Nel, pers. comm., 2009).

2.9 Social beliefs and practices

Social context has historically not enjoyed prominence in the planning and execution of water and waste management projects. Early approaches to implementing water reuse projects often viewed public perception and acceptance as the principal ‘obstacle’ to implementing any recycling projects (Po *et al.,* 2003).

This has contributed to the failure of many initiatives which may have appeared sound in principle. A striking recent example of this in South Africa is the failure of trial implementations of greywater management strategies in informal settlements in the Western Cape. Although the project was planned with the greatest appreciation for inclusive and socially sensitive methodology, past experiences of the settlements with water and sanitation interventions (or lack thereof) had so disillusioned settlement members that the project was not able to meet its objectives. A large part of this was attributed to a lack of a sense of community in the settlement, resulting from previous poor experiences which had made settlement members unwilling to act to improve their own or others’ situation (Winter *et al*., 2010). Worldwide, there is a growing realisation that ‘business as usual’ is not a feasible approach for meeting the water and waste management needs of society in the future (EAWAG/SANDEC, 2000).

Perceptions and acceptance of greywater reuse and any recycled water by communities is detailed by a range of factors, including (Po *et al*., 2003):

- Disgust.
- Perception of the risk associated with recycled water.
- The specific uses of recycled water.
- The sources of water to be recycled.
- The issue of choice.
- Trust and knowledge.
- Attitudes toward the environment.
- Environmental justice issues.
- The cost of recycled water.
- Socio-demographic factors.

The traditional approach to implementing water policy, which may be described as a “decide, announce and defence” approach, has not been effective in addressing factors such as these. Furthermore, the strategy of extensive public education and outreach programs after conception of the project has also been shown to be inadequate. For any successful implementation of a reuse project, a new strategy that involves the potential users prior to the conception of the project is required. This strategy has gained recognition as the most essential component for obtaining long-term public support (Po *et al*., 2003).

Empowerment of the envisaged user community is now recognised as the key strategy in the early public involvement process in any reuse project. The public should be empowered to make informed choices about their water supply options, thus encouraging them to take part in any water reuse solution (Po *et al*., 2003). Public involvement gives the potential project users a sense of ownership and has been proven to be more successful than education and awareness campaigns alone (Po *et al.,* 2003). Although this strategy is time-consuming, it provides an opportunity for informing the public and allowing clarity on any misconception which people may have about their water reuse project. Public involvement, coupled with information provision through media, awareness campaigns and education on a continued basis (rather than a one-off intervention), has been proven to reduce people's concerns, especially those about perceived safety when reusing recycled water. Eight critical steps for successful community support programs have been detailed by Wegner-Gwidt (1998):

- Being upfront and proactive.
- Developing a basic information campaign.
- Working with local media.
- Using credible third party testimony.
- Showing successful projects elsewhere, visibility and creativity.
- Increasing public awareness and using demographic projects.

These lessons have been encapsulated in the Bellagio Statement on Environmental Sanitation, emerging from a meeting of group of experts in Bellagio, Italy, in February 2000 which was convened under the auspices of the Swiss Federal Institute for Environmental Science and Technology (EAWAG/SANDEC). The aim of the meeting was to develop principles for a new approach to environmental sanitation, based on lessons learned from failures of the past. Environmental sanitation for the purposes of the meeting was defined as "interventions to reduce peoples' exposure to disease by providing a clean environment in which to live, with measures to break the cycle of disease. This usually includes hygienic management of human and animal excreta, refuse, wastewater, stormwater, the control of disease vectors, and the provision of washing facilities for personal and domestic hygiene. Environmental sanitation involves both behaviours and facilities which work together to form a hygienic environment" (EAWAG/SANDEC, 2000). Greywater, while not typically considered a sanitation issue, definitely falls within the scope of this definition. Winter *et al.* (2010), too, have defined greywater and measures to manage it as falling within the ambit of sanitation. The meeting at Bellagio produced a statement of principles as quoted in
Table 28.

Table 28: Statement of principles developed by a meeting of experts in Bellagio, Italy, in February 2000, termed "Clean, health and productive living: A new approach to environmental sanitation" (from EAWAG/SANDEC, 2000).

Principles governing a new approach to sanitation	
1	Human dignity, quality of life and environmental security at household level should be at the centre of the new approach, which should be responsive and accountable to needs and demands in the local and international setting. • Solutions should be tailored to the full spectrum of social, economic, health and environmental concerns. • The household and community environment should be protected. • The economic opportunities of waste recovery and use should be harnessed.
2	In line with good governance principles, decision-making should involve participation of all stakeholders, especially the consumers and providers of the services. • Decision-making at all levels should be based on informed choices. • Incentives for provision and consumption of services and facilities should be consistent with the overall goal and objective. • Rights of consumers and providers should be balanced by responsibilities to the wider human community and environment.
3	Waste should be considered a resource, and its management should be holistic and form part of integrated water resources, nutrient flows and waste management processes. • Inputs should be reduced so as to promote efficiency and water and environmental security. • Exports of waste should be minimised to promote efficiency and reduce the spread of pollution. • Wastewater should be recycled and added to the water budget.
4	The domain in which environmental sanitation problems are resolved should be kept to the minimum practicable size (household, community, town, district, catchment, city) and wastes diluted as little as possible. • Waste should be managed as close as possible to its source. • Water should be minimally used to transport waste. • Additional technologies for waste sanitisation and reuse should be developed.

The use of greywater for small-scale irrigation is clearly in line with the principles in

Table 28. However, it is up to the legislative, local authority, project management and user communities to manifest the enabling environment which is also embodied in the principles.

3 Studies undertaken to support development of guidance for small-scale irrigation use of greywater in South Africa

3.1 Case Study 1: Plant growth, soil characteristics and microbiological quality of vegetable crops irrigated with domestic greywater in eThekwini Municipality

This case study was performed to evaluate the impact of medium-term sub-surface irrigation of vegetable crops with domestic greywater on soil, plant growth and yield, and microbiological quality of crops. Thus it evaluated risks of greywater irrigation to soil, plants and human health.

Mixed domestic greywater from eight households in an informal settlement in Cato Crest, Durban, was collected by eThekwini Water and Sanitation, and delivered to the test site at the Howard College campus of the University of KwaZulu-Natal for use in semi-field trials. Representative leafy, above-ground and below-ground (root) crops were chosen, based on the selections generally made by the settlement members for their domestic consumption, and plants were grown in 20 ℓ black plastic bags at the test site. Plants were irrigated by a simple sub-surface irrigation technique tested by eThekwini Municipality in a field trial. A total of six consecutive growth cycles was grown on the same soil. Plant growth, yield, and micro- and macronutrient content were measured. Macro- and micronutrient concentration were also measured in soil. Health-related microbiological quality of crops was assessed. Greywater irrigation was compared with irrigation using a balanced nutrient solution and with tap water.

Results were analysed to evaluate:

- Growth and yield of crop plants irrigated with greywater, relative to plants irrigated with water amended with a balanced source of plant nutrients and with tap water alone.
- Potential accumulation of macronutrients and micronutrients in crops of plants irrigated with greywater, relative to crops of plants irrigated with water amended with a balanced source of plant nutrients and with tap water alone.
- Potential accumulation of macronutrients and micronutrients in soil irrigated with greywater, relative to soil irrigation with water amended with a balanced source of plant nutrients and with tap water alone.
- Microbial loads on and in crops of plants irrigated with greywater, relative to crops of plants irrigated with water amended with a balanced source of plant nutrients and with tap water alone.
- Health risks associated with consumption of crops of plants irrigated with greywater, relative to consumption of crops of plants irrigated with water amended with a balanced source of plant nutrients and with tap water alone.

The following conclusions were drawn:

- Greywater irrigation increased plant growth and crop yield.

- Greywater irrigation was associated with improved plant nutrient content.
- Greywater irrigation could lead to accumulation of sodium and metals in soil with time, and hence in plant crops.
- Greywater irrigation could increase soil salinity and sodicity in time.
- Greywater irrigation could increase microbial loads on plants, although of the microorganisms investigated, only *E. coli* and total coliforms showed significant increases. It is important to note here that microbial results apply specifically to sub-surface irrigation.
- Greywater irrigation increased health risks associated with consumption of unwashed raw crops, but this risk could be reduced to within acceptable limits by simple precautions such as washing and peeling, or cooking crops prior to consumption.

This case study contributes to the Guidance Report sections on “Selecting a Greywater Irrigation Use Scenario: Guide to Managing Uncertainty and Risk” and on “Greywater Quality: Guide to Greywater Constituents”.

3.2 Case Study 2: Consultative process supporting development of the Guidance Report

This case study was performed to allow input of authorities driving greywater irrigation and of potential users of greywater for irrigation into the development of the Guidance Report. It was also intended to gather information on greywater generation and use in sewered settlements (information on unsewered settlements was available from Carden *et al.* (2007)).

The consultative process fell into two phases – up-front consultation and a capacity building workshop near the end of the guidance development process.

The up-front consultative process occurred at three levels in order to engage the broadest possible range of decision-makers and users. Separate consultative processes were employed at each level since different concerns were expected to drive thinking about greywater at each level. The three levels comprised:

- National policy- and decision-makers.
- Regional and local authorities.
- Settlements generating, and potentially using, greywater.

At settlement level, an additional aim was to quantify greywater generation in low-income communities *with* some kind of structured sanitation provision, and to compare this to information presented by Carden *et al.* (2007) for settlements *without* sanitation provision (WRC Project No. 1524).

At national level, a workshop was held with policy-makers and decision-makers in the fields of water management, health and agriculture. The aims of this workshop were:

a) To determine the extent to which greywater use and management are provided for within current legislation and guidelines on water quality, water use and small-scale agriculture;

b) To allow decision-makers to define their needs in terms of guidelines for greywater use;

c) To sensitise national level bodies to the need for understanding of social issues involved in greywater use, which greatly impact the success of any technical interventions which might be undertaken;

d) To identify gaps in the current research available, both nationally and internationally, to guide decision-making on greywater use.

A wide range of issues and concerns were highlighted at this level. Two of the strong conclusions which emerged were:

- There is a need to clarify the status of greywater irrigation in the light of existing legislation. Greywater is not mentioned specifically by the National Water Act and other relevant legislation, creating ambiguity regarding whether greywater irrigation is allowed or excluded.
- There are different needs for guidance for high-income users and low-income users. Particularly at the low-income end, it is necessary for greywater irrigation to occur within a framework of monitoring and guidance / supervision, because of the lower water availability and consequently poorer quality of greywater, and the potential to further degrade already over-burdened environments which are not necessarily well-provided in terms of run-off containment or management. Lower overall education and skills levels in such communities are also a factor.

At regional and local level, a questionnaire survey was conducted, addressing the municipalities represented on the online database maintained by the South African Local Government Association (SALGA).

The major – and very concerning – finding from this level of consultation was the very low levels of awareness of greywater issues at local authority level. The return rate of questionnaires was less than 10%, despite considerable follow-up by telephone, fax and email. The majority of the forms returned were mostly or completely blank. Since local authorities are likely to be the major drivers of greywater irrigation, especially for settlements with few resources, this points to an urgent need for capacity building at local authority level.

At settlement and household levels, a total of six communities were surveyed by household-based interviews using a questionnaire based on that previously used by Carden *et al.* (2007). The criteria for settlement selection were as follows:

- Low income settlement.
- *Either* sewered *or* provided with on-site sanitation in a structured implementation (since unsewered and informal settlements had already been surveyed in WRC Project No. 1524).
- Representative of differing geographic, climatic and geological conditions.
- Good rapport with, and logistical support from, the relevant local authority.

The results were compared with those of Carden *et al*. (2007).

Two significant findings emerged. Firstly, although many respondents expressed reluctance regarding use of greywater for irrigation, a range of informal greywater use activities were being practised. Secondly, an interesting difference between sewered and unsewered settlements was noted. Unsewered settlements provided with on-site sanitation showed distinctly different daily water consumption habits, even among communities that seemed similar in many regards. Similar findings have been shown by Carden *et al.,* for unsewered informal settlements. This implies that, with regard to greywater irrigation implementations, cognisance must be taken of the characteristics of individual unsewered communities. Sewered communities on the other hand, showed statistically significant uniformity in water use level for the most part.

The capacity building workshop, held towards the end of development of the Guidance Report, aimed to inform local authorities about greywater and use of greywater for small-scale irrigation and to introduce the Guidance Report to them. The workshop was also intended to provide local authorities with the opportunity to provide feedback on the perceived applicability of the Guidelines in the context of their own environments. Again, there was poor response to invitations to the workshop – less than 10% and less than half of those that responded, attended. However, the encouraging feature of the workshop was that the local authorities that attended showed enthusiasm for implementing greywater irrigation.

This study contributes to the overall approach to development of the Guidance Report and to the Guidance Report section “Greywater Quality: Guide to Greywater Constituents”.

3.3 Case Study 3: Identifying greywater quality constituents for inclusion in the Guidance Report

This desk study aimed to produce a preliminary list of water quality constituents to be considered for inclusion in the Guidance Report for greywater use in small-scale irrigation in South Africa.

Studies of greywater quality conducted in South Africa were used in combination with South African and international guidelines for water quality for various uses to identify the water quality variables likely to indicate that greywater, as encountered in South Africa, is unsuitable for particular uses. These were termed greywater indicators. A relatively long list of indicators was initially identified.

Based on the comparison of measured greywater quality to available guidelines, the following list of greywater quality constituents was identified for guidance development:

- Total coliforms
- Faecal coliforms / *E. coli*
- pH
- EC
- COD
- Boron
- Chloride
- Total nitrogen
- Nitrite/nitrate – important for assessing potential groundwater contamination

- Ammonia – important where greywater could enter freshwater courses
- Total phosphorus
- Potassium
- Sulphur
- N:P:K:S ratio
- Sodium
- Calcium
- Magnesium
- SAR
- Alkalinity
- Oil and grease
- SS
- Dissolved oxygen – important where greywater could enter freshwater courses.

This list was too long for practical application because of cost and logistical barriers. Peer review via Reference Group was used to identify those constituents from this list of greatest relevance specifically to irrigation use of greywater. These constituents were:

- EC
- SAR
- *E. coli*
- pH
- Boron
- COD
- Oil and grease
- SS
- Total nitrogen
- Total phosphorus.

This case study provided the basis from which the Guidance Report section on "Greywater Quality: Guide to Greywater Constituents" was developed.

3.4 Case Study 4: Greywater treatment

The aim of this case study was to evaluate greywater treatment systems which have been implemented and tested in South Africa.

A qualitative study reviewed a series of interventions for treatment of greywater at Moshoeshoe EcoVillage and at the Hull Street Project, both in Kimberley, Sol Plaatjies Municipality. A further quantitative study was conducted in which a biological treatment system was evaluated. This system was based on experience with the systems in Sol Plaatjies Municipality, and was the same as one intended for implementation in Buffalo City Municipality.

3.4.1 Qualitative study

The Moshoeshoe EcoVillage in Sol Plaatjies Municipality was developed as a pilot project for the Hull Street development in the same Municipality (the latter also jointly developed with the Swedish International Development Corporation, SIDA). The EcoVillage is served by dry sanitation (urine diversion toilets) and hence requires provision for treatment and disposal of greywater.

The initial greywater treatment system which was designed for the development of 11 households comprised a series of four serial compartments for grease trapping, followed by a sand filter. Greywater was treated at household level. Water from the sink and shower was led via a pipe to a treatment system comprising four small serial compartments for grease trapping and then to a larger compartment containing a sand filter. From there, a pipe on the ground surface lead treated greywater to a central storage pond, which also received stormwater from the surrounding area (Ridderstolpe, 2007). This was intended to be used to irrigate food gardens. Greywater treatment at Moshoeshoe Village was not successful because of saturation of the underground sand filters and the development of anaerobic conditions. This was at least partially attributable to poor implementation of the design. As a result of treatment failure, users became disillusioned with the system, failed to maintain it correctly and did not want to reuse the water for irrigation. While the original design could not be verified as functional for greywater treatment, it also could not be fully rejected on the basis of experiences at Moshoeshoe Village. What could be concluded was that it is vital for construction and implementation of treatment designs be monitored closely to ensure that the original design principles are met.

The Hull Street Project comprised an urban development of 114 households, served by dry sanitation (urine diversion toilets). Each household had a small private plot, and the units were arranged around a common area of ground. The design provided for on-site pre-treatment and subsequent use of greywater. Initial provisions for greywater (and urine from urine diversion toilets) encompassed leading the liquid into a soakaway of approximately 1 m^3 in the private plot associated with each unit. This was said to be temporary until a better solution was found (Ridderstolpe, 2007).

Soon after the soakaways went into operation, it became apparent that they were not adequate. After some experimentation with various options, one house was set up as a demonstration facility with the following treatment configuration:

1) An above-ground mulch tower, for straining and degradation of particulates, and fats and grease prior to infiltration.
2) A sub-surface artificial infiltration unit, which provided a large surface area for biofilm formation, the purpose of which was BOD removal.
3) A surrounding gravel-filled trench which acted as a resorption bed, directing the treated greywater to the surrounding soil (Ridderstolpe, 2007).

The system functioned satisfactorily for a 10 month period, after which it was decommissioned. During this period, it was able to absorb the additional load from several months of extremely high rainfall, ten times the average rainfall for the area. Monitoring of the mulch tower and the infiltration unit showed no sign of development of anaerobic conditions. Upon decommissioning, the gravel of the resorption bed and the geotextile lining the resorption bed looked unchanged, indicating that the SS and BOD load were successfully removed before the resorption bed.

Unfortunately, the intervention came too late to change plans for connecting greywater outlets from the entire Hull Street settlement to a central sewer. However, the system demonstrated that successful on-site (household-based) treatment of greywater is possible, even in areas of flat topography and impermeable soil.

An important observation which arises out of this experience is the necessity to have both the manager of any greywater treatment / management project and all members of the households served by the project committed to its success. Part of this commitment depends on community education and a pro-active community involvement plan, which were in place at Hull Street. Part is dependent on thorough design and testing of the intended greywater intervention prior to full-scale implementation. In this instance, a number of interventions had been tested and had failed before the successful demonstration system described here was implemented. By that time, many of the residents of the Hull Street housing project, and most importantly its manager, had lost interest and faith in the greywater management system. This, and not failure of greywater treatment, ultimately led to decommissioning of on-site greywater management at Hull Street.

3.4.2 Quantitative study

A combination of primary and secondary treatment processes for treatment of greywater was tested experimentally. It was conceptually derived from the treatment system implemented as a demonstration facility in the Hull Street Project. The specific combination of components tested in this investigation was designed by Ridderstolpe (2004) for implementation in a low-cost housing pilot project in Buffalo City Municipality, South Africa. The system comprised a mulch tower as primary treatment and a subsurface resorption bed with embedded infiltration zone as secondary treatment, although this was configured a little differently from that in Hull Street. Removal was tested under three loading scenarios, representing low load, normal load and high load.

Samples of the inflow water to the mulch tower, the outflow from the mulch tower and the outflow from the infiltration zone and resorption bed, respectively, were analysed for pH, EC, COD, SS, ammonia nitrogen, total phosphorus, total coliforms and *E. coli*.

For most of the measured parameters, removal varied with changes in greywater load and was also not consistent for a particular loading volume tested. Therefore the variation in inflow greywater volume did affect treatment performance over time.

The mulch tower was the most effective treatment stage in removing most of the measured parameters in the minimal time frame. The lag in performance in the secondary treatment stage may have been because there was insufficient time for biofilm development, indicating that the system needed more time to reach pseudo-steady state.

No appreciable removals of health-related indicator bacteria, *viz.* total coliforms and *E. coli,* was achieved and means to enhance removal should be addressed to prevent potential health risks resulting from contact with the effluent. The effluent from the greywater treatment system did not comply with standards permitting discharge thereof into the environment. However, the potential for reuse for irrigation was noted.

This case study contributes to the Guidance Report section on “Greywater Quality: Mitigation of Greywater Quality”.

3.5 Case Study 5: Impact of cleaning products on greywater quality

This desk study aimed to determine the contribution of cleaning products to greywater quality, within the context of detergent formulations used in South Africa.

Unilever SA provided tables of estimated concentrations of detergent products in laundry and washing greywater, based on proprietary information. The estimation assumed that an average household (comprising four to five members) utilised 23 000 ℓ water per month. This figure was based on market surveys performed on behalf of Unilever. The data provided by Unilever were compared to corresponding values in the South African Water Quality Guideline for Irrigation (DWAF, 1996), where available.

The desk study confirmed that the major contributor of detergent products to potential adverse effects of greywater use for irrigation is sodium. This affects salinity and sodicity of soil, with impacts on plant growth and yield, and on soil structure.

This case study contributes to the Guidance Report section on “Greywater Quality: Guide to Greywater Constituents”.

3.6 Case Study 6: Estimating greywater volumes for Irrigation

The aim of this desk study was to develop a method for estimating greywater volumes which could be applied in small-scale irrigation and which would reflect varying agroclimatic conditions across South Africa as well as site-specific factors affecting water use such as soil type and recent rainfall. The final product is meant to be simple to use by users with relatively little background in irrigation planning.

The equation for calculating estimated water use (EWU) as described in Section 2.8.1), taken from Green (1985) and other similar literature, was used (Equation 6, repeated here as Equation 7). This equation was chosen in preference to more accurate methods such as the SAPWAT model because its simplicity allows it to be applied in generic fashion on the minimum of data. Its drawbacks in being less accurately representative of, and responsive to, field conditions are, however, recognised.

$$\mathbf{EWU = E_0 \times CF \times HA} \qquad \textbf{Equation 7}$$

EWU is estimated water use
E_0 is the reference evapotranspiration
CF is a species-specific crop factor
HA is the area to be irrigated, all measures expressed in metric units.

Murphy (2006) presented a table of suggested irrigation volumes for greywater, based on the above equation, using a number of assumed crop factors and agroclimatic conditions. This was based on a table produced by Bennet (1995) for California. The objective was to develop a similar table, relevant to specifically South African conditions, by calculating EWU using local estimates of E_0.

To this end, E_0 values were back-calculated from crop evapotranspiration measurements (Green, 1985) from representative locations for climatic zones in South Africa as identified by Blignaut *et al.* (2009). Using these values for E_0 and assumed crop factors for low water use (CF=0.3), medium water use (CF=0.5) and high water use (CF=0.8) plants, two look-up tables were derived similar to that presented by Murphy (2006) but relevant to agroclimatic regions of South Africa. These tables may be used to obtain quick estimates of EWU in place of calculating this on the basis of personal judgement or researching values for the terms of the equation.

The equation for EWU was further adapted for site-specific conditions by including crop coverage factors from Green (1985), the amount of rainfall over the preceding 24 hours, and adjustments to greywater application rate and frequency of greywater application according to the soil type.

The overall equation developed for determining the amount of greywater to be applied is shown in Equation 8 below.

$$\mathbf{EWU_{adjusted} = ((EWU \times CC) - mm\ rainfall\ in\ preceding\ 24\ hours) \times HA} \qquad \textbf{Equation 8}$$

$EWU_{adjusted}$ is the estimated water use, adjusted for site-specific factors affecting water use
EWU is estimated water use as per Equation 7 and the look-up tables
CC is a crop coverage factor
HA is area to be irrigated (measured in m^2)
mm rainfall is subject to the considerations in the paragraph above
Greywater application rate and frequency are adjusted for soil type as described in the Guidance Report and in Appendix 2.

This case study yielded the underpinning concepts of the section “Greywater Quantity: Guide to Irrigation Volumes”.

4 Implications for developing guidance for greywater use in small-scale irrigation in South Africa

This chapter summarises the most salient points emerging from the literature review (Chapter 2) and the Case Studies (Chapter 3), which can contribute to an understanding of what is required from guidance for small-scale irrigation with greywater in South Africa.

4.1 Greywater quality and quantity

- Kitchen greywater should not be used for irrigation unless it undergoes some form of treatment first.
- It is preferable to use only the rinse water of the laundry greywater fraction for irrigation.
- The greywater constituents identified as being of the greatest relevance to greywater irrigation in South Africa are:
    - EC
    - SAR
    - *E. coli*
    - pH
    - Boron
    - COD
    - Oil and grease
    - SS
    - Total nitrogen
    - Total phosphorus.
- Estimation of greywater quantities for irrigation should be based on the water needs of plants and not on the disposal of greywater.
- Using relatively simplistic methods, it is possible to provide users with an approximate guide to the volumes of greywater that should be applied (*i.e.* the volume required by plants). While this does not take into account the best that science can offer for irrigation water planning, it takes cognisance of the need for guidance to be simple enough for relatively unsophisticated users to apply.

4.2 Health implications

- Sub-surface irrigation provides the best protection from microbial health risks; it can be implemented simply and should be encouraged.
- A multi-barrier approach to limiting human exposure, as advocated by WHO (2006), can reduce risks from even below-ground vegetables to within commonly recognised acceptable limits.
- Personal hygiene is an important exposure barrier in the use of greywater for irrigation.
- Cognisance must be taken of the vulnerability of HIV-positive persons to exposure to potential pathogens.

- Greywater has the potential to improve nutrient intake from home-grown food crops.

4.3 Environmental water quality implications

- Greywater must not be allowed to enter surface water bodies.
- Greywater must not be allowed to pond on the surface.
- While the impact of small-scale greywater irrigation on groundwater quality is likely to be small, groundwater must be considered when planning greywater irrigation implementations.

4.4 Implications for plant growth and yield

- In general, irrigation with mixed domestic greywater improves both growth and yield of crops relative to tap water, although yield appears to be boosted less than growth. It is unclear whether this effect extends to all types of greywater. The effect varies among crops.
- Use of plants tolerant to certain greywater constituents, *e.g.* sodium or boron, can maximise the use of greywater for irrigation.
- Greywater users need to observe their plants for signs of stress and modify their greywater irrigation regime accordingly.

4.5 Implications for soil properties

- Sodium from laundry detergents poses the greatest risk to soil properties, particularly in terms of soil salinity and soil sodicity.
- Soil should be leached to minimise the accumulation of salts (rain and unintended water application in excess of plant requirements, will often provide sufficient leaching).
- Steps should be taken to minimise the development of sodic soil conditions, *e.g.* addition of mulch or gypsum to soil.

4.6 Greywater treatment

- Greywater treatment systems should be sufficiently simple and robust to function effectively in rural and peri-urban settlements, preferably without power or piped water and with minimal technical expertise required for maintenance.
- Greywater treatment systems should use the simplest and most cost-effective technology required to meet the water quality objectives.
- Greywater treatment systems should be thoroughly tested and proven before being implemented in practice, to avoid user fatigue caused by system failure and on-going changes.

- Wherever possible, treatment systems that have been previously proven to work in South Africa should be considered before introducing new technologies which have yet to be proven under local conditions.

4.7 Considerations for implementation of greywater irrigation

4.7.1 Legal issues

- The legal status of greywater use for small-scale irrigation needs to be clarified.

4.7.2 Social issues

- Sewered settlements seem broadly similar in greywater generation characteristics while unsewered settlements must be evaluated on a case-by-case basis.
- Informal settlements often lack a sense of community and this hampers the development of initiatives seen to be for the greater good or even individual improvement. Greywater irrigation implementations in such environments cannot succeed unless a sense of community can first be fostered.
- In informal settlements, the quality of greywater is generally extremely poor. For greywater to be of a quality fit for irrigation use, greywater needs to be separated from other waste streams at source and the number of uses to which it is put need to be limited. This is contingent on provision of adequate water supplied otherwise users are driven by logistical and economic factors to maximise the use to which water is put before disposal. It is also heavily dependent on the provision of adequate sanitation and solid waste management.
- Commitment of users and managers of greywater irrigation implementations is essential if these are to succeed.

4.7.3 Education

- Local authorities urgently require capacity building in knowledge of greywater issues in general, and of the potential of greywater use for irrigation in particular.
- Potential irrigation users of greywater need to be involved in the planning and implementation of any greywater irrigation implementation, and must be educated on the risks, benefits and proper handling of greywater, of irrigated land and of greywater-irrigated crops.
- Although residents of unsewered and sewered settlements expressed reservations about the use of greywater for irrigation, there is already a culture of using greywater several times before disposal. This could be used as a foundation to promote use of greywater for irrigation.

4.7.4 Greywater use in new developments

- Probably the greatest potential for greywater use for beneficial purposes, such as small-scale irrigation, is by including greywater collection, treatment and use in the planning of new communities or alterations to existing communities. However, it is important to ensure that the greywater technologies introduced have been proven to be sound; that designs are implemented correctly and that housing management and users are committed to using the facilities properly. Failure in any of these areas has been shown to lead to failure of greywater use projects.

5 Approach adopted for development of the Guidance Report for irrigation use of greywater

5.1 Underlying Principles

The intended users for this Guidance Report are:

- Municipalities or NGOs who wish to initiate greywater irrigation implementations or wish to support water users in developing and monitoring greywater irrigation implementations.
- Informed members of the public who wish to plan for irrigation use of greywater on their properties or in their settlements, and need guidance in doing so.

The focus of the Guidance Report is:

- Minimisation of risks of *illness* in handlers of greywater and greywater-irrigated produce, or consumers of greywater-irrigated produce.
- Minimisation of risks of *reduction in growth or yield* of plants/crops irrigated with greywater.
- Minimisation of risks of environmental degradation, especially reduction in the *ability of soil irrigated with greywater to support plant growth*.

In addition, the Guidance Report was developed within the following boundary conditions:

- Irrigation use is interpreted as the *beneficial use of greywater to support plant growth within the boundaries of the irrigated property only*. It is important to note that movement of greywater beyond the boundaries of the property is explicitly *excluded*, since this would amount to uncontrolled disposal of greywater to the environment and all the disadvantages and risks associated with that.
- The guidance provided is intended to address irrigation use of greywater only, not to provide a general solution for disposal of greywater. Thus the focus is not on maximising the volume of greywater which can be applied to land, but on minimising risks and on maximising benefits associated *specifically with irrigation use of greywater*.
- The guidance provided is intended to be used within the context of existing knowledge and best practice relating to irrigation, *e.g.* selection of plants, installation and maintenance of irrigation equipment, adaptation of irrigation schedules to local agroclimatic conditions. The guidelines focus not on providing a catch-all manual for small-scale irrigation implementations, but on *managing the additional risks and challenges* arising out of the use of greywater in such implementations.

5.2 Major information sources

Four documents provided the major sources for these guidelines for greywater use in small-scale irrigation applications:

- Department of Water Affairs and Forestry, South African Water Quality Guidelines, Volume 4, Irrigation Use (DWAF, 1996).
- WRC Project No. 1479, A scoping study to evaluate the fitness-for-use of greywater in urban and peri-urban agriculture (Murphy, 2006).
- WRC Project No. 1524, Understanding the use and disposal of greywater in the unsewered areas in South Africa (Carden *et al.*, 2007).
- WHO Guidelines for the safe use of wastewater, excreta and greywater, Volume IV Excreta and greywater use in agriculture (WHO, 2006).

These, together with expert opinion and peer review, provided the background for the principles and content of the Guidance Report.

5.3 Outline of Guidance Report

The structure of the Guidance Report is as follows:

Purpose of Guideline
- Intended Users of Guideline
- Focus of Guideline
- Major Sources Used

What is Greywater?
Why Use Greywater for Irrigation?
Objections to the Use of Greywater for Irrigation
- Health considerations
- Plant Growth and Yield
- Ability of Soil to Support Plant Growth

Legislative Context of Greywater Use for Irrigation
Special Considerations
Guidance for Greywater Use in Small-Scale Irrigation in South Africa
- Managing Risks and Uncertainty in Greywater Irrigation
- Greywater Quality: Guide to Greywater Constituents
- Greywater Quality: Mitigation of Greywater Quality
- Greywater Quantity: Guide to Irrigation Volumes

Appendices

Since the Guidance section provides the bulk of the Document, each of its sub-sections is discussed in greater detail below.

5.3.1 Managing risks and uncertainty in greywater irrigation

Three major risk management scenarios were identified, all relating to the extent of characterisation of the greywater to be used for irrigation. In order of decreasing risk and decreasing uncertainty, these are:

- Category 1: No analysis of greywater prior to use.
- Category 2: Minimum analysis of greywater prior to use (defined as pH, EC, SAR and *E. coli*), and compliance with quality limits set on these.

- Category 3: Full analysis of greywater prior to use (defined as minimum analysis plus boron, COD, oil and grease, SS, total inorganic nitrogen and total phosphorus), and compliance with quality limits set on these.

These three categories recognise that reducing risk and uncertainty by improving greywater quality is costly and may not be within the reach of all potential users of greywater for irrigation. The conceptual framework of the most recent WHO guidelines for reuse of excreta, wastewater and greywater was applied. These guidelines recognise that risk exists only where there is both a hazard and exposure to that hazard, thus risk can be reduced either by improving the quality of the greywater (removing or reducing hazards) or by imposing barriers to exposure (preventing exposure to the hazards). In the guidance presented, flowcharts are used to guide users through decisions associated with each risk management category, leading to a table of restrictions on use for each category. The restrictions represent barriers to exposure of human users, plants or soil to specific hazards. As the knowledge of greywater quality improves (from Category 1 to Category 3), so restrictions apply more to the quality of the greywater and less to the way in which it is used. Thus Category 1 represents almost no knowledge of greywater quality and stringent risk management in terms of exposure barriers, whereas in Category 3 a significant proportion of the risk management effort is directed at the quality of the greywater and exposure barriers are accordingly less restrictive.

5.3.2 Greywater water quality

The greywater quality section provides the quality criteria against which measured greywater constituents are compared in risk management Category 2 (minimum analysis) and Category 3 (full analysis) from the preceding section.

The constituents for inclusion in the quality section of the Guidance Report were identified in Case Study 3 (Section 3.3).

The precautionary principle implemented in a qualitative manner in the SAWQG for irrigation for a number of irrigation-related endpoints, and in a quantitative manner in the WHO guidelines for human health risks, was also applied to these guidelines for the use of greywater in small-scale irrigation. This includes a graded series of quality ranges, indicating preferred quality (*target range*), tolerable quality (*maximum range*), quality which can be used on a site-specific basis for a limited time and with special precautions (*short-term use on site-specific basis only*), or quality which is not considered suitable for irrigation use unless treated (*not recommended for irrigation use*). These quality ranges correspond with increasing risk to human users, plants and soil.

Guidance values for greywater constituents were derived wherever possible from the SAWQG for agricultural irrigation, since these represent a body of collected wisdom on water quality for irrigation, adapted for South African conditions. Where constituents were not available in the SAWQG, other guidelines and available literature were consulted. An abbreviated table showing only constituents and quality ranges is presented in the Guidance Report itself. In the Appendices to the Guidance Report, an expanded table is included which identifies the sources used for each constituent range and provides a short narrative with each range to describe the effects expected from irrigation with greywater of that quality.

Nitrogen and phosphorus represent exceptions in the philosophy underlying selection of the guideline ranges. The guidance ranges presented recognise that nitrogen and phosphorus in greywater are, in the first instance, an opportunity to supplement the nutrient requirements of plants. Both nitrogen and phosphorus are essential plant macronutrients. They are required throughout the lifespan of a plant, but especially at times of growth and development. The guidance ranges recognise that for poor farmers, fertiliser application may be economically infeasible and that greywater used for irrigation is a *de facto* fertiliser. Therefore the ranges consider both the fertiliser potential of greywater and the need to supplement greywater with nutrient-poor irrigation water when nutrient concentrations are likely to exceed the requirements of irrigated plants. Beneficial application rates of 200 kg nitrogen/ha/year applied in a total of 1 000 mm water/ha/year, and 150 kg phosphorus/ha/year applied in a total of 1 000 mm water/ha/year were assumed in developing the guideline ranges (Du Plessis, pers. comm., 2009).

Guidance is also given regarding sampling frequency and number of samples to be collected. As this guidance is based on practical considerations more than on statistical rigour, this will require revisiting in the future.

In assessing greywater for suitability for irrigation use, constituent values should preferably comply with the target guideline limits, but should certainly be within the maximum guideline limits. Furthermore, it should be borne in mind that where extensive or high technology treatment would be required to make greywater suitable for irrigation use of any kind, then off-site disposal is likely to be a safer and cheaper option.

5.3.3 Greywater quality mitigation

Where greywater quality requires mitigation to extend its suitability for irrigation, two approaches are presented in the guideline:

- Integrated mitigative practices which aim to minimise potential adverse effects of, primarily, physico-chemical greywater components (such as EC, SAR, sodium, boron) as part of plant/crop cultivation.
- Treatment systems, either separate from the irrigation application or integrated with the irrigation application, which aim to remove, primarily, suspended solids, oil and grease, COD and health-related bacteria from greywater.

Suggested mitigation practices include:

- Irrigation method.
- Amelioration of soil.
- Leaching of soil.
- Planting of tolerant plant types.
- Miscellaneous irrigation modifications.
- Accepting reduced crop yield.

Treatment options suggested are based on pilot projects which have been conducted in South Africa and all represent forms of physical primary treatment and biological secondary treatment. They include:

- Mulch tower (separate from irrigation application).

- Mulch tower and resorption bed (separate from irrigation application).
- Various forms of tower or tube gardens (integrated with irrigation application).

5.3.4 Greywater quantity

This section provides general guidance in selecting the volume of greywater which can be applied to a garden or in small-scale crop cultivation. The purpose of this guideline is not to provide detailed technical guidance on irrigation planning and management. Therefore this section gives only broad guidance regarding the types of considerations which govern the amount of greywater which can be applied within any given irrigation scenario and should be seen in the context of existing knowledge of good irrigation and plant cultivation practices. As for previous sections, guidance is given within the context of the overall aims of the guidelines (minimisation of risks to human health, plant/crop growth and yield, and soil fertility).

The basis on which suggested irrigation volumes were estimated is described in Section 2.8.1 and Case Study 6 (Section 3.6). The Guidance Report presents look-up tables of maximum estimated water use, EWU, for various regions of South Africa, developed in Case Study 6 (Section 3.6). To derive these tables, it was necessary to use some means of identifying agroclimatic zones throughout the country. A clustering based on mean rainfall and temperature data from 1970 to 2006 was adopted. In South Africa, reference evaporation, E_0, is measured by pan evaporation, or evaporation of water from a container of specified size and shape, and is independent of plant/crop type. The value of E_0 for each of the identified agroclimatic regions in summer and in winter was back-calculated from tables commonly used by agriculturists and farmers to estimate irrigation water requirements for large-scale agriculture. Theoretical values were used adjust for water use of individual crop species – called crop factors, CF. A CF value of 0.8 was used to represent high water use, 0.5 to represent moderate water use, and 0.3 for low water use. Theoretical irrigated areas, HA, of 5, 10 and 20 m^2 were used.

Estimated water use represents only the amount of water required by the plant in light of climatic conditions such as solar radiation, rainfall, windspeed, *etc*. It does not include other factors which modify plant water use and thus represents the *maximum* amount of water which should be applied. The Guidance Report provides numerical factors or qualitative guidance to adjust EWU for crop coverage, soil type and recent rainfall. These steps, together, allow EWU to be adjusted for the site-specific factors.

6 Making greywater use work: Engaging communities

6.1 The problem

Winter *et al.* (2010) eloquently describe the challenges facing implementation of greywater projects in under-serviced low income settlements – in their case, household-level greywater treatment and disposal units. The primary challenge is the lack of a sense of community to begin with, where this may be defined as a group of people willing to work together towards a common goal for the common good. Where such a sense of community is lacking, it becomes difficult, if not impossible, to engage individuals in any activity that is aimed at improving the overall environment and health, or even of improving their own conditions. Individuals in such settlements are often characterised by apathy and distrust towards such initiatives, with a prevailing mindset that this is the responsibility of "the authorities", "the municipality" or "the government". The situation is often compounded by a lack of responsiveness of such bodies to the plight and needs of the settlements in question, driven by many factors including resource limitations, a reluctance to provide services to settlements without legal tenure which are considered to be temporary, and lack of communication or miscommunication between official bodies and settlement representatives.

The next challenge is that such settlements typically have no or insufficient basic services for water, sanitation, stormwater management and solid waste disposal. In such an environment, it is difficult even to identify greywater as a separate waste stream which can be diverted, let alone to interest individuals in making an effort to put it to beneficial use. Residents in such settlements generally do not recognise greywater as being a problem, because their daily lives are fraught with far more basic challenges such as obtaining sufficient water for daily needs, finding a place to urinate or defaecate, disposing of solid waste, and managing mixed waste and water flows in rainfall events.

Furthermore, since water is difficult to obtain and must typically be carried to households, it is used several times prior to disposal. Thus, even where greywater can be identified as a distinct waste stream, its quality at the point of disposal is often very poor and not suitable for any further use.

Finally, the socio-economic constraints under which individuals in such settlements typically live makes it near impossible for them to divert any financial resources to establishing or maintaining greywater irrigation projects. This burden then falls on the local authority which is often operating under constraints of its own.

6.2 One solution: The eThekwini experience

EThekwini Municipality (Durban, KwaZulu-Natal) is a local authority that has made it a strategic policy to tackle service delivery in a pro-active and integrated manner which addresses a number of the challenges outlined above. It provides an example of what can be achieved, and of possible means for doing so. This is demonstrated in the Municipality's approach to water and sanitation service provision, which is presently also being expanded to include greywater irrigation.

EThekwini Municipality provides water, sanitation and hygiene education services as an integrated package, based on international experience that any one of these services provided in isolation does not significantly improve the health and well-being of the newly-serviced settlement. To mediate this mode of delivery, water and sanitation services are combined in a single operational entity with a strong community liaison function. An extensive community building and community education campaign precedes and accompanies any new water and sanitation intervention. EThekwini community liaison workers engage with existing structures such as ward councillors and any existing street committees, *etc.* Meetings of residents of the settlement to be serviced are held and house-to-house visits are conducted. A multi-media approach to community building and community engagement is adopted. These media include conventional meetings and individual interviews, use of street theatre productions to popularise the correct use and advantages of the interventions to be introduced, street competitions to reinforce new behaviours, school visits and distribution of information posters and pamphlets to households. Once the water and sanitation intervention has been introduced, follow-up visits are made to ensure that the facilities are being used and maintained correctly, and that good hygiene practises are being reinforced. Training and logistical support are provided on an ongoing basis.

The integrated approach adopted by eThekwini Municipality is illustrated by the hygiene, water and sanitation programmes implemented by the Municipality in rural areas and in informal settlements. The multi-media multi-phased approach is tailored to the needs and service offerings in each setting.

6.2.1 Rural areas

In rural areas, water is provided by ground tanks or yard taps, while sanitation is provided by dry sanitation in the form of urine diversion toilets. Education and support for emptying of full toilets are provided. During follow-up visits and checks, input from residents is used to inform a rolling plan of repairs and upgrades. An example of this is the changes made to the design of the urine diversion toilet structure on the basis of user feedback regarding problems encountered with initial designs. Dry sanitation creates a disposal problem with respect to greywater and the Municipality provides a programme to manage this. Since plots associated with each household are sufficiently large to absorb the volume of greywater generated per household, household food gardens are promoted. A simple form of sub-surface irrigation using punctured plastic bottles has been introduced to minimise contamination of above-ground plant parts (Figure 10).

A **B**

Figure 10: Greywater irrigation of food gardens in rural areas of eThekwini Municipality. (A) Sub-surface distribution of greywater through the punctured base of a 2 ℓ bottle buried to half its length in the soil. (B) Irrigated vegetable crops.

A further evolution of this community engagement is the recent introduction of so-called 'Community Health Clubs', which are committees elected by residents to oversee water and sanitation practices within a defined area. The concept is based on that described by Waterkeyn (2010). The author is affiliated with a NGO which is helping eThekwini implement Health Clubs in its areas. These structures provide an excellent example of building community in the sense referred to in the preceding section. Following observations that residents often preferred to sub-contract toilet emptying to entrepreneurs of varying charges, structures, skills and integrity, eThekwini Municipality has established a programme of subsidising 'toilet emptiers' who are provided with appropriate training and tools to enable the task to be performed efficiently and safely. Toilet emptiers are linked with small local suppliers of hardware required for basic maintenance of toilets, stocked by the Municipality, and with the local Health Club. Problems are reported by the Health Club to designated structures within the Municipality which provide advice on how to fix small problems and dispatch maintenance teams to deal with larger or more complex problems.

The Health Club is the structure through which new initiatives such as greywater irrigation are introduced to residents. New interventions are trialled by the Municipality prior to roll-out, often in co-operation with research partners such as the University of KwaZulu-Natal. Such up-front studies are undertaken to minimise user fatigue caused by introduction of practices which fail because of design and planning issues. For example, eThekwini has been on the forefront of South African research into low cost systems for greywater irrigation, and into the possible environmental and health impacts of greywater irrigation, which were initiated well before greywater irrigation was introduced at a community level. The Health Club structure is thus an approach through which functioning communities are built in low income settlements, through which settlement members are encouraged to become active in improving their own lives and the life of the settlement as a whole.

6.2.2 Informal settlements

Informal settlements are settlements in transition and therefore not suited to the provision of permanent structures. However, eThekwini Municipality recognises that the period before transition could be as long as 15-20 years so an interim provision of basic services is essential. The eThekwini Department of Water and Sanitation works together with the Housing Department to identify and prioritise settlements to receive services. Sanitation is provided by containerised ablution blocks connected to sewers. If sewerage is not available in a settlement to be serviced, then a sewer line is laid in preparation of introduction of ablution blocks. Blocks are provided with coverage of one block per 70 dwelling units, with a maximum distance of 100 m between serviced dwellings and the nearest ablution block. Each ablution block has three male stalls and three female stalls, with a shower in each stall. Laundry washing facilities are provided and security at night is facilitated by electric lighting on a mast which lights up the ablution block and its immediate surrounds. A caretaker, elected by the members of the settlement, bears responsibility of upkeep of two to three ablution blocks. The Municipality pays the caretaker and supplies toilet rolls and detergents. The caretaker is trained both in maintenance and in passing on further hygiene training to the community.

As in rural settlements, Health Clubs are being piloted in informal settlements. The Health Club committee members come from dwellings served by one ablution block. It takes responsibility for all water and sanitation aspects in the community it represents (here 'community' begins to take on the meaning as defined at the outset of this chapter). This includes overseeing toilet maintenance, health and hygiene education, and solid waste disposal. For solid waste disposal, Durban Solid Waste provides bags for collecting solid waste and collects the full bags. Furthermore, greywater irrigation in informal settlements is being piloted via Health Clubs. Since informal settlements do not have the space available in rural areas, a different means of irrigation is required. This is provided by "Agritubes", cylindrical towers onto which greywater is poured. Openings in the lining of the tower allow seedlings to be planted directly on the tower (see Section 2.7.7 and Figure 7). Health Club members are trained in the use of Agritubes and pass on their knowledge to the community they represent.

6.3 Lessons learned

- A sense of community must be built within a settlement before any intervention in water and sanitation issues, including greywater irrigation, can hope to succeed.
- Sense of community can be built through:
  - Involving existing formal and informal structures
  - Community meetings
  - Household visits
  - School visits
  - Election of individuals and committees from the settlement to take responsibility for part of the service provided.
- Media which have been successful in building a sense of community and in engaging communities include
  - Street theatre

  - Street competitions (structured so that there are many small prizes so that most people win something and the prizes relate to the main message, *e.g.* toilet paper and soap for hygiene programmes, hand tools and seedlings for greywater irrigation programmes)
  - Simple colourful pictorial posters to be hung in the household at the point of use (*e.g.* toilet for sanitation; kitchen, bathroom and laundry area for greywater collection)
  - Simple colourful pamphlets for residents to keep handy as ready sources of information
  - Local sources of reasonably priced hardware for maintenance of structures and systems (*e.g.* toilet parts, irrigation equipment, basic tools)
- Community-based facilities for immediate problem solving and as local points of access to the relevant skills and services within the municipality.

7 Moving forwards: Recommendations

7.1 Implementation: Dissemination of Guidance Report

- All local authorities, as well as Water Boards, should be informed directly of the imminent release of the Guidance Report, once an approximate release date is known. This should take the form of a one-page brochure and can be disseminated by fax, regular mail and email.

- The Water Institute of Southern Africa (WISA) should be used to publicise the release of the Guidance Report to its members. This is already happening to some extent since a paper on the Guidance Report was presented at the WISA Conference held in Durban in April 2010. WISA should be further requested to publicise the release of the Guidance Report via its membership database.

- Consideration should be given to establishing a Greywater web page on the WRC web site. Besides giving concise information about greywater and greywater irrigation, the Guidance Report, Technical Report and previous WRC reports on greywater should be available for download via this web page.

7.2 Implementation: Capacity building at Local Authority level

- A short educational pamphlet on greywater and greywater irrigation, aimed specifically at local authorities, should be developed. This should be mailed to all local authorities by regular mail, fax and email together with the notification of the release of the Guidance Report, as recommended above. Should the proposal for a WRC Greywater web page be accepted, this pamphlet should also appear on the web page. The pamphlet should give clear contact details for anyone wanting further information.

- Attendees at the capacity building workshop, held in January 2010 to introduce local authorities to the Guidance Report, requested that the workshop be repeated annually. They requested addition of a practical component during which hands-on experience could be obtained of successful interventions, such as that of eThekwini Municipality described in Chapter 6. Such annual workshops could potentially be expanded to feature other aspects of domestic waste reuse and recycling.

- Another request made by attendees at the capacity building workshop referred to above was a forum in which questions could be asked and experiences exchanged on an ongoing basis. A blog was mentioned as a possible means of implementing this request. Such a facility could be linked to a WRC Greywater web page.

7.3 Implementation: Education of greywater users

- Potential greywater users need to be involved in planned greywater implementations from the planning stages, informing them of the benefits and risks of greywater use for irrigation, allowing them to express their views and concerns, and providing a mechanism for them to be involved in decision-making. To facilitate this, multi-media public participation processes such as those described in Section 6.2 should be employed.

- Potential irrigation users of greywater need information to practice greywater irrigation in a safe and sustainable manner. Although this information is provided in the Guidance Report, it would be helpful to provide users with quick reference sheets to support the more comprehensive Document. This could take the use of one-page information sheets on topics such as:
  - Safe handling of greywater
  - Safe, yet inexpensive, practical irrigation methods
  - Safe handling of crops
  - Use of environmentally-friendly ‘green’ cleaning products.

  Such information sheets could be distributed via the offices of the local authorities (potentially as inserts to municipal utilities bills), local libraries, the WRC and bodies of water professionals. They could also be made available electronically on a WRC Greywater web page. Examples of information sheets developed on the basis of the draft Guidance Report by Khanyisa Projects, on behalf of eThekwini Municipality, are included in the Guidance Report.

- Once a greywater implementation has been planned and initiated, greywater users need ongoing monitoring and support. This requires, firstly, capacity building among local authorities to empower them to provide these (addressed above). Different types of users are likely to require different types of support. Middle to higher income users are likely to require guidance up-front, followed by a known person with the local authority whom they can contact, and who will follow-up with them on an infrequent but regular basis. This is because such users generally have access to information and technical resources. On the other hand, low-income communities in either rural or urban/peri-urban environments typically do not have access to such resources and require more direct and ongoing support. A possible means of providing this support are structures such as the Health Clubs described in Section 6.2.

7.4 Legislation: Recognition of greywater and beneficial greywater use in water and waste legislation

- Current legislation pertaining to disposal and use of water and waste falls short in that a definition of greywater as a separate wastewater stream is lacking. This means that the legal status of greywater use for irrigation remains ambiguous in the light of existing legislation, particularly with respect to the National Water Act and National Building Regulations. The Department of Water Affairs has indicated that it supports the managed use of greywater for irrigation as a means of better managing scarce water resources, and as such is willing to consider greywater irrigation to be covered implicitly in light of existing regulation. However, clarity is needed for the future by explicit definition of greywater and the beneficial uses to which it may be put.

7.5 Research: Remaining knowledge gaps

There is a relative lack of published peer-reviewed research on beneficial greywater use and on greywater irrigation, particularly in low-income communities. While regulatory and scientific literature on either wastewater or agricultural irrigation with conventional water supplies is useful, it fails to address the special needs of greywater irrigation. More research specific to greywater is needed, since greywater presents both opportunities and challenges which differ from either wastewater or conventional agricultural irrigation. In particular, studies are needed on:

- Suitable indicator micro-organisms for health protection.
  Research conducted as part of this project (described in Chapter 3 and Appendix 1) suggests that of the most widely used indicator organisms, only *E. coli* and total coliforms were present in excess on greywater-irrigated crops, but these results need validation in other studies.

- Identification of the greywater quality constituents which most contribute to deterioration in plant growth, crop yield, crop quality and soil characteristics.
  Sodium has been proposed and this has been borne out in trials reported in the literature and in the present project (see Case Studies, Chapter 3). There is some literature specific to greywater for oil and grease, but for most other constituents included in the Guidance Report, information and guidance ranges were drawn from literature on wastewater or on irrigation with conventional water sources.

- Maximising fertiliser potential of greywater.

- Trialling of ‘green’ cleaning products to test whether the greywater generated with these does indeed preserve plants, crops and soil relative to greywater generated with conventional cleaning products. Ideally, this should be performed in collaboration with manufacturers of cleaning products so that they gain knowledge of how best to adjust product formulations to allow for maximum beneficial use of greywater.

- Cost-effective proven on-site treatment processes that are sufficiently robust for implementation in low income communities.

- Role of different soil types on interaction with greywater.

- The pollution potential of managed greywater irrigation.
  Statements with respect to this are currently largely based on observations of uncontrolled greywater release and on conjecture. Studies on the potential

impact of managed greywater irrigation on groundwater, surface water and sensitive environments need to be conducted.

In addition, review of the Guidance Report is recommended in one to two years, with updates to be made based on experience in practice.

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Appendix 1

Case Studies Undertaken to Support Development of Guidance Report for Small-Scale Irrigation Use of Greywater in South Africa

Authors:

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L Salukazana, S Jackson, N Rodda

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N Rodda, K Carden, Z Wilson, L Salukazana, T Chalale

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Case Study 6
N Rodda, M du Plessis, JP Nell

Case Study 1
Plant Growth, Soil Characteristics and Microbiological Quality of Vegetable Crops Irrigated with Domestic Greywater in eThekwini Municipality

1. Aims

- To investigate the growth and yield of crop plants irrigated with greywater, relative to plants irrigated with water amended with a balanced source of plant nutrients and with tap water alone.
- To investigate the potential accumulation of macronutrients and micronutrients in crops of plants irrigated with greywater, relative to crops of plants irrigated with water amended with a balanced source of plant nutrients and with tap water alone.
- To investigate the potential accumulation of macronutrients and micronutrients in soil irrigated with greywater, relative to soil irrigated with water amended with a balanced source of plant nutrients and with tap water alone.
- To investigate the microbial loads on and in crops of plants irrigated with greywater, relative to crops of plants irrigated with water amended with a balanced source of plant nutrients and with tap water alone.
- To investigate the health risks associated with consumption of crops of plants irrigated with greywater, relative to consumption of crops of plants irrigated with water amended with a balanced source of plant nutrients and with tap water alone.

2. Introduction

Development of guidance for the use of greywater in small-scale irrigation of gardens and crop plants requires information regarding the potential risks to plant growth and yield, to crop quality, to soil and to human consumers of greywater-irrigated crops. There are relatively few such studies available in the literature and none of sufficient breadth which are applicable to conditions of climate, soil, crop selection, irrigation method, *etc.* which are likely to be encountered in South Africa, particularly with respect to low income communities. This study was initiated for two purposes:

- To support the development of greywater irrigation initiatives in eThekwini Municipality, and
- To support the development of guidance for use of greywater in small-scale irrigation throughout South Africa.

3. Materials and methods

3.1 Experimental design

Eight households in Cato Crest (an informal peri-urban settlement located in close proximity to the University of KwaZulu-Natal, Howard College campus), were selected for collection of mixed domestic greywater. The selection of households was conducted in a preliminary study and was based on the number of people per household, ages, gender and washing applications (bath, hand basin, laundry and dish washing). Interviews and questionnaires were used to measure the greywater-producing activities, dynamics of the family, water usage patterns, age distribution of occupants and lifestyle characteristics. The total number of residents in the experimental group was 53, comprising 37 adults (18-100 yr), 12 children (2-18 yr) and 4 infants (0-2yr). Mixed greywater generated by each of the selected households was collected in a 25 ℓ container. Containers were collected daily (Monday to Friday) by eThekwini Water and Sanitation and were delivered to the experimental site at the Howard College campus of the University of KwaZulu-Natal. Greywater from all participating households was mixed in a 200 ℓ container on-site. There was no pre-treatment of the greywater before use, other than sieving through a metal mesh to remove large particles which might block pipes.

Representative vegetable crops grown included above-ground (spinach *Spinacia oleracea*; green pepper *Capsicum annuum*; and green beans *Phaseolus vulgaris*) and below-ground (carrots, *Daucus carota*; beetroot, *Beta vulgaris;* and onions *Allium cepa*) crops. These were selected on the basis of popular use and of the perceived risk of infection associated with crop consumption:

Above ground	Leafy	Spinach	- high risk
	Non-leafy	Green peppers	- low risk
Below ground		Carrots	- high risk
		Beetroot	- low risk
		Onion	- high risk

Results for spinach and carrot only are presented here since their growth was representative of the above-ground and below-ground crops respectively, and since they represent the highest health risks to consumers.

Seedlings were obtained from a commercial nursery and planted in individual 20 ℓ polyethylene plastic bags filled with Berea red sand, with holes at the base for free drainage. Water was delivered directly to the root zone of each plant by a simple form of drip irrigation, consisting of a 500 mℓ plastic bottle which had been punctured at the base and buried to two-thirds of its length beside each plant, as shown in Figure 1. Pots were not protected from the rain or sun.

A **B**

Figure 1: Sub-surface irrigation of crops using a plastic 500 mℓ bottle punctured at the base (A) and buried two-thirds to half its length alongside plants (B).

Three experimental treatments were employed: (i) tap water; (ii) tap water amended with a commercial plant nutrient medium (Chemicult®), referred to hereafter as nutrient solution; and (iii) greywater. Plant nutrient medium (Chemicult®) consisted of (g/kg): NH_4^+ 83, P 37, K 189, Mg 81, S 192, B 0.17, Fe 0.265, Mn 0.115, Zn 0.105, Cu 0.055 and Mo 0.035. Plants were watered with their respective treatments twice a day in summer and once a day in winter (500 mℓ irrigation solution applied per plant), with the exception of those receiving the plant nutrient medium. In accordance with manufacturer's instructions, the commercial plant nutrient medium was applied once weekly and tap water was used on the remaining days. A total of 25 plants of each species were planted per treatment, of which 15 were used for plant growth monitoring and 10 for microbiological analyses. Plants were allowed a growth period of at least 12 weeks after planting of seedlings. Prior to irrigation with different treatments, irrigation water was analysed for physico-chemical properties, nutrients and health-related microorganisms in each growth cycle. The experiment was terminated after six crop cycles (November 2004 to February 2005, May to August 2005, October to January 2007, March to June 2007, August to November 2007 and December 2007 to February 2008). The same soil was used throughout all six crop cycles to allow for accumulation of chemical constituents in the irrigation treatments, particularly greywater.

Plant parameters measured were plant height and crop yield. At the end of each cycle, crops were harvested and analysed for nutrient and microbiological characteristics as detailed below. Growth, yield and nutrient content of plants from the sixth growth cycle were generally not reported because plants were extremely stunted and it was judged that the soil had reached the limit of its capacity to support repeated cycles of growth.

3.2 Irrigation water characterisation

Prior to irrigation, greywater samples were sent to eThekwini Municipality Water Services Laboratory, for physico-chemical and microbiological analysis. Electrical conductivity was measured using an EC meter. Alkalinity, BOD_5, COD, nitrates, nitrites, orthophosphate and total Kjeldahl nitrogen, were analysed according to standard methods. The concentrations of calcium, lead, chloride, magnesium, sodium, potassium, phosphorus, zinc, cadmium, sulphur, iron and manganese were measured by inductively coupled plasma atomic emission photometry (ICP-AES). Sodium adsorption ratio was determined by calculation, according to Equation 4 in the main body of the Technical Report.

Microbiological analysis included *E. coli*, total coliforms, coliphages, *Pseudomonas* and *Ascaris*. Analyses for *Shigella* and *Salmonella* were conducted if *E. coli* counts were high.

In addition, since irrigation over weekends made use of greywater delivered by Friday of each week, a preliminary trial was conducted monitoring changes in pH, EC, COD, *E. coli*, total coliforms and coliphages in a single sample of pooled greywater over a period of 5 days.

3.3 Plant growth monitoring

Plant growth was measured weekly. Growth parameters included plant height, fresh weight and dry weight. Harvested crops at the end of each crop cycle were measured for fresh and dry weights for the determination of yield. Only dry weights are reported here.

3.4 Plant and soil nutrient analyses

Vegetables were harvested after each crop cycle, and the total mean fresh weight was determined by summing the yields of individual crop type per treatments. At the end of each crop cycle, plants were completely removed (with roots) from the pots at each harvest. All plant material was weighed, placed in paper bags and dried in an oven at 80^0C for 72 hours. Dry mass yield was determined for each pot, and the data were used to calculate total yields for each crop type per treatment.

The dried plant material was milled to pass through a 0.84 mm sieve. Milled plant material was analysed for both macronutrients (nitrogen, phosphorus, calcium, potassium, and magnesium) and micronutrients (sodium, zinc, copper, manganese, iron, aluminium and boron) by the Soil Fertility and Analytical Services Laboratory (KwaZulu-Natal Department of Agriculture and Environmental Affairs, Cedara, South Africa). Subsamples of plant material were dried and ashed at 450˚C overnight. The ash was dissolved in 1 M HCl. The supernatant was analysed for aluminium, calcium, copper, potassium, magnesium, manganese, sodium and zinc were determined by atomic absorption spectroscopy (AAS). Phosphorus concentrations were determined colorimetrically on a 2 mℓ aliquot of filtrate using a molybdenum blue procedure. Potassium was determined from the extract directly on a flame photometer. Samples for boron analysis were ashed separately, and boron determined photometrically by an azomethine H method.

Soil sampling was performed at the end of each crop cycle. Soil samples were taken from a depth of 20 cm and were air dried at room temperature, spread out in drying trays. When dry, the samples were crushed and sieved through a 1-mm sieve. Material coarser than 1 mm was discarded. Soil samples were sent to the Soil Fertility and Analytical Services Laboratory (KwaZulu-Natal Department of Agriculture and Environmental Affairs, Cedara, South Africa) for elemental composition and nutrient analysis. Analyses were performed for organic carbon; for total carbon, nitrogen and sulphur; and for extractable phosphorus, potassium, zinc, manganese and copper.

All analyses were performed using standardised methods of the laboratory. Extractable phosphorus, potassium, zinc, manganese and copper were determined following extraction by the AMBIC-2 method as described by the Non-Affiliated Soil Analysis Working Committee of South Africa (1990). Phosphorus was determined on a 2 mℓ aliquot of filtrate using a molybdenum blue procedure. Potassium was determined by atomic absorption on a 5 mℓ aliquot of the filtrate after dilution with 20 mℓ de-ionised water. Zinc, copper, manganese and magnesium were determined by atomic absorption. Organic carbon in soil samples was determined by the Walleye-Black method, while toctal carbon, nitrogen and sulphur were analyzed by the Automated Dumas dry combustion method using a LECO CNS 2000 (Lecco Corporation, Michigan, and USA). The pH and electrical conductivity were measured in water at a ratio of 1:2.5.

3.5 Microbiological analyses of crops

In line with the literature, it was anticipated that greywater would contain a lesser load of pathogens and faecal indicators than black water or combined sewage. As the water for this project came from relatively impoverished households, it was however expected that certain pathogens endemic to the community would probably be present. It was also expected that there would be some faecal indicator organisms as a result of full body washing particularly of infants and sick household members, as well as washing of laundry, especially infant nappies. Although it was recognized that some members of the selected groups of organisms could re-grow in water given suitable conditions, it was considered that conclusions based on counts under such circumstances would result in even greater protection to user health as the increased numbers resulting from such re-growth would give an apparent increase in risk which would not necessarily be true. Microorganisms for analysis were selected on the basis of these considerations and are shown in Table 1.

Table 1: Microorganisms selected for analysis of irrigated crops

Organism	**Role as indicator**
Total coliforms	General bacterial load
Escherichia coli	Faecal indicator and potential pathogen
Enterococcus sp	Faecal indicator
Pseudomonas sp	Opportunistic pathogen
Staphylococcus sp	Skin commensal / opportunistic pathogen
Ascaris lumbricoides	Endemic helminthic parasite
Somatic coliphage	Enterovirus indicator

Total coliforms are ubiquitous in the environment and give an indication of whether or not there has been any die-off of microorganisms as a result of the handling of the greywater. *E. coli* is a broadly accepted indicator of faecal contamination by warm-blooded animals, including humans, as well as being a potential pathogen. *Enterococcus* species, especially *Enterococcus faecalis,* is also a widely used faecal indicator but tends to survive longer in water than *E. coli. Pseudomonas* species are opportunistic pathogens particularly of the skin and can cause severe illness in immunocompromised persons as well as infants. *Staphylococcus* species are causative agents of skin infections such as boils as well as being part of the normal skin flora. *Ascaris lumbricoides* was analysed both as an endemic pathogen itself and as an indicator of the potential contamination with protozoan or other helminthic parasites. Somatic coliphage was analysed as an indicator for enteric viruses which could be expected in the greywater contaminated with faeces through bathing and washing of faecally soiled laundry.

A limited number of soil samples were analysed for the above micro-organisms, using methods as outlined below.

Harvested vegetables were analysed for microbiological contaminants, on both the surface and the interior of the crop. A representative sample from each crop was selected, weighed wet and then dried at 108^{o}C in a drying oven until a steady mass was obtained. The percentage moisture was calculated and used to convert all further samples used to their dry mass for comparison purposes. In addition, to harvested crops, equivalent crops were purchased from readily available commercial outlets and were similarly examined.

For analysis of external contamination of crops, fresh, weighed samples were placed into suitable volumes of sterile Ringers solution and shaken on a platform shaker at 220 rev/min for one hour. The solution was then drained off and utilised for microbiological analyses. All results were converted back to counts per gram dry weight of sample.

For analysis of internal contamination, fresh samples were weighed, then washed in tap water and sonicated in a 20% solution of a commercial sodium hypochlorite solution (Jik) with 0.1 mℓ of Tween 80 detergent added to ensure removal of any waxy coatings. The rinsed and drained disinfected material was then placed in suitable volumes of sterile Ringers solution in sterile honey jars and macerated with a sterilised domestic food blender. Aliquots of the resultant mixture were analysed as for the external samples.

All analyses were performed according to eThekwini Water and Sanitation standardised methods. Total coliforms and *E. coli* were analysed using a membrane filter technique onto Merck™ Chromocult agar. This is a specific enzyme detection medium capable of enumerating total coliforms and *E. coli on a single medium* by detecting β-glucuronidase and β-galactosidase activity. *Enterococcus* species were enumerated by membrane filtration onto enterococcus selective agar (Oxoid) with positive colonies producing darkening in the agar around positive colonies. Membrane filtration was also used for the analysis of *Pseudomonas* sp. with positive colonies being those that produced green fluorescence on Cetrimide agar. Staphylococci were enumerated by membrane filtration on Slanetz and Bartley agar with positive colonies being black with zones of clearing in the surrounding agar. *Ascaris lumbricoides* was enumerated using the South African recommended method which employs an ammonium bicarbonate separation and microscopic identification of ova (Archer *et al.*, 2006). Somatic coliphages were enumerated using a double layer agar technique.

3.6 Statistical analyses

3.6.1 Plant growth, and plant and soil nutrient data

Analysis for statistical significance of differences among treatments for each crop was performed in SPSS (version 15.0), using analysis of variance (ANOVA). To test the two assumptions of ANOVA, tests for normality of the data distribution and equality of variance among treatments was performed by Kolmogorov-Smirnov Test and Levine's test respectively. One-way-ANOVA with Post Hoc Multiple Comparisons using Bonferroni and Tukey tests were performed to determine the statistical differences among treatments.

3.6.2 Microbiological data

All data obtained were tested for normality using the statistical package Statistica. Where data were not normally distributed, log transformations were used. However, some data remained non-normally distributed even after transformation. Testing for significance of difference in means among treatments was therefore performed using 1-way-ANOVA for normally distributed data (after log transformation) and the Mann-Whitney U test for data sets which were not normally distributed.

3.6.3 Health risk assessment

Health risk estimates were performed using standard Quantitative Microbial Risk Assessment (QMRA) techniques and recommendations were based on these outcomes.

Distributions for use in the calculation of probability of infection were fitted and tested (chi-square test) using the risk modelling program, @RISK (ver 5.5, Palisade Software). These distributions were used as input for the β-Poisson risk model (Equation 1) using appropriate model parameters (α, β) from the literature (Haas *et al.*, 1999).

$$P_{inf} = 1 - (1 + D/\beta)^{-\alpha} \qquad \textbf{Equation 1}$$

P_{inf} = probability of infection
D = dose of micro-organisms
α, β are model parameters.

Risk estimates were derived from 5000 model iterations using Latin hypercube sampling, as implemented in @RISK. The model outcomes were presented by the program as frequency distributions of risk of infection, as per the entered risk model.

4. Results

4.1 Characterisation of irrigation water

Average values of the chemical and microbiological analyses performed on tap water, greywater and nutrient solution at the start of each crop cycle are shown in Table 2. The mean pH of greywater was higher than that of either nutrient solution or tap water. Mean alkalinity of greywater was also much higher than that of the other two irrigation treatments. Mean chloride, sodium, total nitrogen, phosphate and boron levels were also markedly higher in greywater than in either tap water or nutrient solution.

Table 2: Average concentrations (± standard error of mean) and the ranges of water constituents in greywater, nutrient solution and tap water, used to irrigate vegetables.

Constituent	Units	Tap water	Greywater	Nutrient solution	Guideline limits for restriction on use in SAWQG for irrigation (DWAF, 1996)		
					Target range	**Maximum range**	**Short term site-specific use only**
pH		6.8-7.4	8.1-9.8	6.3-7.8	6.4-8.4	-	>8.4
Alkalinity	mg/ℓ $CaCO_3$	29±0.7	330±58	66±0.4	-	-	-
Electrical conductivity	mS/m	30±0.1	26±30	223±15.6	40-90	90-540	>540
Sodium	mg/ℓ	-	188±27	32±0.3	<70	70-460	>460
Biological oxygen demand (BOD_5)	mg/ℓ	-	280-310	-	-	-	-
Chemical oxygen demand	mg/ℓ	-	280-310	-	-	-	-
Calcium	mg/ℓ	<0.05	7.5 ±1.7	<0.5	-	-	-
Copper	mg/ℓ	<0.1	0.1±0.1	<0.1	<0.2	0.2-5.0	>5.0
Magnesium	mg/ℓ	5.6±0.8	7.5±1.7	7.1±0.3	-	-	-
Nitrate + Nitrite	mg/ℓ	0.91±1.0	88±1.1	1.2±0.3	-	-	-
Total nitrogen	mg/ℓ	0.84±0.3	206±5.8	125±0.1	<5	5-30	>30
Ortho-phosphate	mg/ℓ	<0.05	40±7.0	38±0.2	-	-	-
Potassium	mg/ℓ	3.1±1.3	31±2.7	7.1±5.8	-	-	-
Sulphate	mg/ℓ	0.05±1.8	576±27	137±15.8	-	-	-
Total Kjeldahl Nitrogen	mg/ℓ	0.05±0.1	206±2.7	125±15.2	-	-	-
Total phosphate	mg/ℓ	<0.10	69±0.6	49±1.7	-	-	-
Zinc	mg/ℓ	<0.25	0.24±0.4	<0.10	<1.0	1.0-5.0	>5.0
Boron	mg/ℓ	<0.25	3.4±3.2	0.5±0.3	0.5	6.0-15	> 15

At the start of the project and of each crop cycle, microbiological analyses were conducted on several samples of greywater, tap water and the hydroponic solution. The results are given in Table 3. No *Ascaris* ova*, Salmonella, Shigella* or somatic coliphages were detected in any of the greywater samples. The levels of *E. coli* ($p<0.001$), staphylococci ($p=0.001$) and total coliforms ($p<0.001$) were significantly higher in the greywater than in either of the other two water types used for irrigation. The level of enterococci was not significantly different ($p=0.07$) in greywater, relative to the other treatments. From these results, it was expected that harvested crops would show significant levels of *E. coli*, enterococci, staphylococci and total coliforms but little if any of the other microorganisms.

Table 3: Microbiological analyses of random samples of the treatment waters (bacterial counts given as $\log_{10}$).

	Ascaris		***E. coli***	**Faecal enterocooci**	**Somatic coliphage**	**Staphylococci**	**Total coliforms**
	Total	**Viable**					
	Ova/g	**Ova/g**	**CFU/ 100 mℓ**	**CFU/ 100 mℓ**	**PFU/ 100 mℓ**	**CFU/100 mℓ**	**CFU/100 mℓ**
	Greywater						
Avg	0	0	7.7	4.0	0	6.1	9.7
Max	0	0	9.0	5.3	0	7.5	11.1
Min	0	0	0	0	0	0	0
	Nutrient solution						
Avg			0	0	0	0	2.8
Max	0	0	0	0	0.85	0.85	4.1
Min	0	0	0	0	0	0	0
	Tap water						
Avg			0	0	0	0	0.9
Max	0	0	0	0	0	0	1.8
Min	0	0	0	0	0	0	0

CFU = colony forming units; PFU = plaque forming units

In addition, tests were performed on a composite sample of greywater over a five day period to determine whether or not storage had a significant effect on basic parameters. The results are presented in Table 4. The levels of *E. coli* and total coliforms were very high (>10^5 CFU/g) on each of the days. From the results it appeared that there was little if any change in the parameters except for the chemical oxygen demand which showed an overall slow decrease. The brief storage of the greywater could therefore not be regarded as offering any health related treatment value to the greywater.

Table 4: Results of analysis of stored greywater over a five day period.

	Alkalinity	Ammonia (free)	Chemical oxygen demand	Conductivity	*E. coli*	Total coliforms
	mg/ℓ	mg/ℓ	mg/ℓ	mS/m	Log CFU /100 mℓ	Log CFU /100 mℓ
Day 1		20	1135	146	>5	>5
Day 2		8.6	1135	148	>5	>5
Day 3	300		1060		>5	>5
Day 4	340		1805	144	>5	>5
Day 5	334	16	825		>5	>5

4.2 Plant growth and crop yield

Two above-ground crops (spinach and green pepper) and three root crops (carrot, onion and beetroot) were grown. Results were broadly similar within each group so data for only one above-ground crop (spinach) and one root crop (carrot) are presented here. These may be considered to be representative results.

4.2.1 Plant growth

Spinach

Nutrient solution and greywater boosted growth of spinach when compared to tap water only, which yielded very stunted plants (Figure 2). The growth of greywater-irrigated plants improved from the first growth cycle to the second, and declined thereafter. Growth declined noticeably by the sixth cycle.

Carrot

As seen for spinach, nutrient solution and greywater yielded similar heights of above-ground plant parts, which were significantly ($p \leq 0.05$) greater than that obtained with tap water. The plant heights for all treatments decreased from the second cycle onwards. By the fifth and sixth crop cycles, plant height had decreased significantly for all treatments (Figure 3).

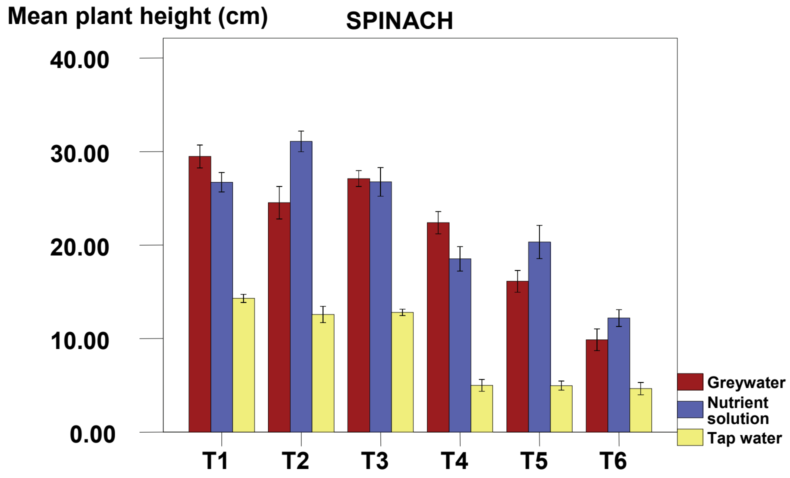


Figure 2: Spinach growth as indicated by plant height, monitored from the first to the sixth crop cycles (T1 to T6). Bars represent arithmetic mean (n=15) and error bars represent the standard error of mean.

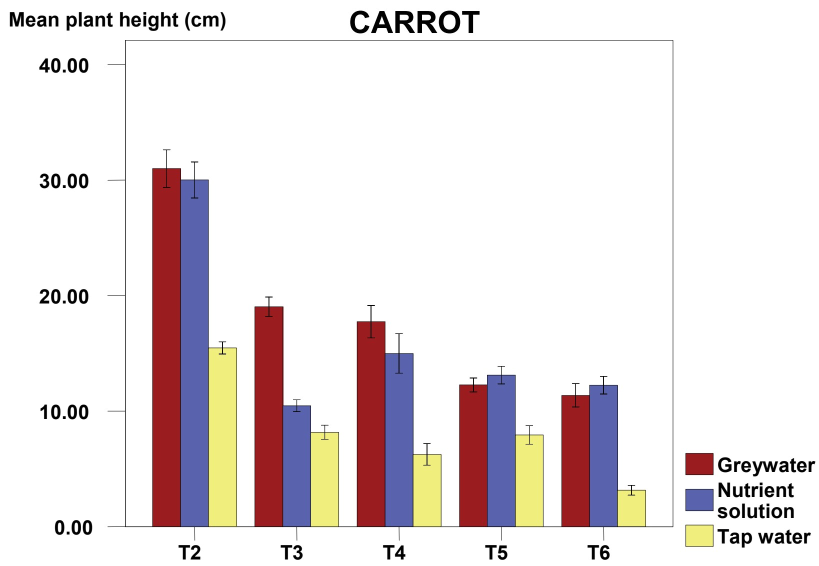


Figure 3: Carrot growth as indicated by height of above-ground plants, monitored from to sixth crop cycles (T1 to T6). Bars represent arithmetic mean (n=15) and error bars represent the standard error of mean.

4.2.2 Crop yield

Spinach

Spinach plants irrigated with nutrient-amended solution showed significantly ($p=0.01$) greater yield than greywater- and tap water-irrigated spinach. Yield was consistently lower for greywater-irrigated plants than for those irrigated with nutrient solution despite instances in which plant height was higher in greywater-irrigated ones. Yield decreased markedly in later crop cycles. Yield from tap water-irrigated plants was extremely low at all times. Representative results for spinach are shown in Figure 4.

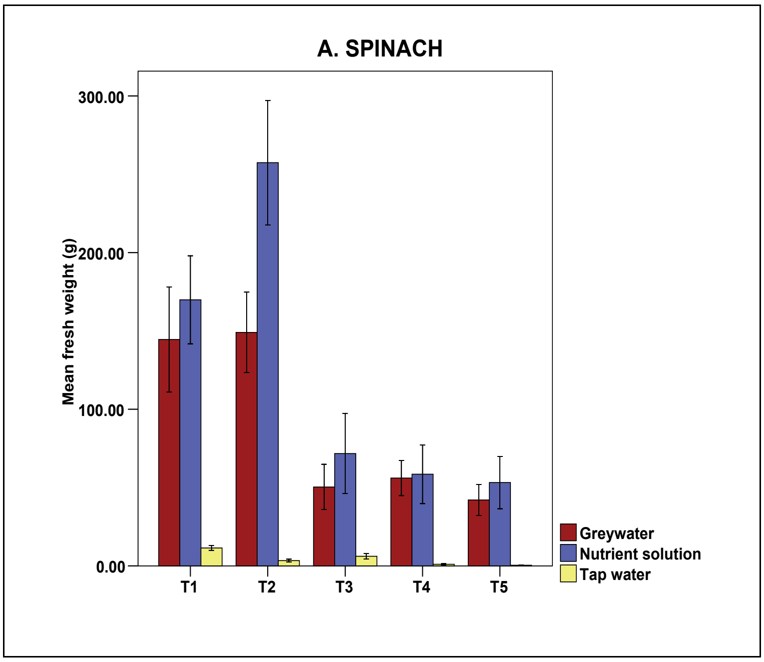


Figure 4: Total yield of spinach throughout the first (T1), second (T2), third (T3), fourth (T4) and fifth (T5) crop cycles. Bars represent arithmetic mean ($n=15$) and error bars represent the standard error of mean.

Carrot

Yields among the three irrigation treatments differed significantly ($p=0.012$). Yield was highest from plants irrigated with nutrient solution and greywater. There was no stage at which crops irrigated with tap water had yields comparable to the other two treatments. Overall, yield of all treatments was much higher in the first crop cycle than in subsequent cycles (Figure 5).

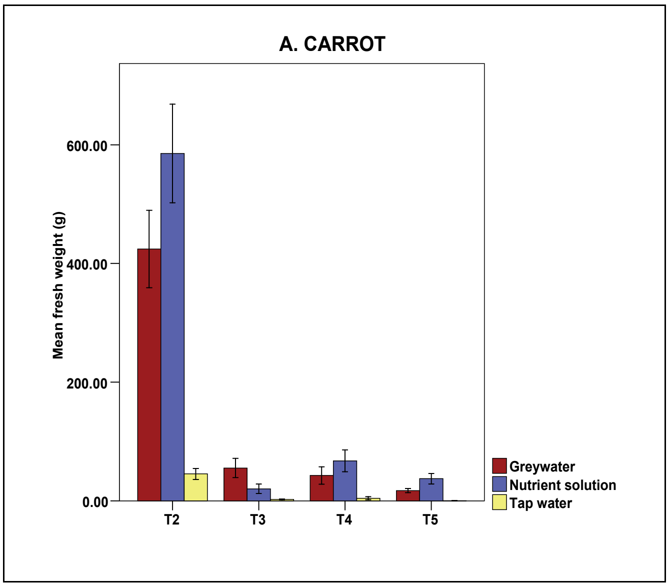


Figure 5: Total yield of carrots throughout the second (T2), third (T3), fourth (T4) and fifth (T5) crop cycles. Bars represent arithmetic mean (n=15) and error bars represent the standard error of mean.

4.3 Macronutrient concentrations in crops

Spinach

Irrigation with either nutrient solution or greywater resulted in significantly higher concentrations (on a dry weight basis) of the micronutrients nitrogen, phosphorus, potassium, calcium, magnesium and sulphur in spinach leaf tissue than did irrigation with tap water alone. Concentrations of phosphorus increased with consecutive crop cycles in spinach plants irrigated with nutrient solution and greywater, while calcium decreased relative to the second crop cycle. The other micronutrients did not show a consistent trend over successive crop cycles (Figure 6)

Carrot

Although spinach is an above-ground leafy crop and carrots are a root crop, the trend in micronutrient concentrations in carrot crops over five crops cycles were similar between the two crops (Figure 7).

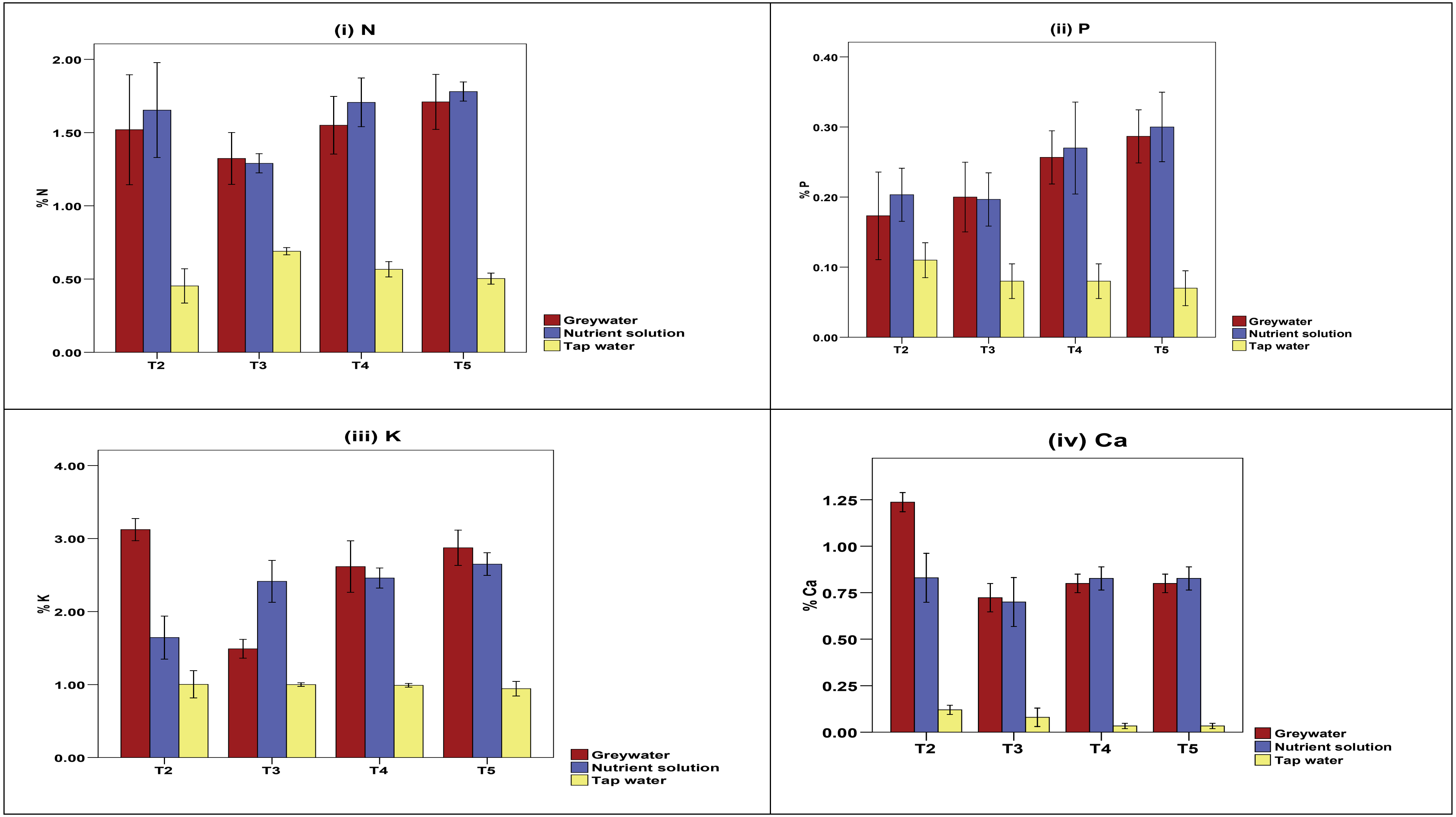


Figure 6: Macronutrient levels in spinach (i) Nitrogen (N), (ii) Phosphorus (P), (iii) Potassium (K) and (iv) Calcium (Ca), over the second crop cycle (T2), third crop cycle (T3), fourth crop cycle (T4) and fifth crop cycle (T5). Bars represent arithmetic mean (n=15) and error bars represent the standard error of mean.

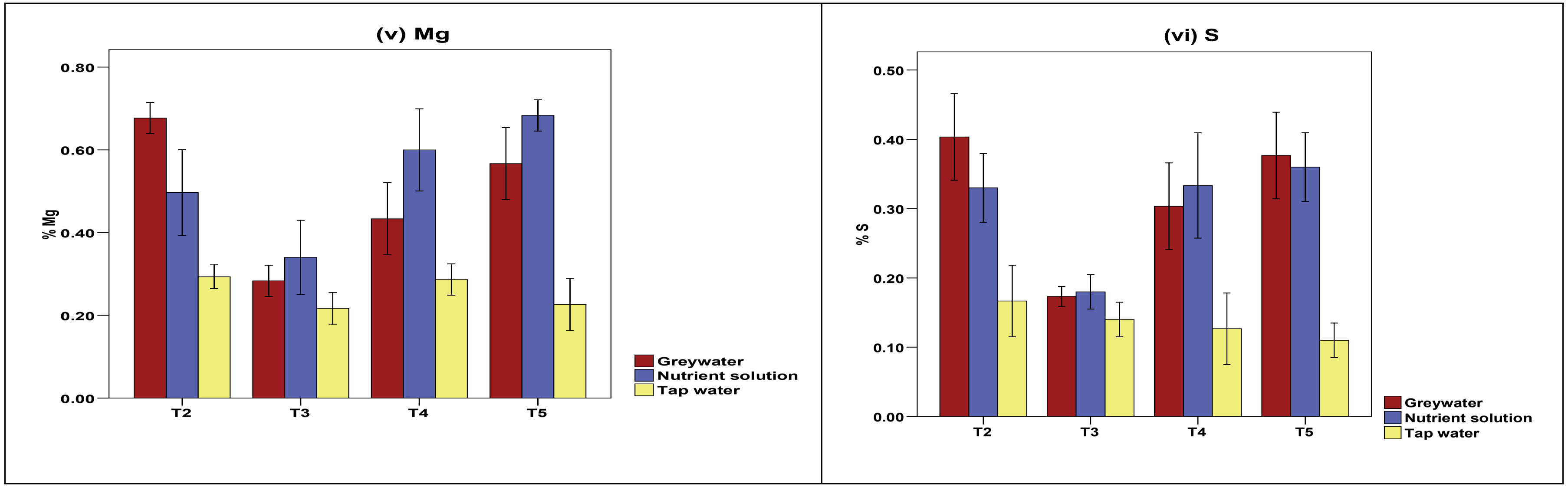


Figure 6 continued: Macronutrient levels in spinach (v) Mg and (vi) S, over the second crop cycle (T2), third crop cycle (T3), fourth crop cycle (T4) and fifth crop cycle (T5). Bars represent arithmetic mean (n=15) and error bars represent the standard error of mean.

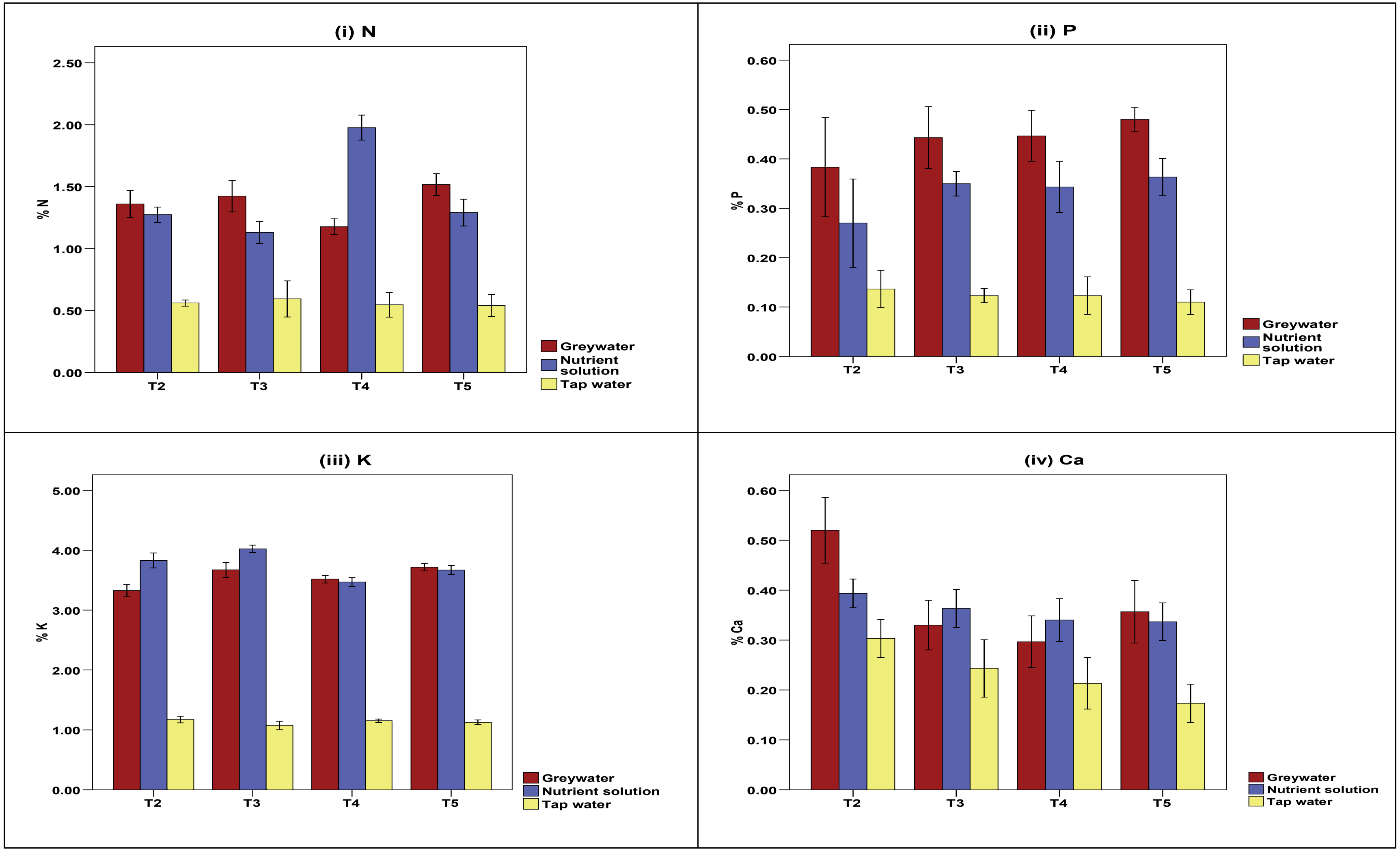
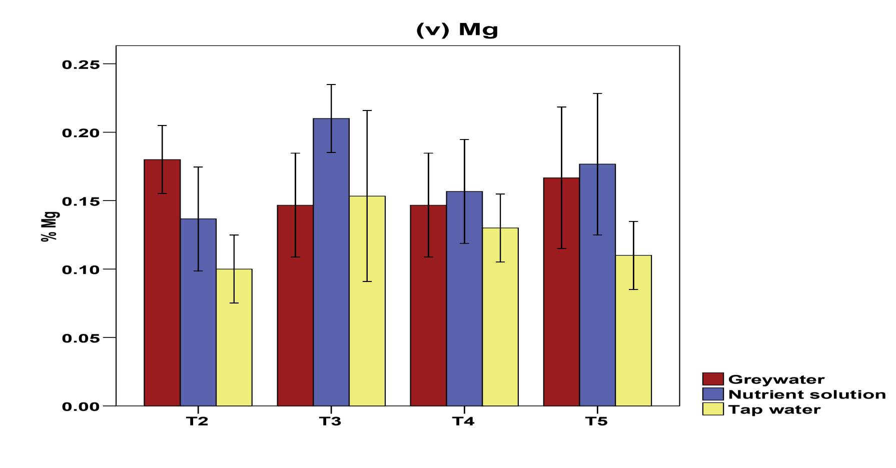


Figure 7: Macronutrient levels in carrot (i) Nitrogen (N), (ii) Phosphorus (P), (iii) Potassium (K) and (iv) and Calcium (Ca), over the second crop cycle (T2), third crop cycle (T3), fourth crop cycle (T4) and fifth crop cycle (T5). Bars represent arithmetic mean (n =15) and error bars represent the standard error of mean.



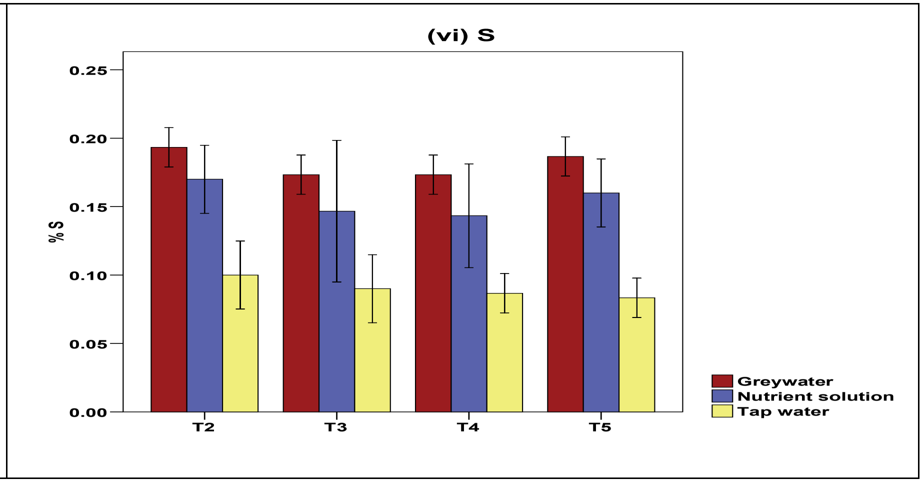


Figure 7 continued: Macronutrient levels in carrot (v) Magnesium (Mg) and (vi) Sulphur (S), over the second crop cycle (T2), third crop cycle (T3), fourth crop cycle (T4) and fifth crop cycle (T5). Bars represent arithmetic mean (n =15) and error bars represent the standard error of mean.

4.4 Micronutrient content in crops

Spinach
Spinach leaves of plants irrigated with greywater and with nutrient solution contained similar mean concentrations (on a dry weight basis) of the micronutrients zinc, copper, manganese, iron, aluminium and boron. All levels were significantly higher than in plants irrigated with tap water only. Sodium was mostly present in higher levels in leaves of plants irrigated with greywater, although not always significantly so. Mean sodium levels in plants irrigated with greywater and with nutrient solution increased with consecutive crop cycles. Mean levels of zinc, copper and manganese also increased with successive crop cycles in plants irrigated with nutrient solution and greywater. Iron, aluminium and boron showed no consistent trend with time (Figure 8).

Carrot
Carrots from plants irrigated with nutrient solution and with greywater always had significantly higher mean levels of all measured micronutrients (on a dry weight basis) than did carrots from plants irrigated with tap water. Mean levels of copper, manganese and boron were similar in carrots from plants irrigated with nutrient solution and greywater. Levels of sodium, zinc, iron and aluminium were significantly higher in plants irrigated with greywater. Sodium, zinc, iron and aluminium levels increased with successive crop cycles in crops from plants irrigated with greywater (Figure 9).

Thus, both above-ground crops and root crops showed a tendency to accumulate sodium and metals. This effect was especially marked with greywater irrigation of root crops.

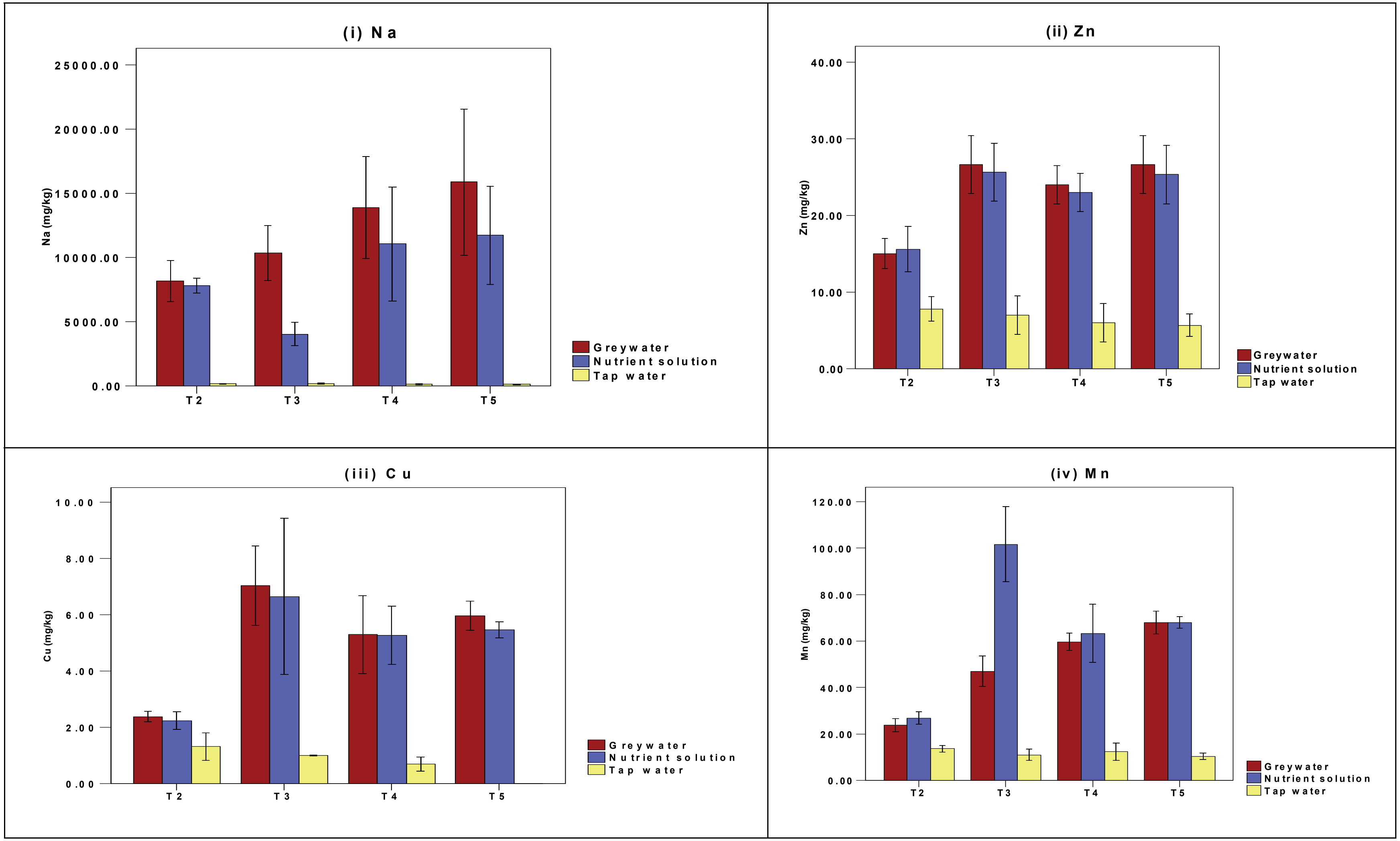


Figure 8: Micronutrient levels in spinach (i) Sodium (Na), (ii) Zinc (Zn), Copper (Cu) and (iv) Manganese (Mn) over the second crop cycle (T2), third crop cycle (T3), fourth crop cycle (T4) and fifth crop cycle (T5). Bars represent arithmetic mean (n=3) and error bars represent the standard error of mean.

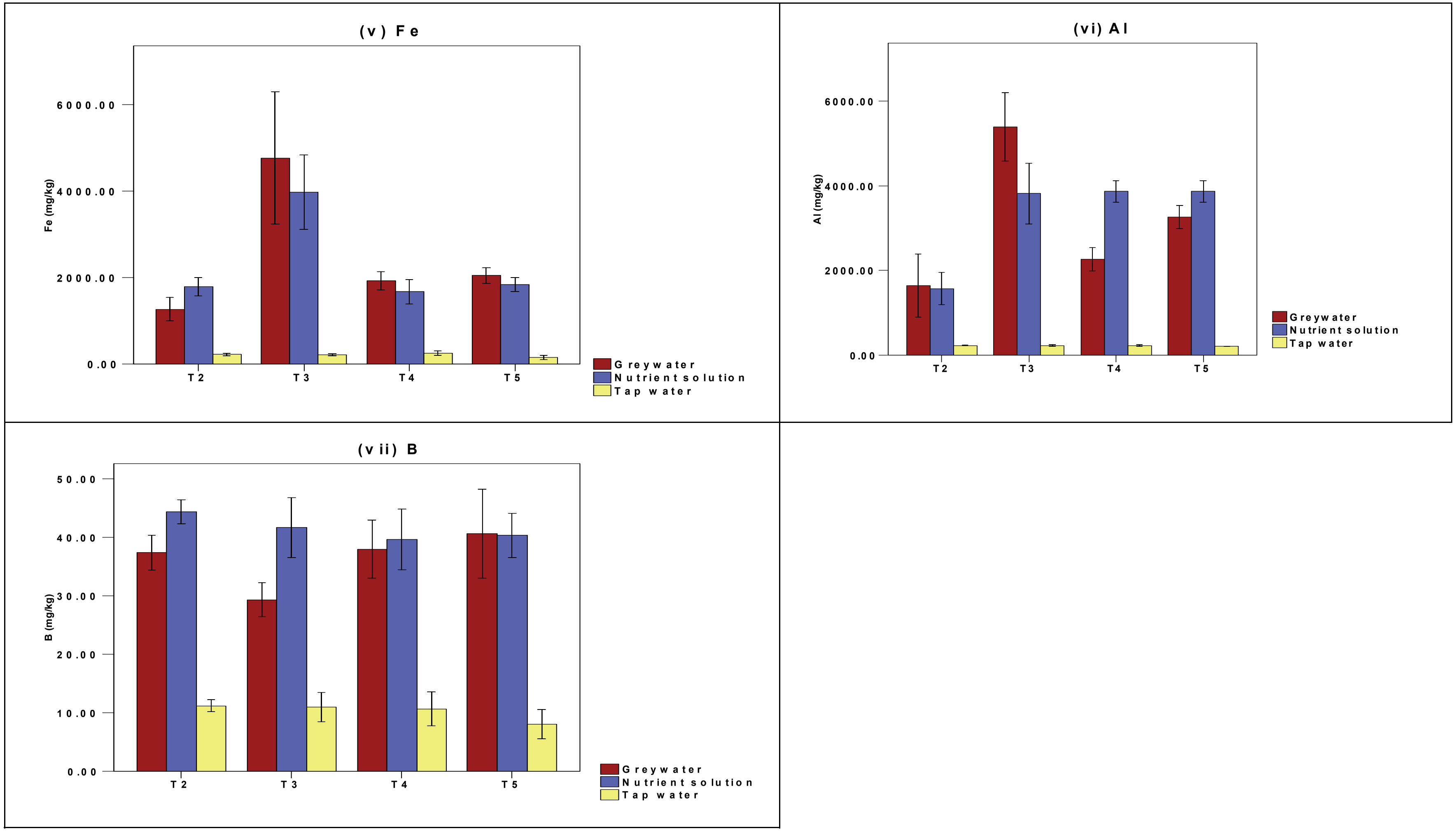


Figure 8 continued: Micronutrient levels in spinach (v) Iron (Fe), (vi) Aluminium (Al) and (vii) Boron (B) over the second crop cycle (T2), third crop cycle (T3), fourth crop cycle (T4) and fifth crop cycle (T5). Bars represent arithmetic mean (n=3) and error bars represent the standard error of mean.

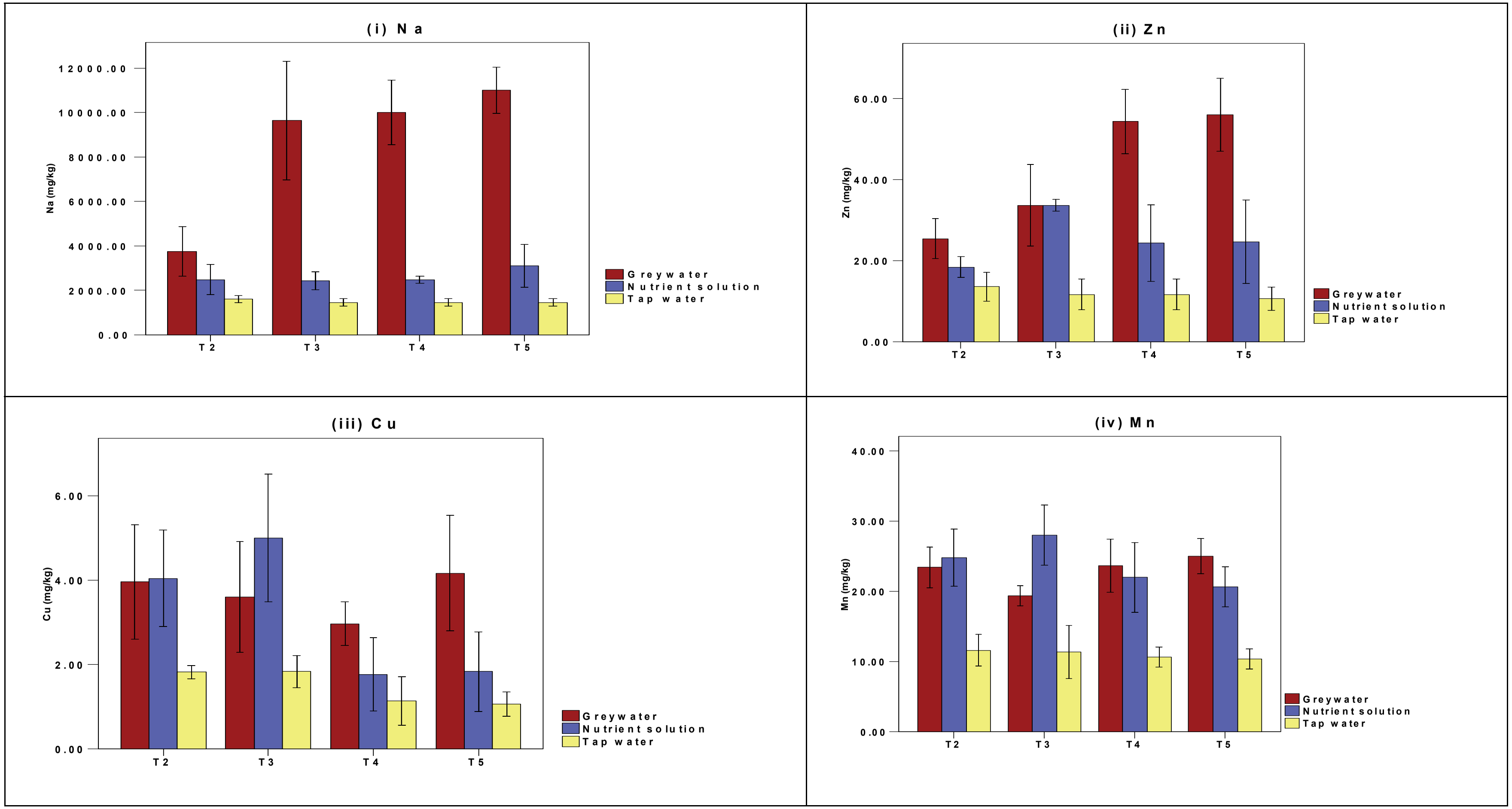


Figure 9: Micronutrient levels in carrot (i) Sodium (Na), (ii) Zinc (Zn), (iii) Copper (Cu) and (iv) Manganese (Mn), over the second crop cycle (T2), third crop cycle (T3), fourth crop cycle (T4) and fifth crop cycle. Bars represent arithmetic mean (n=15) and error bars represent the standard error of mean.

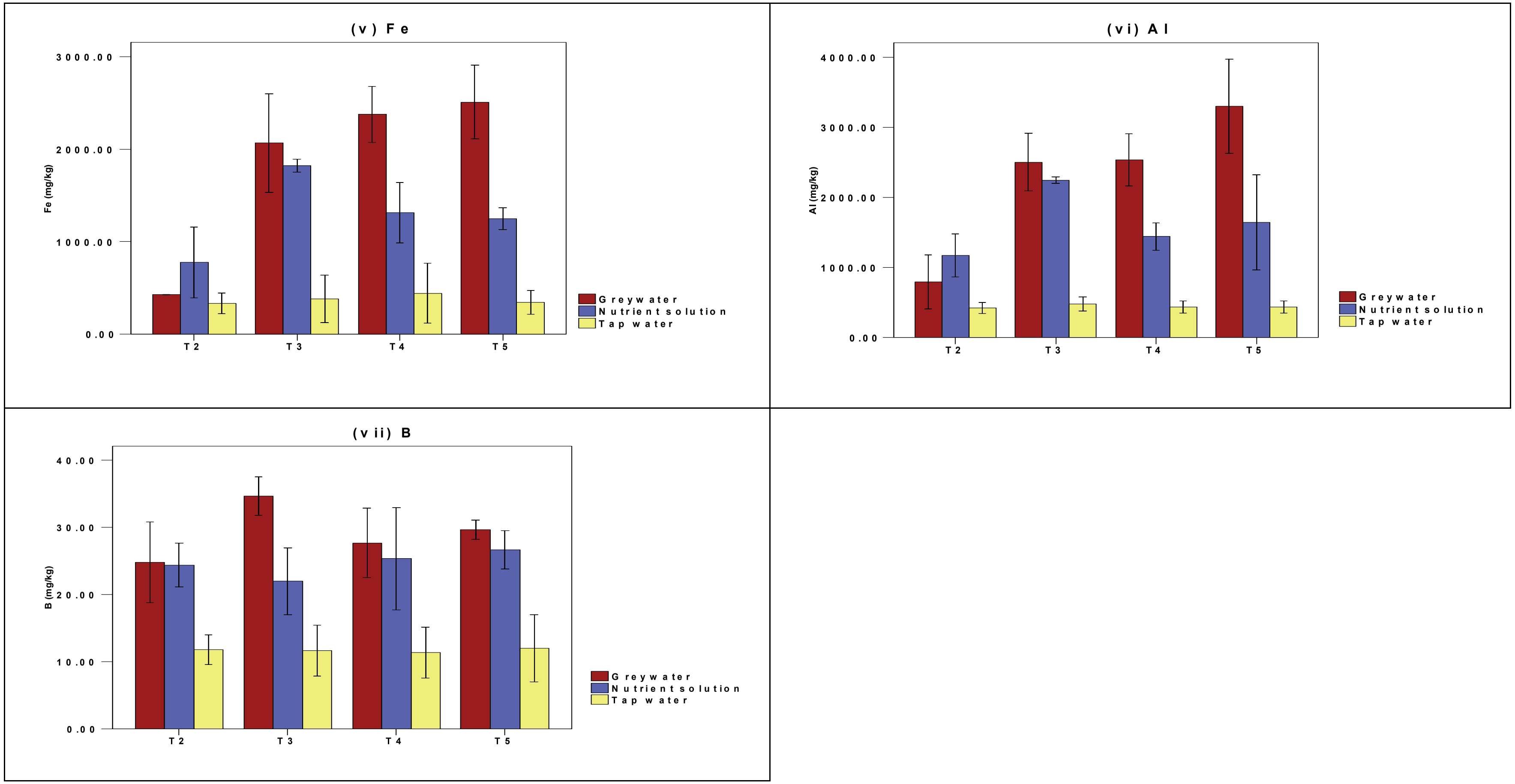


Figure 9 continued: Micronutrient levels in carrot (v) Iron (Fe), (vi) Aluminium (Al) and (vii) Boron (B), over the second crop cycle (T2), third crop cycle (T3), fourth crop cycle (T4) and fifth crop cycle. Bars represent arithmetic mean (n=15) and error bars represent the standard error of mean.

4.5 Macronutrients and micronutrients in soil

4.5.1 Macronutrients

Levels of total nitrogen, total sulphur, phosphorus, calcium, potassium and magnesium in soils irrigated with greywater, nutrient solution and tap water over five crop cycles are shown in Figure 10. There were no significant differences between concentrations in soil irrigated with nutrient amended water and in greywater-irrigated soil, but concentrations in soil irrigated with tap water were significantly lower throughout. A trend of increasing concentration with successive crop levels was noticed for sulphur, phosphorus and potassium.

4.5.2 Micronutrients

Unfortunately no results can be reported for sodium because of sample loss during analysis. However, electrical conductivity can be used as a broad indicator of sodium concentration since sodium ions are a major contributor to soil electrical conductivity. Electrical conductivity of soil irrigated with nutrient solution increased three-fold over five crop cycles while that in greywater-irrigated soils increased four-fold. Electrical conductivity stayed approximately constant in soil irrigated with tap water (Figure 11).

Zinc, manganese and copper concentrations were highest in soils irrigated with greywater over five crop cycles, significantly so for zinc and manganese. Concentrations in soils irrigated with nutrient solution were intermediate between those in greywater-irrigated soil and those in soil irrigated with tap water (Figure 12).

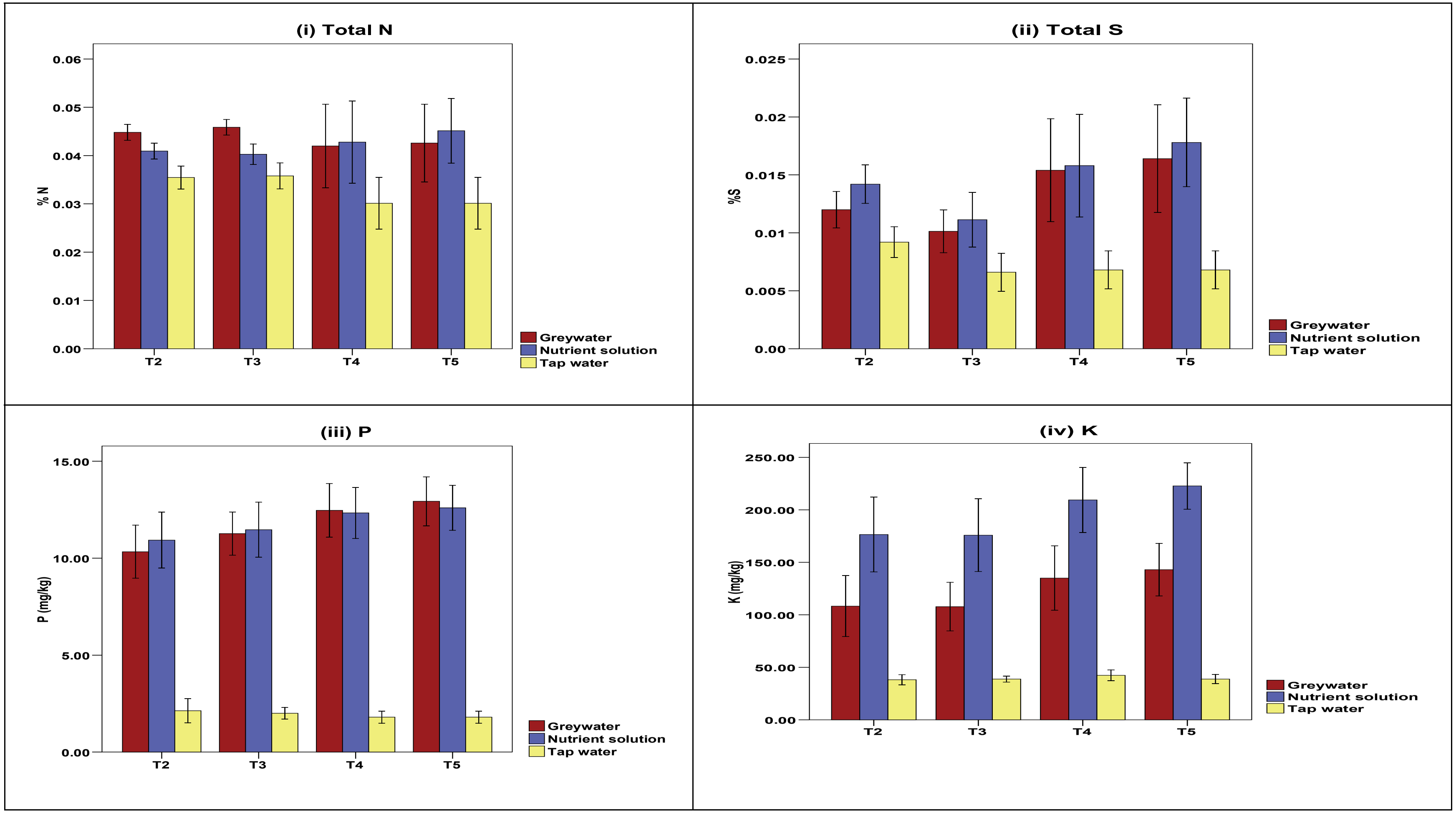


Figure 10: Macronutrient levels in soils irrigated with greywater, nutrient solution and tap water, sampled at the end of the second (T2), third (T3), fourth (T4) and fifth (T5) crop cycles. (i) Total nitrogen (Total N), (ii) Total sulphur (Total S), (iii) Phosphorus (P), (iv) Potassium (K). Bars represent arithmetic mean (n=15) and error bars represent the standard error of mean.

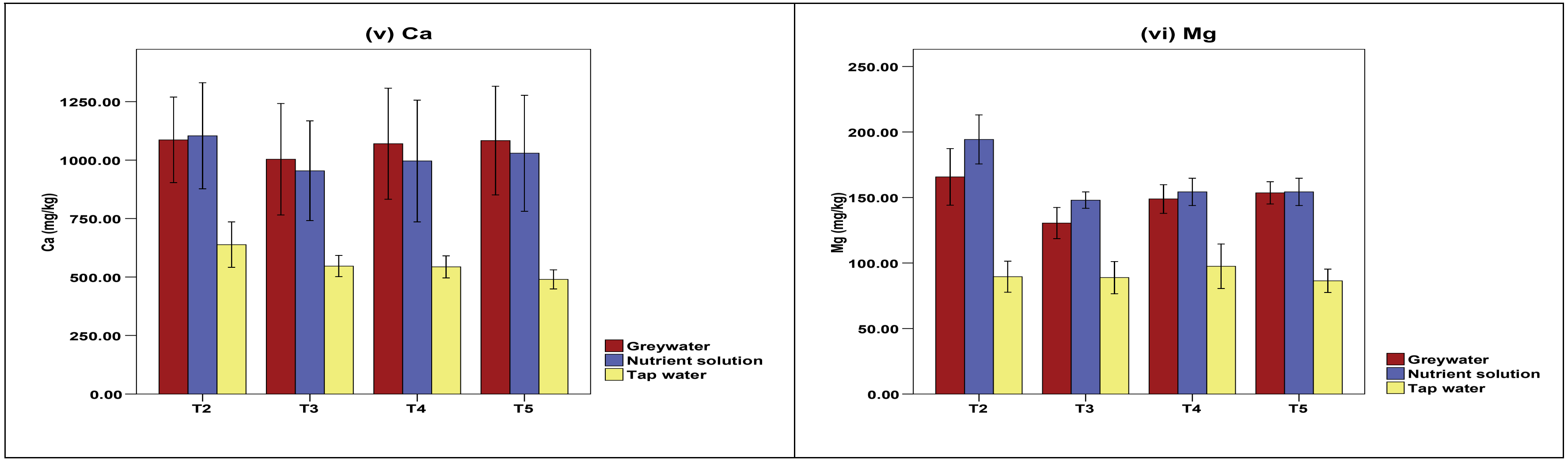


Figure 10 continued: Macronutrient levels in soils irrigated with greywater, nutrient solution and tap water, sampled at the end of the second (T2), third (T3), fourth (T4) and fifth (T5) crop cycles. (v) Calcium (Ca), (vi) Magnesium (Mg). Bars represent arithmetic mean (n =15) and error bars represent the standard error of mean.

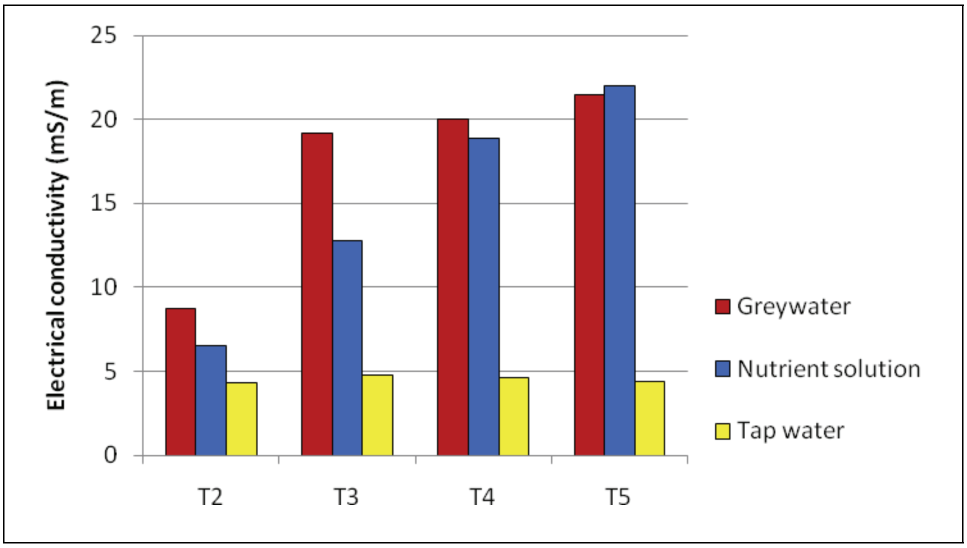


Figure 11: Electrical conductivity of soils irrigated with greywater, nutrient solution water and tap water, sampled at the end of the second (T2), third (T3), fourth (T4) and fifth (T5) crop cycles.

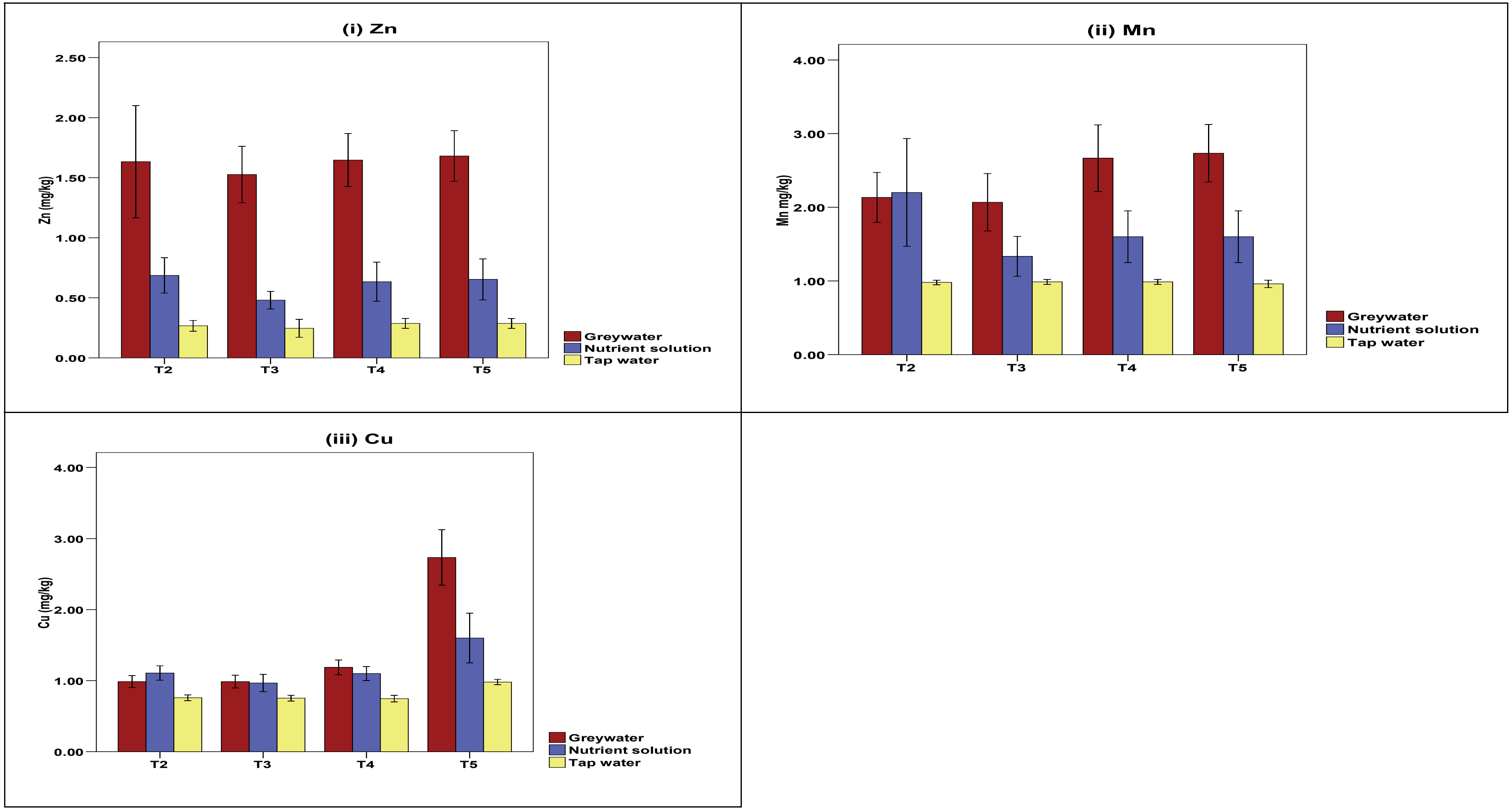


Figure 12*:* Micronutrient levels in soils irrigated with greywater, nutrient solution and tap water, sampled at the end of the second (T2), third (T3), fourth (T4) and fifth (T5) crop cycles. (i) Zinc (Zn), (ii) Manganese (Mn), (iii) Copper (Cu). Bars represent arithmetic mean (n =15) and error bars represent the standard error of mean.

4.6 Health-related soil microbiology

At the start of the experiment and at intervals throughout it, samples of the irrigated soils were analysed for health-related microorganisms as identified in the Methods, together with a limited number of chemical constituents. Mean results are presented in Table 5, with all the microbiological readings presented as $\log_{10}$ values. Greywater-irrigated soil contained high counts of *E. coli*, while the other treatments showed essentially no *E. coli*. By contrast, the other microorganisms did not show marked differences among the three irrigation treatments. It is of interest to note that there was an apparent increase in COD across all the treatments with the tap water treatment showing the greatest increase. This unexpected result warrants future investigation.

Table 5: Mean results of analyses performed on soil throughout the trial (n=20).

Soil sample	COD	Ascaris, Total	Ascaris, Viable	*E. coli*	Enterococci	Staphylococci	Total coliforms
	mg/ℓ	Ova/g	Ova/g	$\log_{10}$ CFU/g			
Baseline soil	118	0.00	0.00	0.00	2.19	3.57	5.32
Irrigated with greywater	299	0.45	0.00	4.12	2.56	3.23	5.50
Irrigated with nutrient solution	365	0.82	0.00	0.00	1.48	3.34	5.22
Irrigated with tap water	781	0.00	0.00	0.00	1.41	3.15	5.27

4.7 Health-related microbiological quality of crops

As for plant growth and plant nutrient data, results are presented only for spinach and carrots. Unlike previously, these two crops were selected here because they represent the two highest risk crops among the above-ground and root crops, respectively, since both may be eaten raw. Root crops in general represent a greater potential health hazard than above-ground crops because prolonged direct contact with irrigation water occurs.

In addition to harvested crops, equivalent crops were purchased from readily available commercial outlets and were similarly examined.

4.7.1 Spinach

There was a wide range of leaf sizes in this crop across the various treatments. This variance meant that the amount of sample examined for each treatment was not always as large as had been expected.

The crops were examined as laid out in Methods. No increase in contamination was found over the growing cycles therefore microbiological data from all growth cycles was combined for analysis.

No *Ascaris* ova, pseudomonads, or coliphage were detected in any of the samples. The remaining micro-organisms varied in concentration. The means of the microbial loads were calculated and comparisons were made using the Mann-Whitney rank correlation test on untransformed data and ANOVA on log-transformed data to determine whether there was a significant difference in microbial loads internally or among treatments. In the figures and tables presented below T, G and H represent plants from the groups irrigated with tap water, greywater and nutrient amended water, respectively. The results are presented in Figure 13 to Figure 16 and Table 6.

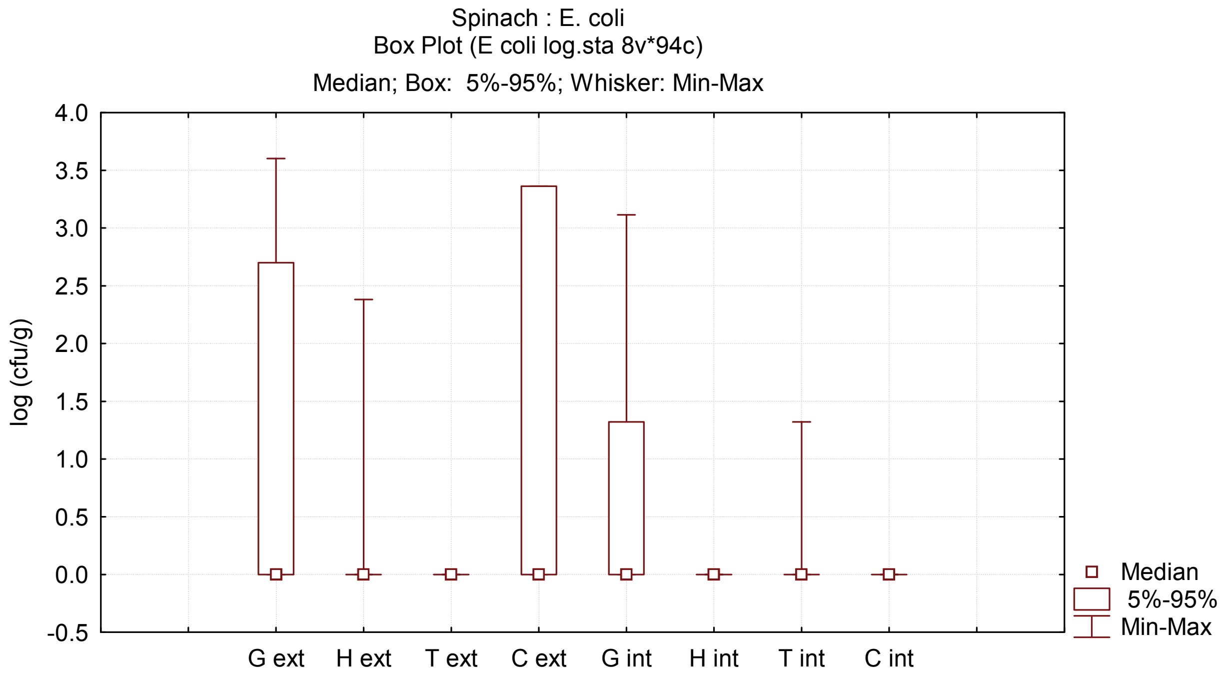


Figure 13: *E. coli* load detected on the exterior surfaces (ext) and interior (int) of spinach irrigated with greywater (G), nutrient amended water (H) and tap water (T), and of commercially sourced spinach (C). Results are based on all samples taken over the experimental period.
(G_{ext}, n=94; H_{ext}, n=93; T_{ext}, n=70; C_{ext}, n=11; G_{int}, n=84; H_{int}, n=84; T_{int}, n=60; C_{int}, n=11)

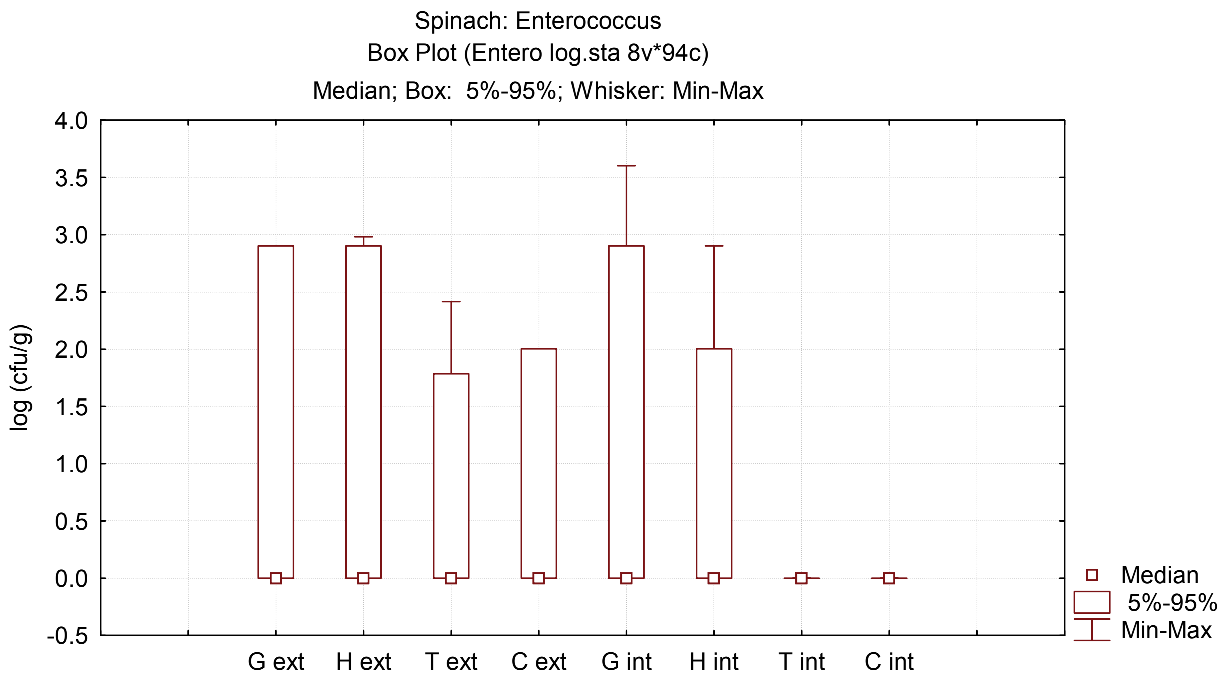


Figure 14: Enterococcus load detected on the exterior surfaces (ext) and interior (int) of spinach irrigated with greywater (G), nutrient solution (H) and tap water (T), and of commercially sourced spinach (C). Results are based on all samples taken over the experimental period.
(G_{ext}, n=101; H_{ext}, n=101; T_{ext}, n=77; C_{ext}, n=8; G_{int}, n=84; H_{int}, n=84; T_{int}, n=60; C_{int}, n=14)

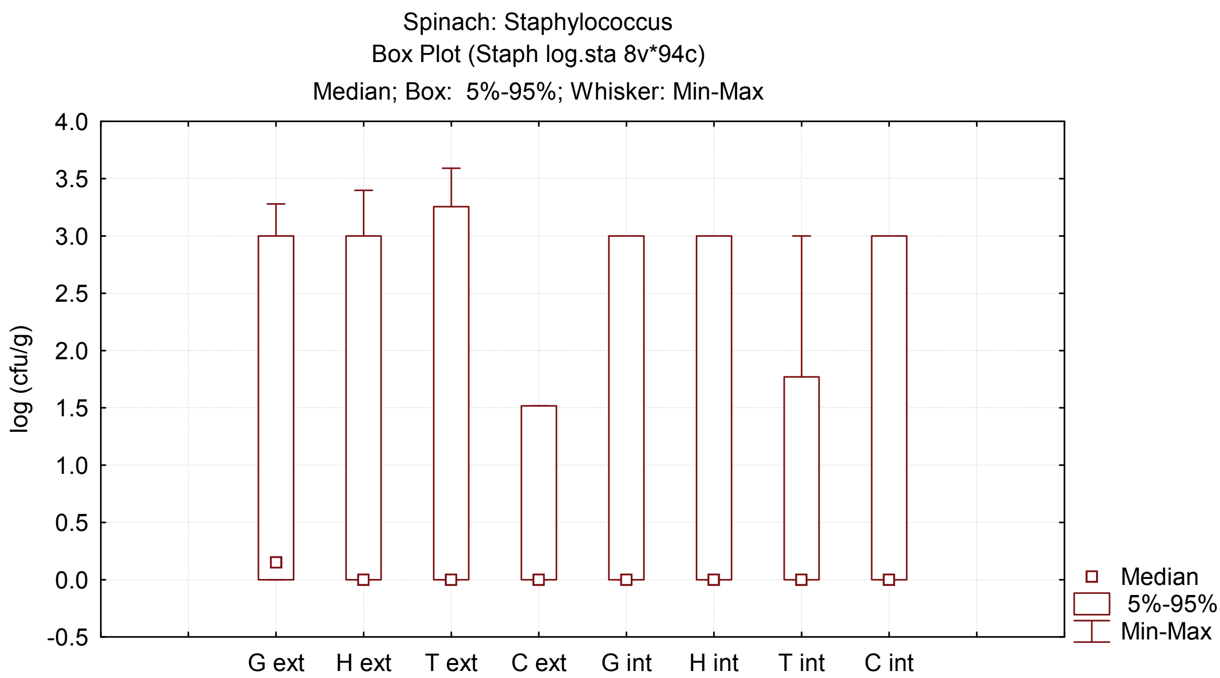


Figure 15: Staphylococcus load detected on the exterior surfaces (ext) and interior (int) of spinach irrigated with greywater (G), nutrient solution (H) and tap water (T), and of commercially sourced spinach (C). Results are based on all samples taken over the experimental period.
(G_{ext}, n=94; H_{ext}, n=95; T_{ext}, n=70; C_{ext}, n=8; G_{int}, n=84; H_{int}, n=84; T_{int}, n=60; C_{int}, n=14)

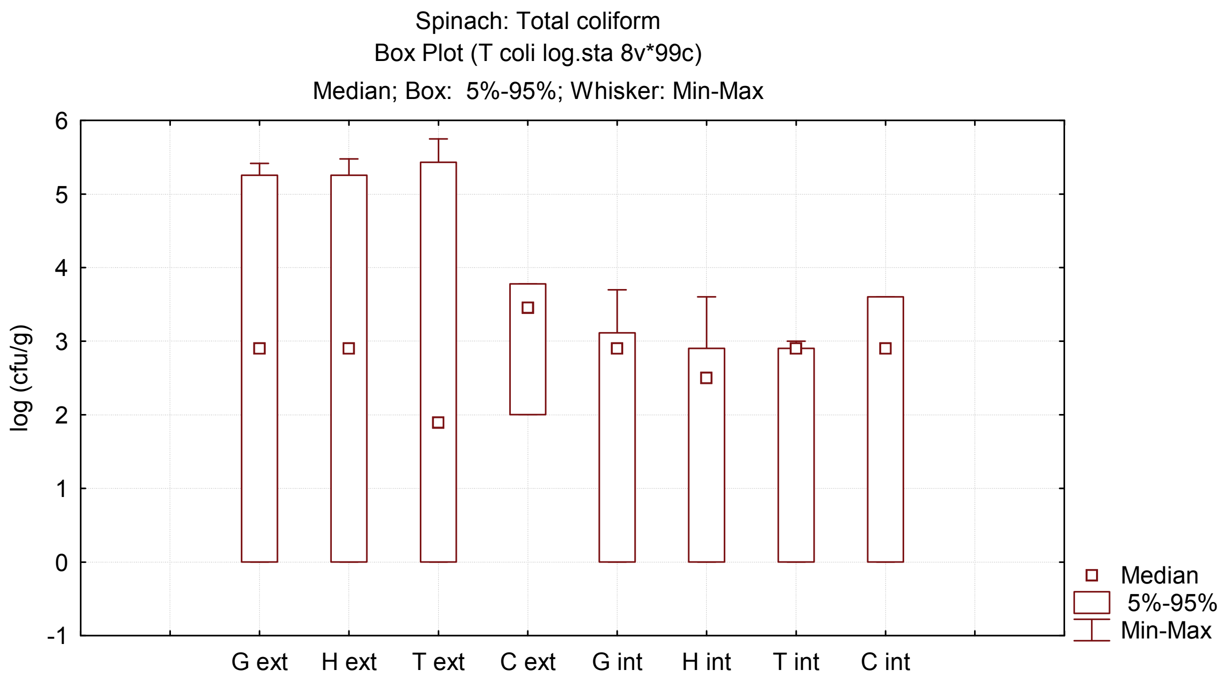


Figure 16: Total coliform load detected on the exterior surfaces (ext) and interior (int) of spinach irrigated with greywater (G), nutrient solution (H) and tap water (T), and of commercially sourced spinach (C). Results are based on all samples taken over the experimental period.
(G_{ext}, n=94; H_{ext}, n=94; T_{ext}, n=70; C_{ext}, n=8; G_{int}, n=84; H_{int}, n=84; T_{int}, n=60; C_{int}, n=14)

As a result of the large number of nil detections for both *E. coli* and *Enterococcus*, these determinands did not fit a log-normal distribution. It can be seen from the non-parametric statistical evaluation that there was no significant difference in bacterial loading for spinach across the three treatments except for *Enterococcus* where the external loading of greywater-irrigated plants was higher than for commercially purchased plants. This could be as a result of the commercial produce being washed before sale. When the statistics from the normalised data were examined, it appeared that greywater irrigation had significantly increased the *E. coli* load on the exterior of the crop. This could be an artefact of the poor fit to the normal distribution, or could be related to the relatively higher counts of *E. coli* detected in greywater-irrigated soil (Table 5). For *Staphylococcus* and total coliforms, the normalised distribution showed a significant increase in loading for greywater-irrigated crops over tap water irrigated crops except for interior detection of total coliforms. The statistical comparison is presented in Table 6.

Table 6: Statistical comparison of mean microbial loads detected on the exterior surfaces (ext) and interior (int) of spinach irrigated with greywater (G), nutrient solution (H) and tap water (T), and of commercially sourced spinach (C) (p≤0.05).

		E. coli		Enterococcus		Staphylococcus		Total coliform	
		External	Internal	External	Internal	External	Internal	External	Internal
Mann-Whitney	G *vs* H	ND	ND	ND	ND	ND	ND	ND	ND
	G *vs* T	ND	ND	ND	ND	ND	ND	ND	ND
	G *vs* C	ND	ND	G>C	ND	ND	ND	ND	ND
ANOVA on log data	G *vs* H	G>H	G>H	ND	ND	ND	ND	ND	ND
	G *vs* T	G>T	ND	ND	ND	G>T	G>T	G>T	ND
	G *vs* C	G>C	ND	ND	ND	ND	ND	ND	ND

ND = No significant difference detected

4.7.2 Carrots

Data for the health-related microbiological quality of carrot crops were found to fit a log-normal distribution where sufficient non-zero data were available. No significant differences in bacterial load were seen across growth cycles so data were combined across growth cycles for analysis. Except for total coliforms, the median bacterial load was low for all treatments, although in some cases the range was wide. No enterococci were found internally for any of the samples. The results are presented in Figure 17 to Figure 20.

Greywater-irrigated carrots crops had significantly higher external loadings than carrots irrigated with nutrient solution and commercially obtained crops, but not for tap water-irrigated crops. Internally, the greywater-irrigated crop had significantly higher loading than carrot crops irrigated with nutrient solution or tap water, but there was no significant difference from commercially obtained produce except for staphylococci where the commercial crop showed higher internal loading (Table 7). The loading of total coliforms was high and the expectation that carrots would be a high risk produce was therefore supported.

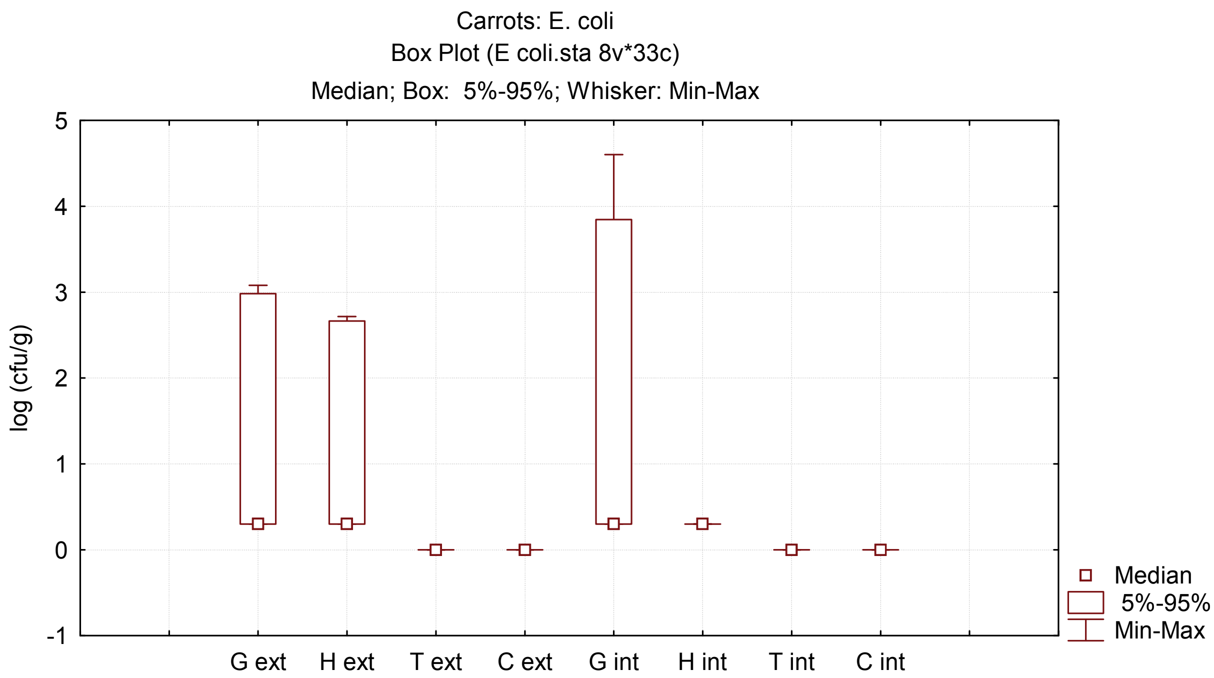


Figure 17: *E. coli* load detected on the exterior surfaces (ext) and interior (int) of carrots irrigated with greywater (G), nutrient solution (H) and tap water (T), and of commercially sourced spinach (C). Results are based on all samples taken over the experimental period.
(G_{ext}, n=25; H_{ext}, n=31; T_{ext}, n=26; C_{ext}, n=6; G_{int}, n=27; H_{int}, n=29; T_{int}, n=26; C_{int}, n=11)

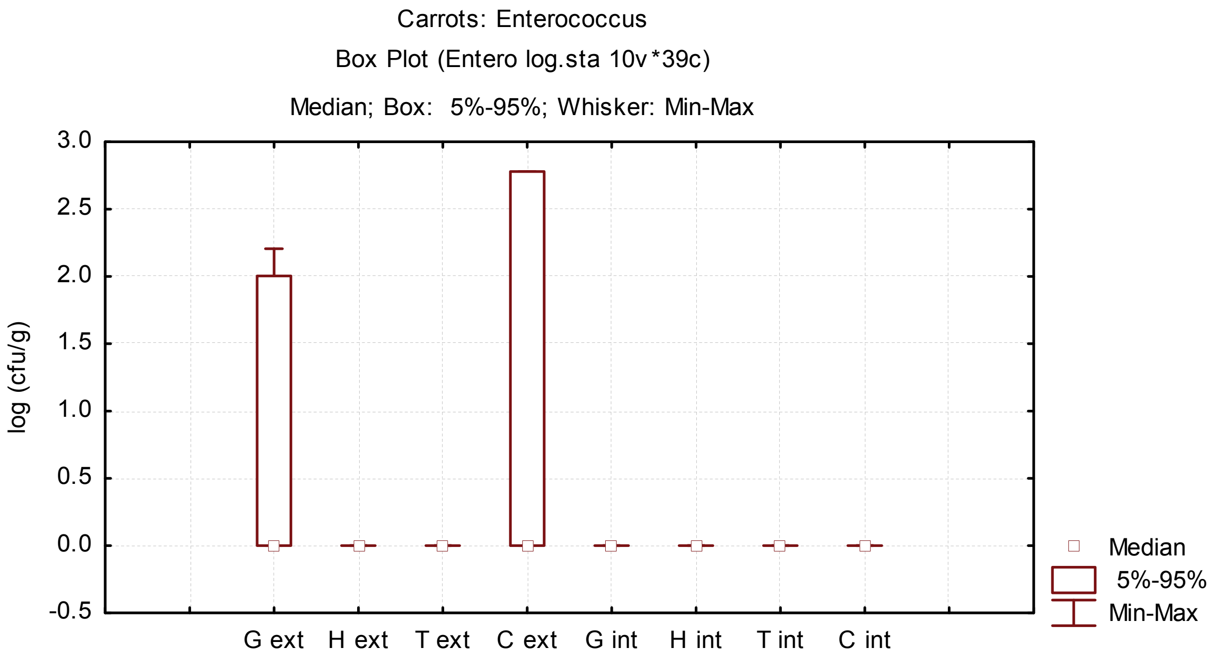


Figure 18: Enterococcus load on the exterior surfaces (ext) and interior (int) of carrots irrigated with greywater (G), nutrient solution (H) and tap water (T), and of commercially sourced spinach (C). Results are based on all samples taken over the experimental period.
(G_{ext}, n=25; H_{ext}, n=31; T_{ext}, n=26; C_{ext}, n=6; G_{int}, n=25; H_{int}, n=31; T_{int}, n=26; C_{int}, n=12)

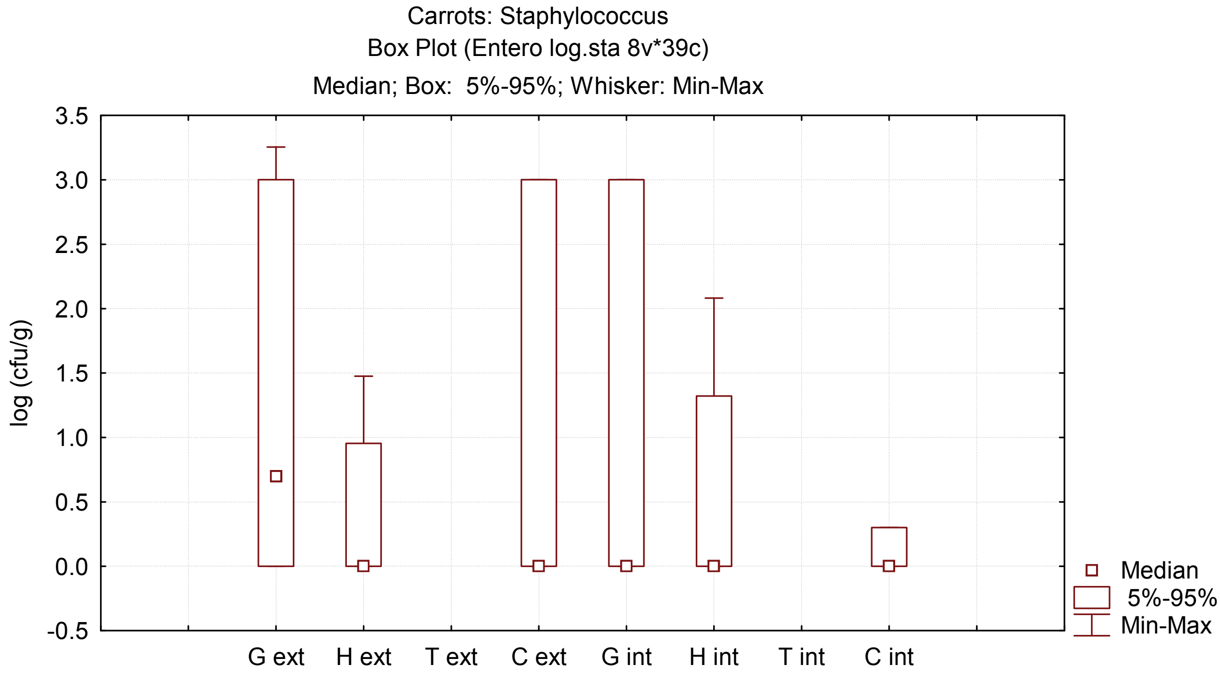


Figure 19: Staphylococcus load on the exterior surfaces (ext) and interior (int) of carrots irrigated with greywater (G), nutrient solution water (H) and tap water (T), and of commercially sourced spinach (C). Results are based on all samples taken over the experimental period.
(G_{ext}, n=25; H_{ext}, n=31; T_{ext}, n=26; C_{ext}, n=11; G_{int}, n=25; H_{int}, n=31; T_{int}, n=26; C_{int}, n=6)

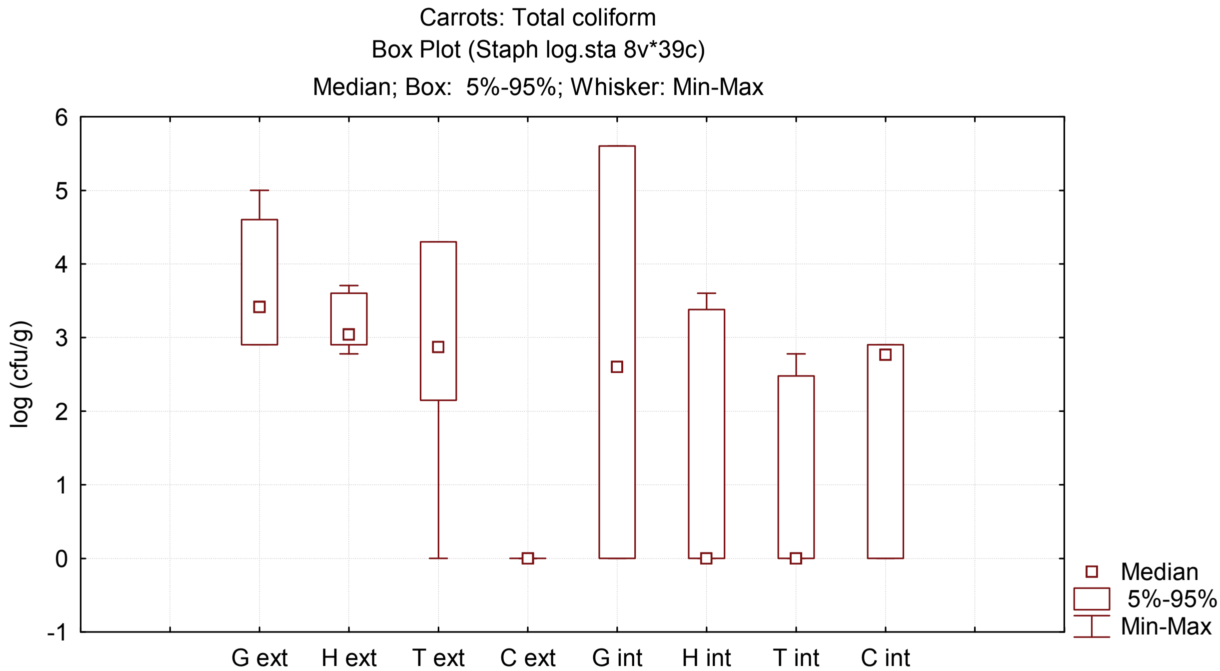


Figure 20: Total coliform load on the exterior surfaces (ext) and interior (int) of carrots irrigated with greywater (G), nutrient solution (H) and tap water (T), and of commercially sourced spinach (C). Results are based on all samples taken over the experimental period.
(G_{ext}, n=25; H_{ext}, n=31; T_{ext}, n=26; C_{ext}, n=6; G_{int}, n=25; H_{int}, n=31; T_{int}, n=26; C_{int}, n=11)

Table 7: Statistical comparison of mean microbial loads detected on the exterior surfaces (ext) and interior (int) of carrots irrigated with greywater (G), nutrient amended water (H) and tap water (T), and of commercially sourced spinach (C).

		E. coli		Enterococcus		Staphylococcus		Total coliform	
		External	Internal	External	Internal	External	Internal	External	Internal
Mann-Whitney	G *vs* H	ND	ND	ND	-	ND	ND	ND	ND
	G *vs* T	ND	ND	ND	-	ND	ND	ND	ND
	G *vs* C	G>C	ND	ND	-			ND	ND
ANOVA on log data	G *vs* H	ND	G>H	ND	-	G>H	ND	G>H	G>H
	G vs T	G>T	G>T	ND	-	G>T	ND	ND	G>T
	G *vs* C	ND	G>C	ND	-	G>C	C>G	G>C	ND

ND = no significant difference detected

4.8 Health risk assessment: Consumption of carrots Irrigated with greywater

A health risk assessment was performed for carrots only. This crop was regarded as the highest risk crop choice as it is a root that penetrates deeply into the irrigated soil and, in addition, is frequently eaten raw as a salad vegetable or even directly from the ground with skin intact.

Bacterial loading data were fitted to a best-fit distribution using the @RISK distribution fitting function and the chi-squared non-parametric test for goodness-of-fit. As total coliforms provided the most non-zero data, this indicator was used for further calculations as a conservative estimator. A factor of 0.001 was used for the likelihood of pathogens being present at a given level of total coliforms. The amount of the vegetable consumed daily and the percentage of the population likely to consume that amount was taken from the data presented by Nel and Steyn (2000).

The highest health risk to the consumer is represented by eating the vegetable raw, unpeeled and unwashed although with soil brushed off. For this scenario, the risk was calculated using a β-Poisson model for probability of infection (P_{inf}) where the model parameter α was taken to be 0.21 and the parameter β was taken to be 42.86 in accordance with the figures given for *Salmonella* by Soller (2006). These figures are considered to be conservative and likely to give a good representation for either bacteria or virus.

The cumulative frequency for risk of infection associated with consumption of unwashed commercially obtained crop is presented in Figure 21. The 95^{th} percentile (generally accepted as a conservative upper limit on risk) is 9.4×10^{-5}, or 9.4 excess infections in a population of 100 000.

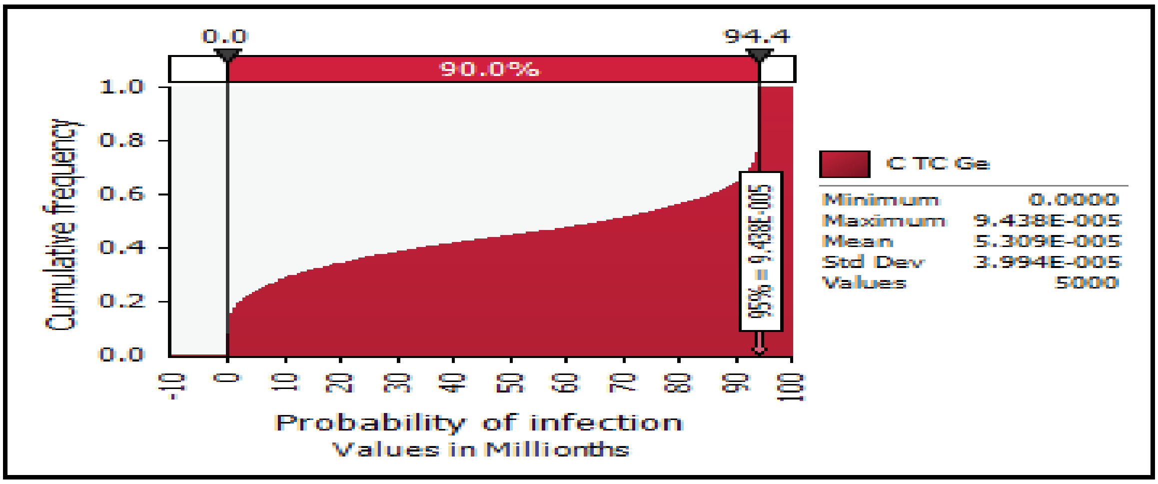


Figure 21: Ascending cumulative distribution of risk of infection for the daily consumption of washed and peeled carrots obtained commercially. The 95th percentile is shown as a vertical block on the graph.

The cumulative risk of infection for consumption of greywater-irrigated crops is presented in Figure 22. The 95th percentile of risk is 6.1×10^{-3} (6.1 infections in 1 000).

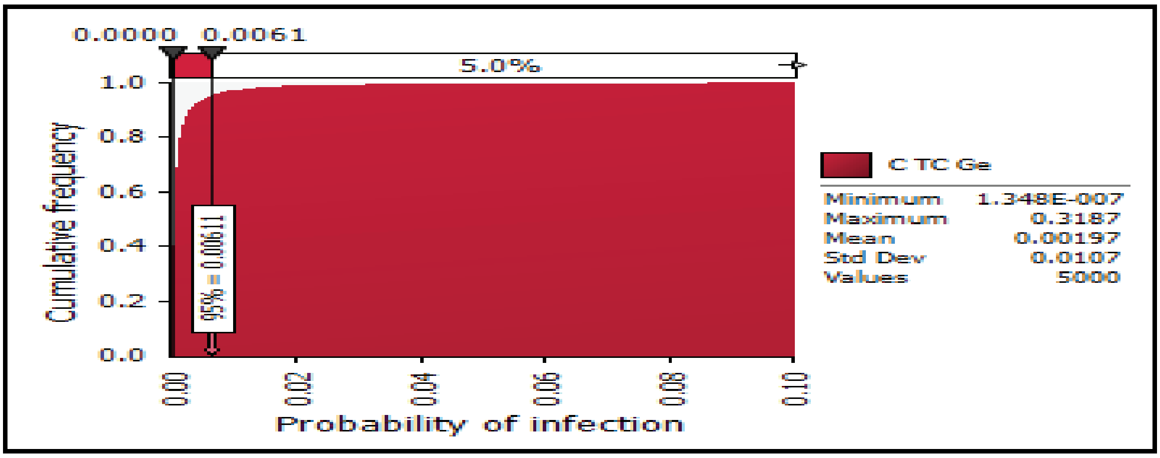


Figure 22: Ascending cumulative distribution of risk of infection for the daily consumption of raw, unwashed, unpeeled carrot irrigated with greywater. The 95th percentile is shown as a vertical block on the graph.

It is apparent that there is an approximately three orders of magnitude difference in risk between the two scenarios. However, the risk of infection associated with consumption of raw greywater-irrigated crop can be reduced by taking very basic precautionary measures such as peeling, washing or cooking. Log reductions resulting from these actions were taken from the data produced by the World Health Organisation (WHO, 2006). If the vegetable is washed and peeled, a 3-log reduction could be expected whereas if it was boiled until cooked a 6-log reduction was indicated. The cumulative frequency distributions for these exposure scenarios are shown in Figure 23 and Figure 24, respectively. The 95th percentile of risk of infection associated with consumption of greywater-irrigated carrots after washing and peeling reduces to 6.0×10^{-5} (6 infections per 100 000). That associated with greywater-irrigated carrots which have been cooked reduces to 6.2×10^{-7} (6.2 infections per 10 000 000).

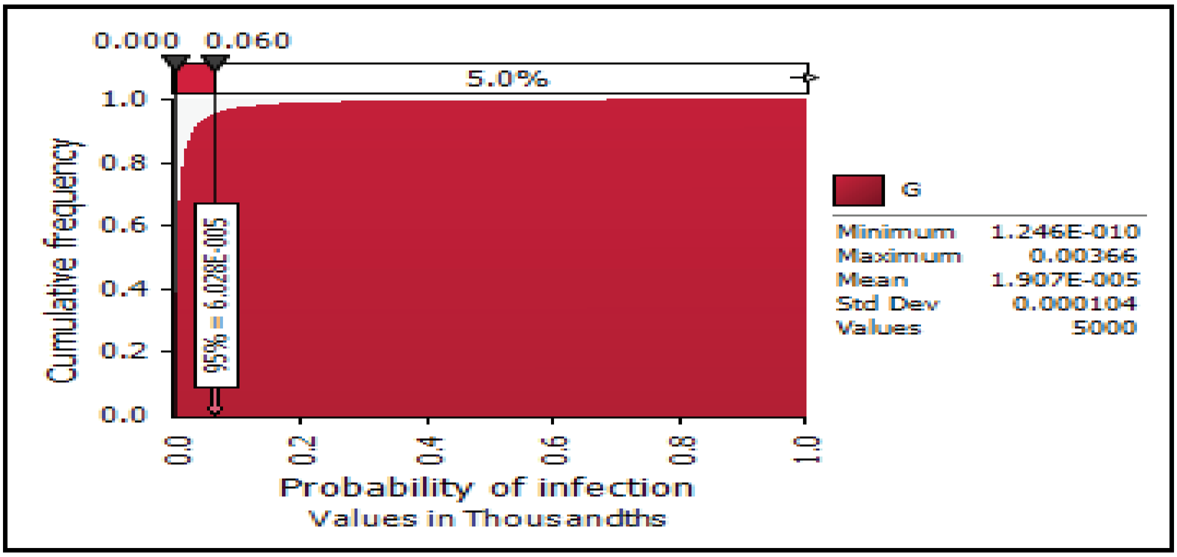


Figure 23: Ascending cumulative distribution of risk of infection for the daily consumption of washed and peeled carrots. The 95th percentile is shown as a vertical block on the graph.

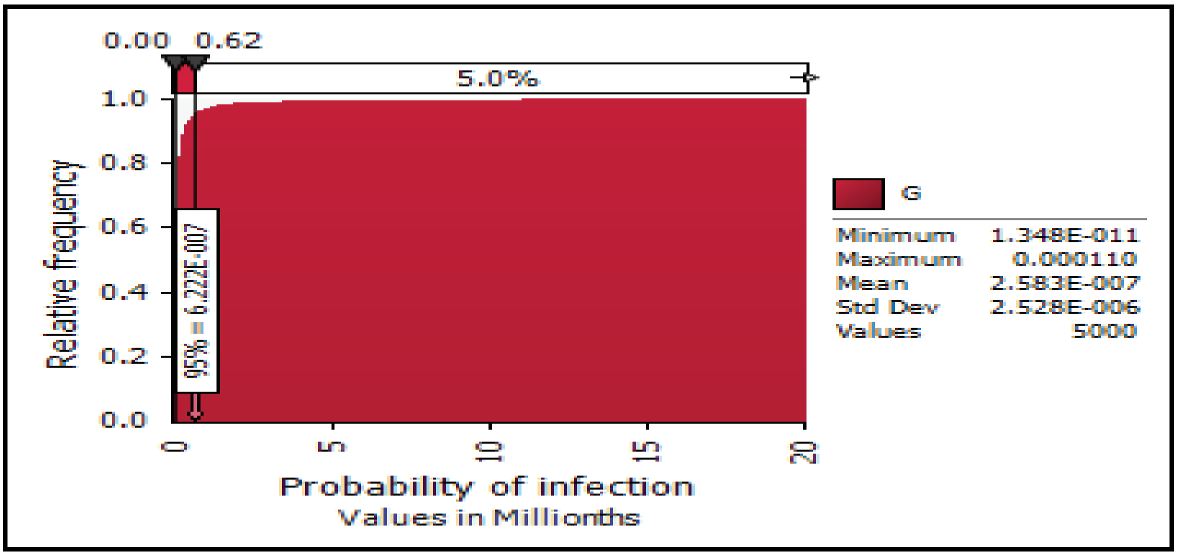


Figure 24: Ascending cumulative distribution of risk of infection for the daily consumption of boiled carrots. The 95th percentile is shown as a vertical block on the graph.

5. Discussion

Comparison of the quality of mixed domestic greywater from eight households in an informal settlement to the South African Water Quality Guidelines (SAWQG) for irrigation (Table 2) shows that only pH and total nitrogen fell outside the maximum range. Of these, nitrogen is not necessarily a disadvantage since the SAWQG assume that plant nutrient needs are met by fertiliser and that irrigation water adds nutrients in excess of this. In small-scale irrigation, it is most likely that no fertiliser would be added. Sodium levels were in the upper end of the maximum range. Comparing greywater quality from this study to literature values presented in the main body of the Technical Report, it can be seen that values for most constituents are higher, with the exception of calcium and magnesium. Since calcium and magnesium counteract the effect of sodium, the lower concentrations of these ions relative to sodium in the present study points to a potential exaggerated effect of sodium in the greywater tested. In terms of chemical and physical properties, this suggests that greywater from low income informal settlements in South Africa is of relatively lower quality than recorded in the literature, as previously reported by Carden *et al.* (2007). However, comparison of microbial quality of the greywater used in this study (Table 3) to international data showed that levels of microbial contamination were similar or only slightly higher. This differs from results reported by Carden *et al*. (2007) in a wider survey of greywater quality in South Africa.

Investigation of the growth of crops irrigated with greywater, in comparison with irrigation with nutrient solution water or with tap water, showed that irrigation greywater yielded growth similar to irrigation with water amended with a balanced plant nutrient source. Yield was not boosted as much as growth, but was also increased relative to tap water irrigation alone. These results are in contrast with those of Pinto *et al*. (2010) who report no increase in plant biomass with greywater irrigation compared with irrigation with potable water. The difference probably relates to the extremely low inherent nutrient levels in the soil used in the present study, and consequently extremely poor growth of plants irrigated with tap water.

Crops of plants irrigated with greywater showed higher levels of major plant macronutrients than was observed in plants irrigated with tap water. A similar trend was seen for plants irrigated with nutrient solution. Analysis for micronutrients revealed that all crops irrigated with greywater showed increased levels of sodium, and that sodium levels increased with successive growth cycles on the same soil. Furthermore, other micronutrients, especially metals, were also present at elevated levels in greywater-irrigated crops, particularly root crops, relative to crops irrigated with other treatments. This effect, too, increased with successive growth cycles on the same soil. Thus while greywater irrigation improved the nutrient status of plants, indications are that some nutrients can potentially accumulate to toxic levels. Al-Hamaiedeh and Bino (2010), reporting on quality of crops irrigated with treated greywater in Jordan, found no evidence of adverse effect on the chemical properties of the greywater-irrigated crops relative to the same crops irrigated with fresh water. Nutrient levels were broadly similar, with slight elevation of nitrogen, phosphorus and sodium in the fruit, but not the leaves, of olive trees. This trend is similar to, although less pronounced than, trends observed in the present study.

Greywater-irrigated soil showed increasing electrical conductivity with time, suggesting accumulation of salts, especially sodium. Accumulation of sodium in soil is of greater significance than direct plant toxicity alone: sodium contributes to soil salinity which makes it more difficult for plants to take up water from soil, and soil sodicity which means that soil structure changes in ways that makes it less able to support plant growth by several mechanisms (DWAF, 1996). Metal ions analysed in greywater-irrigated soil also increased in concentration with time. Thus soil appeared to exhibit the same accumulation of sodium and metals as crops, which explains increasing levels of these in greywater-irrigated crops over time. Other studies on long-term irrigation with reclaimed water also indicated that salts (Pinto *et al*., 2010) and metals (Madyiwa *et al*., 2004) accumulated in soil, with subsequent potential for uptake by plants (Madyiwa *et al*., 2004). However, Pinto *et al.* (2010) demonstrated that this accumulation could be counteracted by alternating irrigation with greywater and with fresh water. By contrast, Gross *et al*. (2005) reported no increase in metals and soil electrical conductivity, and only slight increase in SAR, when comparing soil irrigated with greywater and soil irrigated with a fertiliser solution. However, these authors, as also Travis *et al*. (2010), noted an increase in boron and surfactants in greywater-irrigated soil.

Investigation of the levels of health-related micro-organisms on the exterior and in the interior of greywater-irrigated produce revealed that median levels of all micro-organisms on this produce were nil or near nil except for total coliforms, although counts for *E. coli*, enterococci and staphylococci did range widely. Statistical testing of the difference in counts among greywater-irrigated crops, crops irrigated with nutrient solution, crops irrigated with tap water and commercially sourced crops showed that greywater irrigation resulted in significant elevation of *E. coli* and total coliforms. These differences were detectable only when tested by 1-way ANOVA, not by the less stringent non-parametric Mann-Whitney test. However, ANOVA was not an appropriate method of comparison in all cases since not all data distributions met the assumptions of the test. Thus occasional excess contamination by faecal micro-organisms (indicated by *E. coli*) or microorganisms of general sanitary relevance (indicated by total coliforms) does occur during irrigation of crops with greywater, although generally microbial loads are similar to crops not irrigated with greywater. It should be noted that relatively high loads of particular total coliforms were detected intermittently on all crops tested, including commercially sourced crops.

Any increase in microbial loading on greywater-irrigated produce represents a potential hazard, since risk of infection in consumers of crops can be driven by only a single exposure to a high load of potentially pathogenic organisms. This is in contrast to risks to plant growth, crop yield and quality, and soil characteristics, which are related to medium to long term exposure and are resilient to isolated instances of increased exposure. Therefore, a quantitative microbial risk assessment of consumption of greywater-irrigated crops was performed.

The highest health risk to the consumer would be in eating the vegetable raw, unpeeled and unwashed although with soil brushed off. For unwashed commercially obtained carrots (representative upper risk crop), the 95th percentile of this risk was 9.4×10^{-5}, or 9.4 infections in 100 000. This equates to 0.94 infections per 10 000 and is approximately the same as the acceptable limit for risk of infection accepted by the

United States Environmental Protection Agency (US EPA) and the WHO, namely 10^{-4} or 1 excess infection in a population of 10 000 (WHO, 2006). For unwashed greywater-irrigated carrots, the 95th percentile of risk was 6.1×10^{-3}, or 61 infections per 10 000, considerably above the limit of 10^{-4} (1 infection per 10 000).

Two possible interventions were considered to reduce exposure associated with crop consumption: washing and peeling before consumption, and cooking before consumption. The 95th percentile of risk of infection associated with consumption of greywater-irrigated carrots after washing and peeling reduced to 6.0×10^{-5} (0.6 infections per 10 000). That associated with greywater-irrigated carrots which have been cooked reduced to 6.2×10^{-7} (0.006 infections per 10 000). Both of these risks are well below the limit of 10^{-4} (1 in 10 000). Therefore consuming the highest risk vegetable irrigated with the greywater, as investigated in this study, did not present an unacceptable risk to consumers provided certain precautions are taken in the preparation for consumption. This approach is in line with that advocated by the WHO (WHO, 2006) which recognises that risks to consumers can be reduced by a combination of mitigation measures.

The total restriction on growing root crops with greywater irrigation, as is commonly accepted in guidelines for the use of various types of wastewater for crop irrigation, thus appears to be excessively restrictive. However, guidelines on the handling of the crop for consumption would be required, and such root crops should not be eaten raw unless they have been thoroughly washed and peeled. The health risks presented by other crops investigated was found to be similar in nature and could be reduced to acceptable levels through the use of very simple measures.

6. Conclusions

- Greywater irrigation increases plant growth and crop yield.
- Greywater irrigation is associated with improved plant nutrient content.
- Greywater irrigation can lead to accumulation of sodium and metals in soil with time, and hence in plant crops.
- Greywater irrigation increases electrical conductivity over time, indicating that it can increase soil salinity and sodicity in time.
- Greywater irrigation can increase microbial loads on plants, although of the micro-organisms investigated, only *E. coli* and total coliforms showed significant increases.
- Greywater irrigation increases health risks associated with consumption of unwashed raw crops, but this risk can be reduced to within acceptable limits by simple precautions such as washing and peeling, or cooking, crops prior to consumption.

7. Acknowledgements

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Case Study 2
Consultative Process Supporting Development of Guidance Report

1. Up-front consultative process

1.1 Aims

The aim of this study was to engage three levels of thought about greywater use, in order to inform the development of guidance for the use of greywater for irrigation. The three levels comprised:

- National policy- and decision-makers
- Regional and local authorities
- Settlements generating, and potentially using, greywater.

1.2 Methods

This section of the report describes the consultative process undertaken to characterise current knowledge and practices regarding greywater generation, disposal and use throughout South Africa.

The consultative process occurred at three levels in order to engage the broadest possible range of decision-makers and users. Separate consultative processes were employed at each level since different concerns were expected to drive thinking about greywater at each level.

1.2.1 National level consultation

A workshop was held with policy-makers and decision-makers in the fields of water management, health and agriculture. The Departments invited to send representatives to the workshop included Department of Water Affairs and Forestry, Department of Health, Department of Environmental Affairs, Department of Science and Technology, and Department of Agriculture. Representatives of consultants and NGOs were also invited. Unfortunately, attendance at the workshop was lower than desirable.

The aims of this workshop were:

- To determine the extent to which greywater use and management are provided for within current legislation and guidelines on water quality, water use and small-scale agriculture.
- To allow decision-makers to define their needs in terms of guidelines for greywater use.
- To sensitise national level bodies to the need for understanding of social issues involved in greywater use, which greatly impact the success of any technical interventions which might be undertaken.

- To identify gaps in the current research available, both nationally and internationally, to guide decision-making on greywater use.

Participants were guided through the agenda and objectives of the workshop by means of PowerPoint slides, which were used as the focus of discussions.

1.2.2 Regional and local authority level consultation

A large number of regional authorities and municipalities were initially selected for survey by questionnaire, using information from the South African Local Government Association (SALGA). Municipalities were contacted by telephone, email and fax to identify the person responsible for wastewater management. Co-operation in the survey by completion and return of a questionnaire was requested. The questionnaire was designed to elicit information on issues such as extent of water and sanitation service delivery; volumes of water supplied to communities; expected greywater return volumes; expected fate of greywater at present; possible greywater practices and management systems; and the capacity of municipalities to adopt and execute greywater use. The full questionnaire is presented at the end of this Case Study Report (Section 4.1).

Because of poor initial response rates, SALGA and eThekwini Municipality Water and Sanitation were approached to assist in compiling a shorter list of municipalities from which a response was likely to be received. This resulted in consultation at this level involving predominantly larger municipalities where there was some awareness of greywater issues in the management of water and sanitation.

1.2.3 Settlement level consultation

A total of six settlements were surveyed (Table 8). The criteria for community selection were as follows:

- Low income settlements
- *Either* sewered *or* provided with on-site sanitation in a structured implementation (since non-sewered and informal communities have already been surveyed in WRC Project No. 1524)
- Representative of differing geographic, climatic and geological conditions
- Good rapport with, and logistical support from, the relevant local authority.

Consultation at this level aimed to describe greywater generation and use at household levels. Specifically, greywater generation in low-income settlements was quantified in settlements *with* some kind of structured sanitation provision, in order to compare this to the decision tree for greywater management developed by Carden *et al.* (2007) for settlements *without* sanitation provision (WRC Project No. 1524).

Table 8: Location of, and service provision in, settlements surveyed with respect to greywater use and generation habits.

Municipality and Region	Settlement	Type of water and sanitation provision	Reason for inclusion in study
eThekwini Municipality (KwaZulu-Natal, Durban)	Mntamntengayo	Community Tank (water) Urine Diversion (UD) toilets	Structured on-site sanitation delivery program
eThekwini Municipality (KwaZulu-Natal, Durban)	Siyanda	Roof tank/Stand pipe Pour flush (toilet)	Sewered; coastal; summer rainfall
eThekwini Municipality (KwaZulu-Natal, Durban)	Sawpitts	Yard tap/Ground tank UD (toilet)	Structured on-site sanitation delivery program
Ekurhuleni Municipality (Gauteng, East Rand)	Barcelona	Yard tap Pour flush (toilet)	Sewered; inland on dolomitic rock; summer rainfall
Ekurhuleni Municipality (Gauteng, East Rand)	Kingsway	In-house tap Pour flush (toilet)	Sewered; inland on dolomitic rock; summer rainfall
Worcester (Western Cape)	Zwelethemba, Worcester Coloured, Worcester coloured (Roodeville), Esselen Park, Roodewal (selection of formal dwellings)	Formal dwellings, on-site water and sanitation provision	Sewered; coastal; winter rainfall

Once the settlements were selected, meetings were held with local councillors and/or community liaison officials to obtain consent to administer questionnaires. Households were randomly chosen for interview. Interviews were conducted where householders were present and informed consent to participate was obtained.

The questionnaire used in this study was closely based on that used by researchers from UCT in WRC Project No. 1524, to ensure that data from that project could be used to inform the present project regarding greywater generation and management in non-sewered and informal communities. The questionnaire was translated into local languages with the assistance of language departments in local Universities. The questionnaire was designed to source information on general greywater generation and reuse practices, community perceptions of greywater use and general site characteristics. It is presented in full at the end of this Case Study Report (Section 4.2).

Data collected in the questionnaire survey were captured matching the data entry format as closely as possible to that used in WRC Project No. 1524. The database of survey information collected in that project was obtained from Ms Kirsty Carden at UCT and data from both projects were consolidated as far as possible.

Qualitative data were used to develop a description of greywater generation and use in the settlements. Quantitative data on water use and greywater returns was used to calculate the *greywater generation rate*, a measure developed by Carden *et al*. (2007) to guide decisions regarding the management of greywater at settlement level.

The equation for greywater generation rate (Q) was used, as defined by Carden *et al*. (2007) and given in the main body of the Technical Report as Equation 1. The volume of greywater generated was obtained using means estimated of water use for each community, multiplied by 0.75 since a greywater return of 75% was deemed representative by Carden *et al.* (2007). Estimation of the density of dwelling units was performed either by using aerial photographs provided by the local authorities or by using satellite images available on Google Earth (www.googleearth.com), whichever source was the more recent and provided the better resolution for counting households. Aerial images of the communities were located using GPS coordinates recorded for each household during the survey, using hand-held GPS devices. Blocks of size 1 ha (100m×100m) were demarcated on the satellite images and the roofed structures within the blocks counted to give number of dwelling units per hectare. This procedure was repeated four times per settlement and the mean value taken.

Estimates of mean daily water consumption, dwelling unit density and calculated greywater generation rate G) were compared across non-sewered settlements (reported by Carden *et al*., 2007), and the sewered communities. G values for each community were compared and categorized as per the *greywater management decision tree* developed by Carden *et al.* (2007) for unsewered settlements. This is shown in as Figure 1 in the main body of the Technical Report and is repeated here for convenience as Figure 25.

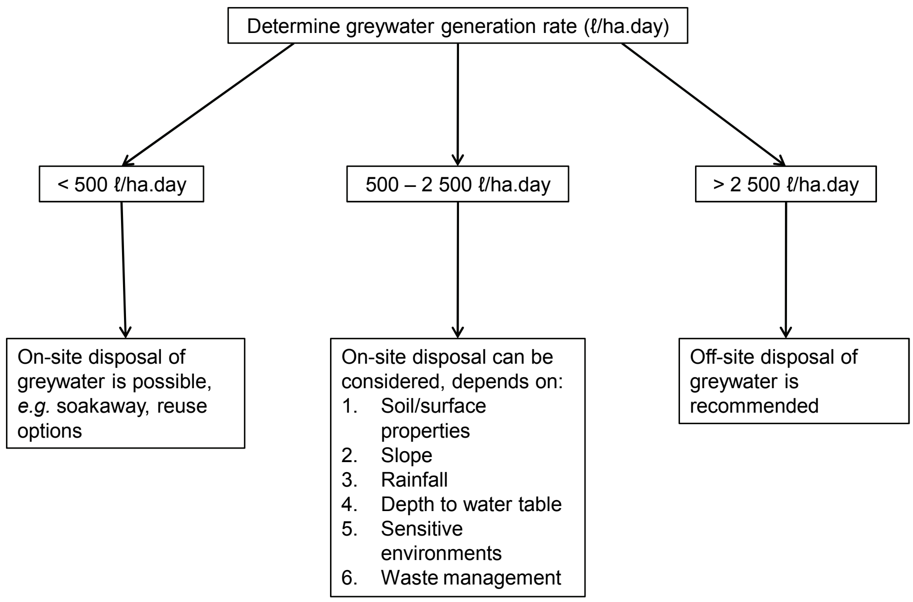

Figure 25: Decision tree for determining appropriate greywater management options, linked to greywater generation rate (from Carden *et al.*, 2007)**.**

1.3 Results and discussion

To review, the three levels of consultation comprised:

- National policy- and decision-makers
- Regional and local authorities
- Communities generating, and potentially using, greywater.

1.3.1 National level consultation

The workshop served to elicit information that helped guide the lower levels of the study, by identifying the issues of concern among policymakers. Views expressed at the workshop are listed below.

Introduction/background

A need was identified for socially relevant technically feasible scientifically-based guidelines for South Africa. It was recognised that this had been hampered to date by uncertainty about the risks associated with, and acceptability of, greywater re-use. This meant that it is uncertain whether greywater use should be promoted, discouraged or otherwise regulated.

Existing relevant legislation, guidelines and practices

The Department of Water Affairs and Forestry listed documents of relevance to greywater, including the Water Services Act, (WSA, Act 108 of 1997), the National Water Act (NWA, Act 36 of 1998), and the Strategic Framework for Water Services (DWAF, 2003). The NWA suggests that greywater use should constitute a controlled activity; but greywater is not specifically mentioned. In the Strategic Framework, the word 'greywater' is also not specifically used. It was questioned whether greywater falls within the definition of sanitation. Workshop participants highlighted that it would be important for any guidance for greywater use to establish a common understanding of greywater definition.

It was pointed out that there are existing greywater guidelines which deal with higher-income households (Australia – New South Wales, USA – Arizona and California) and these could be very useful in the drafting of guidance for fully serviced middle to high-income households in South Africa. The greater challenge would be posed by low-income settlements where there could be a desire to use greywater for income-producing purposes (*i.e.* risks are greater). It would be imperative to ensure that there are sufficient risk barriers in place in poorly managed systems to prevent environmental and health impacts.

It was commented that certain areas in South Africa are heavily reliant on groundwater and the potential for pollution of aquifers by greywater should be considered when compiling greywater irrigation guidance. Pollution of aquifers at Merrydale, Northern Cape and consequent pollution of boreholes was cited as an example.

Any guidance or policy would have to balance the dual forces of technological (including local geohydrological) factors and social imperatives. It was acknowledged that this posed a significant challenge.

It was commented that it is in the nature of society that it is impossible to control or regulate much of the greywater reuse. Reuse is part of survival strategies. There were concerns about the wide variety of behaviour regarding the use of water – hence also greywater. It was recognised that where greywater irrigation was practised on an *ad hoc* household level, applying any form of regulation would be unlikely to be successful. Only at settlement level and upwards would any kind of significant impact be likely.

It was noted that in many impoverished communities there are home-based “cottage” industries which could involve heavy metals (*e.g*. soldering, automotive industry; panel beating, respraying, *etc*.) and other pollutants (*e.g*. hairdressing chemicals). These may be expected to cause a deterioration of greywater quality on a settlement level in impoverished settlements, causing greywater quality to go “from bad to worse”. One suggestion was that it may be necessary to decide which set of conditions allow sustainable use of greywater in small-scale agriculture. Situations identified as not allowing for sustainable reuse should include indication of some other form of greywater management.

It was highlighted that proper behaviour studies are required. People can be expected to use greywater in unpredictable and unexpected ways, thus studies on present uses were necessary. Further, it was noted that people say and do different things, and that studies would need to be carefully designed to take this into account. In this regard, it was noted that studies and activities of NGOs should be taken into account since they often have relevant experience at settlement level. It would also be necessary to incorporate awareness of entrepreneurs and small companies in designing and providing greywater treatment devices. These were identified as being the two sectors which have the most knowledge of and contact with practices at settlement level.

It was highlighted as imperative that the development of guidance makes use of and references existing studies.

Greywater characteristics
Certain greywater would need to be excluded from any reuse initiative upfront. Kitchen water and anything with fats, oil and grease would need to be excluded because the bacterial load is too great. The water from the first laundry wash would also need to be excluded because the detergent load is too great.

Stored greywater changes in composition during storage, thus guidance for irrigation would need to state that greywater must be used within short time period and it must not be stored. Ideally, greywater should be used within 12 hours and definitely within 24 hours.

It was noted that there was still uncertainty around the effects of greywater on plants – the need to get results from studies in progress was highlighted as a necessary input to the guidelines. Floriculture was suggested as an alternative to irrigating food crops.

The need to take into account interaction between water quality, soil quality, and plant growth and quality, was highlighted. Not all heavy metals and pathogens affect all plants in the same manner. Sodicity issues were highlighted as very important – these relate to detergent composition. A possible solution to detergent-related problems would be for manufacturers to change detergent compositions to reduce sodium content and thus sodicity problems in the soil.

Settlement-related features which should be considered include user behaviour, literacy and perceptions regarding food security. They should also include economic aspects, type of water provision and impact on HIV/AIDS.

Among health-related issues, promotion of the use of *E. coli* as the preferred indicator of faecal pollution was recommended. Thermotolerant (faecal) coliforms are not regarded as specific to faecal pollution and total coliforms indicate a different water quality (general hygienic quality, typically of environmental waters). It was mentioned that spore-forming bacteria (*e.g. Clostridium* sp.) should also be investigated as possible indicators for the risk of food poisoning outbreaks. There were also concerns around the movement of pathogens through the soil/plant system and the possibility that immigrants could introduce new pathogens.

It was acknowledged that greywater from informal settlements was of mixed and very low quality, and individual behaviour is very important to its safe disposal or further use. This was recognised as a challenge. Most poor people do not reuse greywater by preference; they are driven by necessity. This would not be the case for high income users of greywater. The need to acknowledge and accommodate this difference in drivers for individual behaviour was highlighted.

The difficulty of influencing individual behaviour in poor communities was recognised as a major issue of concern. People would look to government for guidance and government would want to be seen to be doing the right thing. This would make it preferable to err on the side of safety in any guidance supported by government. There was reluctance on the part of national authorities to recommend a practice that could have health implications and therefore would be up to good NGOs and education campaigns, *etc.* to monitor progress. It was recognised that the level of behaviour modification might have to be on a par with the education campaign associated with the installation of UD toilets in the eThekwini municipal area.

A concern was expressed about levels of fluoride in greywater in areas where fluoridation of drinking water is being considered.

It was felt that heavy metal content in greywater should be established before any reuse initiative is considered, as well as other kinds of dangerous pollutants related to home businesses, such as hair salons and automotive repairs. These kinds of businesses were perceived to be common in informal settlements.

It was strongly felt that guidance would have to provide very practical directions to users, *e.g.* need to stipulate no storage of greywater or use within 12 hours; the types of crops/plants that are tolerant to certain greywater constituents, *e.g.* salts, would have to be stipulated.

Site-specific features

The following represent examples of the types of site-specific features highlighted as ones which would need to be considered when planning a new greywater use initiative, or formalising existing practices:

- Aquifer characterization/classification
- Soil-type characterisation, extending also to soil classification (texture, quality, clay content, *etc.*)
- Relationship between soil and sub-soil
- Sodium
- Drainage
- Presence of dolomite
- Water repellence
- Infiltration rate
- Parasite load
- Use of anti-microbial soaps (middle to high income households)
- Jeyes fluid (low to middle income households)
- Use of other substances affecting bacteria to flourish, *e.g.* Hibitane handwashing soap in hospitals
- Geohydrology

Dissemination of information

It was emphasised that there was an urgent need for a clear statement of basic principles of greywater use to guide local authorities, which they in turn could use to advise individual users. A key aspect of the ability of local authorities to support users would be their ability to monitor behaviour, especially in low income settlements. It would be particularly useful to have community development workers (or customer service agents) as used by eThekwini Municipality.

Schools were recognised as useful medium to drive behaviour change. National authorities (DWAF, SALGA, Department of Local Government, Department of Health, and Department of Environment Affairs) were also possible avenues through which to disseminate information. Groups working in settlements – *e.g.* NGOs, agricultural extension agents – were further possibilities.

Conclusions

Two main user groups were identified for which the guidance would have to cater:

1. High-income, sewered users – for these, amended Australian/Arizona guidelines might be suitable.
2. Low-income settlements – some form of supervision would be required in any reuse system. This is acceptable in the eThekwini situation where all households get 300 ℓ/d and there is generally enough space for greywater disposal; *i.e.* the municipality can provide guidance and accept accountability. When it comes to informal settlements in other areas, where water is scarce, densities are high, knowledge and literacy levels are poor, then greywater is generally very poor quality and major difficulties are anticipated in managing the use thereof.

In all cases the precautionary principle would have to be applied, *i.e.* guidance would need to provide means to determine risks and prescribe ways in which to minimise these. Municipal capacity would thus be critical for successful management of greywater use.

1.3.2 Regional and local authorities

Of all the local authorities to whom questionnaire surveys were sent out, less than 10% responded. Of the questionnaires returned, many were completely or mostly blank. Telephonic follow-up, used to try to improve the response rate, revealed that many authorities could not identify a person who would have access to the information requested. This indicates both a lack of knowledge and a lack of capacity at local authority (municipal) level regarding water and sanitation delivery in general, and greywater issues in particular. Although little information was generated at this level of consultation (the response rate was too low to allow conclusions to be drawn with any confidence), it is significant in that it highlights *urgent need to improve the capacity of local authorities to provide basic services, including greywater management*.

1.3.3 Communities generating, and potentially using, greywater

Consultation at this level yields two types of information:

- Greywater generation, calculated at least semi-quantitatively from data collected during on-site surveys and from GPS co-ordinates of households surveyed.
- Qualitative social descriptions, based on qualitative questions about user preferences and opinions, as included in the survey questionnaire, given at the end of this Case Study Report (Section 4.2).

Greywater generation rates

Greywater generation rates (G) were calculated for the settlements surveyed, as described in Methods. Mntamntengayo had the highest G and water use rate of all settlements surveyed, while Sawpitts had the lowest values in both cases. Kingsway had the highest dwelling density (28 du/ha), while Sawpitts had the lowest (6 du/ha) (Table 9).

Sawpitts had the lowest daily water consumption of the two non-sewered settlements, while Siyanda had the highest water consumption of the four sewered communities. Sawpitts had the lowest greywater generation rate of all the six settlements while Mntamntengayo has the highest greywater generation rate of all six settlements.

Non-sewered settlements appeared to have distinct daily water consumption habits (differences in daily water consumption confirmed by ANOVA, $p \leq 0.05$). Such differences, even among settlements that seemed similar in many regards (*i.e.* both settlements were low-income, non-sewered, had dry sanitation, receive daily 200 ℓ water supply), may be attributed to fact that household water conservation measures tend to vary among settlements (Murphy, 2006). Similar findings have been shown by Carden *et al.* (2007), who reported that the non-sewered informal settlements in Cato Manor (KZN) and Khayelitsha (WC), among others, showed distinct water consumption levels. This implies that, with regard to guidance for greywater use, cognisance must be taken of the characteristics of individual settlements. Sewered settlements, on the other hand, showed statistically significant uniformity in water use level for the most part (exceptions were the settlements surveyed in Worcester which showed greater variation), thus implying that low-income sewered settlements may be characterised by relatively similar water use habits, and greywater generation, despite differences in geographic location. This difference between non-sewered settlements with or without on-site sanitation, and sewered settlements, may be the distance to water and/or the availability of water in volumes greater than the free basic water supply of 200 ℓ/day. In non-sewered settlements, it has been shown that the distance between the household and water supply is one of the main determinants of the daily volumes of water consumed by households (Carden *et al.,* 2007).

Table 9: Water consumption (mean water use per day), dwelling density (dwelling units per hectare), and greywater generation rate (litres generated per hectare per day) for the settlements surveyed.

Settlement	Municipal Region	Sanitation Type	Dwelling Density (du/ha)	Mean Water Use/day (ℓ/d/du)	G (ℓ/ha.d)
Mntamntengayo	eThekwini	Mixed unserviced and on-site dry sanitation	0.1	135	10.1
Sawpitts	eThekwini	Mixed unserviced and on-site dry sanitation	1-10 Mostly <5	89	67.2-672 Mostly <336
Siyanda	eThekwini	Sewered	20	85	1244
Barcelona	Ekurhuleni	Sewered	20-35	68	1020-1785
Kingsway	Ekurhuleni	Sewered	28-32	64	1344-1536
Worcester - Zwelethemba - Roodewal - Esselen Park	Western Cape	Sewered	 40 12 15-18 Mean: 22-23	68	 2040 612 765-918 Mean: 1139-1190

Another interesting observation was that Mntamntengayo (KZN), despite being non-sewered (dry-sanitation, 200 ℓ/day water supply), had the highest mean daily water consumption values of all surveyed communities, and the lowest dwelling density when compared only to sewered communities. This observation correlates with that reported by Carden *et al*. (2007), and similarly may be a result of under-reporting of water use in sewered communities with the convenience of in-house taps. Since the settlement in question is serviced by 200 ℓ groundtanks, users may have been more aware that they were using close to the capacity of the tank per day.

Comparison of greywater generation rates among the settlements surveyed showed that Sawpitts (KZN) had the lowest greywater generation rate, while Mntamntengayo (KZN) and Zwelethemba, Worcester, had the highest. Sawpitts (KZN) qualifies for the first category of greywater management options as per Carden *et al.* (2007) (Figure 25), as its G value was less than 500 ℓ/ha.d (Table 9). Onsite disposal or reuse of greywater, with minimal health risks should be possible for Sawpitts (KZN). The rest of the settlements fell into the second category of greywater management options, where on-site disposal or reuse may be possible, but site-specific factors would need to be taken into account.

Social perceptions of greywater use in settlements supplied with on-site sanitation and in sewered communities

The survey gave a sense that the concept of greywater is generally not understood by communities. To a number of people interviewed, the perception was that greywater referred to observably dirty and unusable water, while all the used, soapy but observably 'clean' water was considered clean water. This observation implies therefore, the possibility of greywater practices that may have gone unrecorded because of false perceptions of the concept of greywater.

On the question of reuse, approximately 31%, 55%, 76%, 75%, 68%, and 70%, of households surveyed in Worcester, Mntamntengayo, Siyanda, Sawpitts, Barcelona, and Kingsway respectively, indicated some form of reuse of greywater. The percentage of households practising some form of reuse was notably lower in Worcester than in the other communities surveyed. The reuse practices included using dish-washing water for floor cleaning; using laundry water or bath water for toilet flushing, floor washing, car washing, trapping dust or plant/garden irrigation; using laundry rinse water for clothes washing; using bathwater for laundry; reuse of cooking water to cook other food.

Health concerns were raised. Approximately about 18% of respondents thought use of greywater may cause health problems. Concerns ranged from the fear of offensive smells, 'germs', mosquito-transmitted diseases, cholera and other intestinal infections, especially among children who may be exposed to greywater. About 82% of the respondents in settlements other than Worcester however, felt that, if proper control and monitoring were practised, greywater use could be beneficial. Again, the percentage in Worcester was much lower than in other settlements (35%). Among examples of suggested controls were that greywater should not be allowed to pond, and that contact between greywater and children must be prevented.

2. Capacity building workshop, held on completion of final draft of Guidance Report

2.1 Aims

The aims of holding a capacity building workshop were:

- To inform local authorities about greywater and use of greywater for small-scale irrigation.
- To introduce the Guidance Report to them.
- To provide local authorities with the opportunity to provide feedback on the perceived applicability of the Guidance Report in the context of their own environments.
- To provide relevant government departments with an opportunity to express their opinions on the Guidance Report.

2.2 Methods

In planning for capacity workshops, and in the light of poor response to the previous workshop and questionnaire calls, it was decided to hold only one central workshop at the offices of the WRC in Pretoria. The workshop was planned for 29 January 2010. Invitations were sent out by fax to all local authorities listed on the SALGA database, as accessed via the SALGA website. This amounted to a total of 248 local authorities. Invitations were sent out over the period 20-24 December 2009, to be available to municipal decision-makers as soon as work resumed in January 2010.

In addition, invitations were issued telephonically to representatives of the Department of Water Affairs and Department of Environment and Tourism, but none attended the workshop. Attempts to reach representatives of the Departments of Agriculture and Health were unsuccessful. Unfortunately, most responses from municipalities were received late so that it was initially unclear whether it would be possible to hold the workshop as planned. Consequently, invitations were issued to government departments at short notice and this was probably the largest factor contributing to their lack of attendance.

2.3 Results

A total of 12 local authorities responded positively to the invitations sent out. Of these, six were represented at the workshop. In addition, representatives of Rhapsody Water Treatment and Unilever SA attended. Mr L.R. Gravelet-Blondin, previously of the Department of Water Affairs and Forestry and presently a private consultant, also attended the workshop.

The workshop was conducted successfully, with the represented authorities indicating that they found the Guidelines as presented informative and useful. Several suggestions were made, for incorporation into the Guidelines and the Technical Report. These included the following:

- The need to clarify the legal status of greywater use was highlighted.
- The Guidance Report should specifically mention risk to surface water and groundwater.
- There was a question regarding whether SAR would be practical to implement as part of the requirements for minimum analysis of greywater.
- Total nitrogen was considered to be a more appropriate constituent to include than inorganic nitrogen.
- The Guidance Report should refer to thermotolerant coliforms rather than faecal coliforms, and *E. coli* should be the indicator organism specified because it is more specific for faecal contamination than thermotolerant/faecal coliforms.
- Greywater use projects should include management options for greywater which is not suitable for use; otherwise greywater use becomes uncontrolled release of greywater.
- Kitchen greywater was recognised as being a problem for use. A grease trap would be required for kitchen greywater.
- The importance of user education was emphasised

- Local authorities expressed a need for information on greywater use and management.
- A need was expressed for smaller local authorities to have access to experience and advice of municipalities which have experience with greywater use, notably eThekwini Municipality.

3. Acknowledgements

This study was funded and logistically supported by the Water Research Commission.

4. Questionnaires Used in Up-front Consultation

4.1 Questionnaire used for local authorities

WATER RESEARCH COMMISSION PROJECT K5/1639: ASSESSMENT OF GREYWATER COLLECTION, DISPOSAL AND REUSE SURVEY QUESTIONNAIRE FOR LOCAL AUTHORITIES	
The primary aim of this project is to undertake a comprehensive study of the management of greywater (all domestic wastewater except that from toilets) in the sewered and non-sewered areas of South Africa.	
Question	**Answer**
Name of local authority (include province)	
Area administered by local authority (square km)	
% Area with formal (established) housing	
% Area with RDP housing	
% Area with informal housing (shacks)	
% Dwellings served by in-house running water	
% Dwellings served by individual household provision other than in-house running water (*e.g.* yard taps, ground tanks, roof tanks)	
% Dwellings served by communal standpipes	

WATER RESEARCH COMMISSION PROJECT K5/1639: ASSESSMENT OF GREYWATER COLLECTION, DISPOSAL AND REUSE SURVEY QUESTIONNAIRE FOR LOCAL AUTHORITIES	
The primary aim of this project is to undertake a comprehensive study of the management of greywater (all domestic wastewater except that from toilets) in the sewered and non-sewered areas of South Africa.	
Question	**Answer**
% Dwellings with other water service delivery (specify)	
% Dwellings with no water provision	
Approximate volume of water supplied monthly	
% Dwellings with in-house flushing toilets	
% Dwellings with on-site sanitation (*e.g.* pit latrines, VIPs, urine diversion toilets)	
% Dwellings with other types of sanitation provision (specify)	
% Dwellings with no formal sanitation provision	
Approximate amount of wastewater treated monthly	
% Treated wastewater of domestic origin	
% Treated wastewater of industrial origin	
What provision is made for stormwater collection and treatment?	
Is any provision made for greywater collection and treatment? If so, what?	
Is the authority aware of any legislation or guidelines for the collection, treatment or re-use of greywater? If so, what?	
Does the authority have any by-laws which address the collection, treatment or re-use of greywater? If so, what?	

WATER RESEARCH COMMISSION PROJECT K5/1639:
ASSESSMENT OF GREYWATER COLLECTION, DISPOSAL AND REUSE
SURVEY QUESTIONNAIRE FOR LOCAL AUTHORITIES

The primary aim of this project is to undertake a comprehensive study of the management of greywater (all domestic wastewater except that from toilets) in the sewered and non-sewered areas of South Africa.

Question	**Answer**
Does the authority have an official stance on the re-use of greywater for small-scale irrigation of food crops and gardens? If so, what?	
Does the local authority have, or know of, any greywater re-use projects in the area under its jurisdiction? Specify.	
What would be the response of the local authority, if approached by community members for guidance on re-use of greywater for small-scale irrigation of food crops and gardens?	
Name of person interviewed: Position of person interviewed: Date:	

Thank you for your co-operation!

4.2 Questionnaire used for data collection from individual households at settlement level

WATER RESEARCH COMMISSION PROJECT K5/1639:
GREYWATER REUSE FOR IRRIGATION
SURVEY QUESTIONNAIRE

Note to interviewers: Before posing questions to interviewee, briefly explain the context of greywater management. Cover topics such as what is greywater; how is it generated; what proportion of wastewater in the household does it represent; can it by reused; what types of greywater may be suitable for reuse for irrigation; for what other purposes can greywater be reused; what are the advantages and disadvantages of reusing greywater; what management options are available for greywater if it is not reused (or if it is reused so often within the household that it is not fit for any further use when it is disposed by the householder). Be sensitive, and open, to related issues raised by community members, and take notes on these – on the back of the questionnaire sheet, if necessary.

To be completed by interviewer:

Please write short notes on how the interview sample was identified and interviews conducted.

____

____

____

____

____

____

____

The following questions are to be answered by community members, assisted by project team member and a translator. The final section on Biographical Data is optional, but would be desirable. Interviewers and translators should try to establish sufficient trust and rapport during the rest of the questionnaire that community members feel comfortable answering questions in the Biographical Data section.

Section 1: Sanitation and Water Supply

1. Type of sanitation system available:

[ ] None

[ ] Communal facility (state type of system)

____

[ ] Bucket (state how and where emptied)

___

[ ] Pit latrine (state VIP or other)

___

[ ] Source separation (state type, and whether attached to house or free-standing)

___

[ ] Pour flush (in-house or other)

___

[ ] Other (specify)

___

2. Is toilet facility provided on or off the property?

[ ] On

[ ] Off

3. Distance from your house to water point:

[ ] Water available at or in house

[ ] < 10m

[ ] 10-50m

[ ] 50-100m

[ ] 100-200m

[ ] 200-500m

[ ] > 500m

4. What source of water do you use?

[ ] In-house tap, full pressure

[ ] In-house tap, roof tank

[ ] Yard tap or household groundtank

[ ] Communal standpipe

[ ] Borehole/well

[ ] River/dam

[ ] Other (specify)

___

Section 2: Water Use in the Household

5. Daily water use per household:
[ ] < 20 ℓ (less than two 10 ℓ or one 20 ℓ bucket)
[ ] 20-50 ℓ (from 2 to 5 10 ℓ buckets)
[ ] 50-100 ℓ (from 5 to 10 10 ℓ buckets)
[ ] 100-150 ℓ (from 10 to 15 10 ℓ buckets)
[ ] > 150 ℓ (more than 15 10 ℓ buckets)
(**Note to interviewers**: Before going out to interview communities, ensure that you are aware of the various containers usually used to collect water in the community in question, and of the approximate volume of each. You should be able to interconvert among container volumes to facilitate estimation by community members – *e.g.* you should know how many 10 ℓ buckets are needed to fill a jerry can.)

6. How much water do you think you would use, if there were no restrictions (*e.g.* cost, distance or time involved in fetching water)?

____

7. Time taken fetching water per day:
[ ] < 15 minutes
[ ] 15-30 minutes
[ ] 30-60 minutes
[ ] 1-2 hours
[ ] > 2 hours

8. Who fetches the water, if it is not available in-house or on the property ?

____

9. For what do you use the first fresh water drawn or collected each day?

____

10. Type of containers used for storing clean water:
[ ] Open-top. Specify (type of container, material of which it is made, any previous use of the container)

____

[ ] Closed-top. Specify (type of container, material of which it is made, any previous use of the container)

____

11. Volume of water that is kept in the house during the course of one day (estimate volume as before):
[ ] < 20 ℓ
[ ] 20-50 ℓ
[ ] 50-100 ℓ
[ ] > 100 ℓ

12. Period of time for which water is stored in the household before use:
[ ] < 1 hour
[ ] 1-2 hours
[ ] 3-12 hours
[ ] 12-24 hours
[ ] > 24 hours

13. Other purposes for containers used for water storage:
[ ] Beer brewing
[ ] Laundry
[ ] Dish washing
[ ] Cooking
[ ] Gardening
[ ] Bathing
[ ] Other (specify):

____

Section 3: Greywater Generation and Reuse within the Household

14. Which brands of the following products do you use, and approximately how much of each?
[ ] Bath soaps:

____

[ ] Washing powders:

____

[ ] Dish washing liquids:

[ ] Shampoos:

[ ] Other detergents (specify):

---

15. To help us work out how the expected amount of greywater: How often do you wash your clothes?

[ ] Daily

[ ] Once a week

[ ] Twice a week

[ ] Other (specify):

---

16. To help us work out the expected amount of greywater: How often do you / members of the family take baths?

[ ] Once daily

[ ] More than once daily

[ ] Less than once daily (specify):

---

17. How often would you like to bath, if there were no restrictions on the amount of water available?

---

18. What do you do with the dirty water (greywater) after use?

[ ] Throw away (Specify where – street, drain. other)

[ ] Water plants (Specify type of plants)

[ ] Reuse

[ ] Other (specify):

---

19. What extra sources of water do you have for use in your household (additional to main source of water)?

[ ] Rainwater collected from roofs

[ ] Reuse of grey water

[ ] No other source

[ ] Other (specify):

____

20. If greywater is reused, describe the type of greywater reused, the volumes reused and the purposes for which it is reused. (e.g. using cooking water for dishes; bathing water for laundry):

____

____

____

Section 4: Greywater Reuse Outside the Household (with Emphasis on Reuse for Irrigation)

21. Do you think that reuse of greywater, once you have finished using it in your household, would be useful in your community? Please specify types of reuse which you think would be appropriate and give reasons for your answer:

____

____

____

____

____

22. Are you aware of any food gardening, small-scale agriculture or similar activities occurring in your community? Specify.

____

____

23. If there are, do you know what gardeners think limits productivity of their plants the most?

____

____

24. Do you think greywater reuse for irrigation could help in such projects? Explain your answer.

____

____

25. If you think that greywater reuse for irrigation is not advisable in your community, please explain why you think so.

____

____

____

____

Section 4: General Service Provision and Greywater Management Systems

26. Which are the most important services that you think would make life better in your community?

[ ] Houses

[ ] Electricity (or other sources of power)

[ ] Drinking water

[ ] Toilets

[ ] Refuse removal

[ ] Schools

[ ] Clinics

[ ] Nutrition (food security, nutritional advice)

[ ] Air quality (particularly where firewood or coal are burnt)

[ ] Other (specify):

____

27. What do you consider to be the major health problems in your community?

____

____

28. Do you think greywater contributes to health problems in your community? Please explain.

____

____

29. Do you think other water-related problems contribute to health problems in your community? Please explain.

____

____

____

30. Are you aware of any systems for managing disposal or reuse of greywater in your community?

[ ] Yes

[ ] No

If yes, please describe these systems:

31. What do you think are the major problems associated with greywater and its management in your community? Please explain your answer.

32. Please list, in order from most preferred to least preferred, three means of greywater disposal which you think are suited to the type of greywater generated in your community.

Biographical data (OPTIONAL, BUT WOULD BE APPRECIATED)
(Numbering system is separate from the main questionnaire to reinforce the idea that this section is separate from the main questionnaire and will not be used to identify/penalise respondents who gave critical responses on the main questionnaire.

1. Name of settlement/province:

2. House Number/ GPS coordinates:

3. Interviewee's Name:

4. Race and Gender:

____

4. Age:

____

5. Religion:

____

6. Occupation:

[ ] None

[ ] Formal

[ ] Informal (no regular income)

Additional information, if given:

____

____

____

7. Household Income per month (or estimate based on material belongings):

[ ] None

[ ] R1-1000

[ ] R1001-R2000

[ ] R2001-R3000

[ ] >R3000

[ ] Not cash-based (e.g. home care, child care, exchange of services for accommodation, food, etc). Please describe.

____

8. Formal education:

____

9. Informal education or training:

____

10. Number adults (18 years and older) in household, age and gender:

____

____

____

____

11. Number of children, ages and gender:

____

____

____

____

12. Type of house:

[ ] Traditional dwelling

[ ] RDP/brick structure

[ ] Informal dwelling

[ ] If not brick structure, describe building materials used:

____

13. How long have you lived at the present site? __________________________

If less than one year, where did you live before?

____

14. Do you have any questions you would like to ask me?

____

____

____

____

____

Thank you for your co-operation!

Interviewer: _____________________________Date________________________________

Case Study 3
Identifying Greywater Quality Constituents for Inclusion in Guidance Report

1. Aims

This desk study aimed to produce a preliminary list of water quality variables to be considered for inclusion in guidelines for greywater use in small-scale irrigation in South Africa.

2. Methods

Studies of greywater quality conducted in South Africa were used in combination with South African and international guidelines for water quality for various purposes to identify the water quality constituents which are likely to indicate that greywater, as encountered in South Africa, is unsuitable for particular uses. A relatively long list of constituents was initially identified, and subsequently reduced to yield a list of greywater quality constituents relevant specifically to irrigation use and short enough to be feasible for cost-effective analysis. The following discussion describes the process followed.

3. Results and discussion

Murphy (2006) pointed out that while greywater quality in middle to upper income sewered households is probably comparable to values reported for Western style households in the literature, there is a lack of data on greywater quality in poor communities, and particularly in unsewered dense informal settlements. This data gap was addressed by Carden *et al.* (2007). Table 10 provides a summary of a number of key water quality constituents in greywater sampled in various dense informal settlements throughout South Africa. The number of samples per site varies and repeat samples were taken in isolated cases only, so the variability in greywater quality reported reflects variability in both time and space. Wide variability in COD, total phosphorus, oil and grease, and EC are worth noting. Unfortunately, the limits of field test kit equipment used in many instances meant that the full range in some variables, particularly total phosphorus, TKN and ammonia, could not be measured.

Table 10: Greywater quality at dense informal, unsewered settlements in South Africa (from Carden *et al.,* 2007).

Name of settlement	N	Prov #	Average values for greywater samples							
			COD (mg/ℓ)	DO (mg/ℓ)	pH	NH_3 (mg/ℓ)	TKN (mg/ℓ)	Tot P (mg/ℓ)	Oil & Grease (mg/ℓ)	EC (mS/m)
Clanwilliam	0	WC	-	-	-	-	-	-	-	-
Redhill	10	WC	1470	-	7.6	-	20	27	176	155
Lingelethu	4	WC	6190	-	-	-	-	-	-	-
Fairyland	3	WC	2320	-	-	-	60	88	30	-
Kleinmond	2	WC	3510	-	-	-	110	146	29	-
Masiphumelele	3	WC	7850	-	-	-	130	98	242	-
Khayelitsha RR	5	WC	3580	3.7	-	-	-	-	-	-
Sweet Home	3	WC	8490	-	-	-	172	144	307	-
Masakhane*	5	MP	-	-	7.3	3+	-	5+	-	1040
Doornkop*	3	MP	-	-	9.6	3+	-	5+	-	126
Mashati*	2	LIM	-	-	10.4	3+	-	5+	-	289
Manapyane*	1	LIM	-	-	9.3	3.0	-	5	-	112
Tlhalampye*	2	LIM	-	-	9.3	3+	-	5+	-	461
Leeufontein*	1	LIM	-	-	10.9	-	-	-	-	770
Jane Furse*	1	LIM	-	-	10.3	2.9	-	1.6	-	389
Winnie Park*	1	LIM	-	-	10.1	3+	-	5+	-	234
Seshego Zone 5*	3	LIM	-	-	8.6	3+	-	5+	-	140
Mahwelereng*	2	LIM	-	-	9.1	0.5	-	5+	-	90
Doornkraal*	1	LIM	-	-	9.7	3+	-	5+	-	489
New Pietersburg*	1	LIM	-	-	8.9	3+	-	5+	-	1530
Mothlakaneng*	2	LIM	-	-	9.4	3+	-	5+	-	196
Mpathi	0	EC	-	-	-	-	-	-	-	-
Mthento	0	EC	-	-	-	-	-	-	-	-
Emahobeni*	2	EC	-	-	7.8	3+	-	2.9	-	381
Mputhi*	2	EC	-	0.2	8.9	2.0	-	1.3	-	783
Phakamisa Park*	2	EC	-	-	8.8	3+	-	1.9	-	514
Bongweni*	1	EC	-	-	7.8	3.0	-	3.5	-	916
New Payne*	1	EC	-	-	7.7	2.6	-	4.5	-	113
Silvertown*	1	EC	-	-	8.0	3+	-	5+	-	189
Orange Grove*	1	EC	-	-	7.6	2.2	-	5+	-	764
KwaShange	8	KZN	-	0.1	9.1	12.5	56	57.4	730	59
Emambedwini	8	KZN	-	0.6	9.9	8.5	39	112.4	1365	567
Emaqedini	5	KZN	-	0.6	8.7	5.7	7	115.6	397	70
Boboyi	10	KZN	-	0.6	9.5	3.0	20	34.4	1948	128
Zolani	9	KZN	-	1.2	8.8	3+	45	37.6	1947	199
Cato Manor	3	KZN	-	0.6	8.8	7.6	164	7.5	108	54
Barcelona	0	GP	-	-	-	-	-	-	-	-
Mayfield Ext	1	GP	-	0.6	9.8	21.8	43	240.0	1484	653
Freedom Square	0	GP	-	-	-	-	-	-	-	-
Average			**4770**	**0.9**	**8.8**	**-**	**72**	**-**	**730**	**366**

Notes:
1. * indicates sites where analyses were conducted with field test kits only
2. + indicates extent of measurement range for field instrument
3. WC – Western Cape, MP – Mpumalanga, LIM – Limpopo, EC – Eastern Cape, KZN – KwaZulu-Natal, GP – Gauteng

Table 11 represents the average of pooled samples taken at 4 time points over approximately a year, hence may be expected to dampen the fluctuations of time and space. Also shown are the comparisons of greywater quality to that of tapwater and a balanced plant nutrient solution. This gives an indication of the water quality variables that change the most as a result of bath, laundry and kitchen use (pooled), and the extent to which greywater, particularly that from unsewered dense informal settlements, offers the potential for adding nutrients if used to irrigate plants.

Table 11: Mean chemical and microbiological analyses of greywater from an informal settlement (Cato Manor, eThekwini), tap water and nutrient solution (n=4 over 4 crop cycles, corresponding to a period of approximately 1 year). Greywater (highlighted) represents pooled sample from 8 households at each of the 4 sampling events (from Case Study 1).

Constituent	Units	Tap water	Greywater	Nutrient solution
pH		6.8-7.4	**8.1-9.8**	6.3-7.8
Alkalinity	mg/ℓ $CaCO_3$	29	**330**	66
Electrical conductivity (EC)	mS/m	30	**267**	223
Sodium	mg/ℓ	-	**188**	32
BOD_5	mg/ℓ	-	**280-310**	-
COD	mg/ℓ	-	**280-310**	-
Calcium	mg/ℓ	<0.05	**7.5-9**	<0.5
Chloride	mg/ℓ	16	**220**	115
Chrome	mg/ℓ	<0.1	**0.14**	0.1
Copper	mg/ℓ	<0.1	**0.1**	<0.1
Lead	mg/ℓ	<0.05	**0.5**	<0.2
Magnesium	mg/ℓ	5.6	**7.5**	7.1
Nickel	mg/ℓ	<0.10	**<0.10**	<0.10
Nitrate + Nitrite	mg/ℓ	0.91	**88**	1.2
Total nitrogen	mg/ℓ	0.84	**206**	125
Ortho-phosphate	mg/ℓ	<0.05	**40**	38
Selenium	mg/ℓ	<0.05	**0.08**	<0.05
Potassium	mg/ℓ	3.1	**31**	7.1
Sulphate	mg/ℓ	0.05	**576**	137
Total Kjeldahl Nitrogen	mg/ℓ	0.05	**206**	125
Total phosphate	mg/ℓ	<0.10	**69**	49
Zinc	mg/ℓ	<0.25	**0.24**	<0.10
Boron	mg/ℓ	<0.25	**3.4**	0.5
Total coliforms	CFU/100 mℓ	Not detected	**4.2×0^9**	Not detected
E. coli	CFU/100 mℓ	Not detected	**4.0×10^9**	Not detected
Coliphage	PFU/100mℓ	Not detected	**Not detected**	Not detected
***Ascaris* ova**	Ova/ℓ	Not detected	**Not detected**	Not detected

Palmquist & Jönnson (2003) compared the fertiliser value of urine, faeces, flush water and greywater from an apartment development in Sweden. Greywater was found to have the lowest fertiliser value based on the N:P:K:S (nitrogen: phosphorus:

potassium: sulphate) ratios. Their results indicate that application of greywater on the basis of plant phosphorus requirements would result in the over-application of sulphate and potential acidification of soil. Relative to phosphorus, and depending on factors such as plant species and soil type, plants take up 4-10 times as much nitrogen, 1-8 times as much potassium and 0.3-1 times as much sulphate. Applying this ratio to the greywater analysis represented in Table 11 yields a N:P:K:S ratio of 3:1:0.5:8, confirming the results of Palmquist & Jönnson (2003). However, pH measurements of South African low income greywaters (Table 10 and Table 11) are typically more alkaline than reported in international studies, so the predicted acidification may not be as marked. Also, application of excess greywater is commonly used to counteract the accumulation of undesirable ions in soil by leaching.

In terms of greywater constituents likely to present a problem for irrigation, comparison of greywater and nutrient solution in Table 11 suggests that untreated pooled greywater from unsewered dense settlements is more alkaline than desirable for plant growth and contains excess of the following:

- Alkalinity
- Sodium
- Calcium
- Chloride
- Nitrate/nitrite
- Total nitrogen, Total Kjeldahl Nitrogen
- Potassium
- Boron
- Total coliforms
- *E. coli*

However, taking into account the N:P:K:S ratio described above, if concentrations were normalised to the phosphorus concentration, it is likely that the apparent excess in nitrogen and potassium would not be evident.

Table 12 compares results from a number of studies on greywater quality conducted in South Africa, while Table 13 presents a summary of a number of international greywater studies. Comparison of the same constituents across the two tables, and of those in Table 13 to corresponding constituents in Table 10 and Table 11, strongly supports Murphy's argument that published studies of greywater from Western style households do not reflect greywater quality generated in the majority of households in South Africa (*i.e.* low income households), and hence that these studies are of limited use in developing greywater guidelines relevant to significant sectors of the South African population (Murphy, 2006).

Table 12: Comparison of greywater quality results from a number of South African studies (from Carden *et al.*, 2007)

Constituent	WRC Project No. 1524 (results as recorded in 2005)	Eriksson *et al* (2002)	Källerfelt & Nordberg (2004)	Stephenson *et al* (2006)
pH	3.3-10.9	5.0-8.7	6.1-7.0	-
Conductivity (mS/m)	28-1763	32-2000	83-132	-
PO_4-Phosphorus	0.7-769	0.6-68	14.8-56.2	0.3-18.9
COD	32-11451	13-549	530-3520	999-1625
Suspended solids	-	6.4-330	69.0-1420	265.2-1261
Oil & Grease	8-4650	3.1-12	-	-
Total Kjeldahl Nitrogen	0.6-488.0	2.1-31.5	-	-
Ammonia Nitrogen	0.2-44.7	0.03-25.4	-	-
Sodium	96-1700	29-230	-	-

Note: Values are quoted in mg/ℓ if not stated otherwise.

Site surveys have been conducted for a number of sewered communities in South Africa, typically low to middle income, representing a range of climatic and geohydrological conditions. Values for greywater by source are available for greywater from 10 middle income households in the greater Durban area, with greywater separated by source (Table 14). Comparison of Table 14 with Table 13 suggests that even for sewered households, greywater in South Africa tends to contain higher concentrations of measured contaminants than reported in international studies. Since the households represented in Table 14 would be unlikely to be driven to conserve water on a cost basis only, it is possible that South Africans generally are more conscious of water use than consumers in more water-rich countries in Europe and North America. By comparison of the three sources, Table 14 suggests that the water quality variables of greatest concern are likely to be:

- COD
- sodium
- EC
- sulphate

In order to make the comparison to Table 11 consistent, greywater from each of the three sources (Table 14) was compared to the nutrient solution in Table 11. This revealed that the following water quality variables were in excess of a balanced plant nutrient solution for each of the three greywater sources:

- Kitchen Alkalinity
Calcium
- Bath Alkalinity
Calcium
- Laundry pH
Alkalinity
Sodium
Sulphate
Total phosphorus

This list compared well with the one above it, COD not having been measured for the plant nutrient solution. Either list is noticeably shorter than the same list compiled for greywater originating from an unsewered dense settlement also situated in the greater Durban area, again highlighting the different greywater qualities to be expected from sewered and unsewered communities. Interestingly, boron did not appear to represent a problem, despite the probable presence of boronate-based salts as fillers in detergents.

Table 13: Physical, chemical and microbiological characteristics of greywater, by source, as reported by various investigators (from Roesner *et al*., 2006).

	Eriksson *et al*. (2003)	**Rose *et al*. (1991)**				**Cassanova *et al*. (2001)**
	Composite	**Shower**	**Laundry wash**	**Laundry rinse**	**Composite**	**Composite**
Constituent	**Range**	**Range**				**Range**
Temperature ^{0}C	21.6- 28.2					
pH	7.6-8.6				6.54	7.47
COD	77-240				76.3	
BOD_5	26-120				0.74	64.85
Total suspended solids	7-207				0.98	35.09
Turbidity (NTU)		28-96	39-296	14-29	1.7	43
Ammonium-Nitrogen	0.02-0.42	0.11-0.37	0.1-0.37	0.06-0.33	9.3	
Nitrate-Nitrogen	<0.02-0.25					
Total Nitrogen	3.6-6.4				22.9	
Orthophosphate as P					9	
Total Phosphorus	0.28-0.779				144	
Sulphate					158	59.59
Chloride						20.54
Hardness						
Alkalinity						
Calcium	99-100					
Magnesium	20.8-23					
Potassium	5.9-7.4					
Sodium	44.7-98.5					
Total bacterial pop. (CFU/100 mℓ)	4.0×10^7-1.5×10^8	1.0×10^7-1.0×10^8	1.0×10^7-1.0×10^8	1.0×10^7-1.0×10^8	6.1×10^8	
Total coliforms (CFU/100 mℓ)	6.0×10^3-3.2×10^5	1.0×10^5	199	56	2.8×10^8	8.03×10^7
Faecal coliforms (CFU/100 mℓ)		6.0×10^3	126	25	1.82×10^4-7.98×10^8	5.63×10^5
Faecal Streptococci (CFU/10 0mℓ)						2.38×10^2
***E. coli* (CFU/100 mℓ)**	<100-2800					

Note: Values are quoted in mg/ℓ if not stated otherwise.

Table 14: Greywater quality analysed by source, for middle income households. Values represent mean of grab samples from 10 households, same households used for all three sources. Highlighted values show where a particular greywater constituent is clearly in excess for a given source (Chalale, 2007).

Constituent	Greywater source		
	Kitchen	Bath	Laundry
Total Phosphorus (mg/ℓ)	8.8	0.54	**91.06**
Nitrate+Nitrite (mg/ℓ)	0.14	0.17	0.21
Potassium (mg/ℓ)	3.1.1	3.56	10.33
Chemical Oxygen Demand (mg/ℓ)	**2056**	900	393
Sodium (mg/ℓ)	3.1.2	41.3	**229.4**
Conductivity(mS/m)	59.1	31.2	**207.2**
Boron (mg/ℓ)	0.096	0.12	0.51
Chloride (mg/ℓ)	78	47	61
pH	6.68	7.05	8.05
Sulphate (mg/ℓ)	41.23	10.06	**541.61**
Calcium (mg/ℓ)	15.68	11.25	16.6
Magnesium (mg/ℓ)	9.02	4.08	8.48
Zinc (mg/ℓ)	0.003	0.005	0.07
Ammonia-free (mg/ℓ)	4.69	0.59	3.08
Alkalinity (mg/ℓ)	115	90.8	480

Assessing two of the three greywater types as a plant nutrient source on the basis of their N:P:K:S ratios (some values were missing for kitchen greywater so the corresponding ratio could not be calculated), bath greywater contains excess nitrogen and sulphate relative to total phosphorus, while laundry greywater contains less than the required amount of nitrogen and potassium, and excess sulphate. This would seem to imply that untreated laundry greywater would make a better nutrient source than untreated bath greywater, but does not take into account the high sodium content and EC of laundry greywater which would have a deleterious effect on soil quality. Untreated kitchen greywater would present a problem in terms of high COD, which could clog soils (and probably also any irrigation equipment other than bucket transfer).

Thus the comparison of greywater sources in Table 14 on balance agrees with that of other authors, as reviewed by Murphy (2006) and Carden *et al*. (2007), *viz*. that water from the bath represents the best source of greywater for irrigation where greywater is separated by source. However, as pointed out in Carden *et al.* (2007), in poor unsewered households, bath greywater would probably be used for at least one and possibly several other purposes before being discarded and would be a far more highly polluted water at that point.

Table 15 and Table 16 compare the results of the site-specific studies in the tables above to relevant guideline values. Table 15 refers to variables listed in the South African Water Quality Guidelines for irrigation use (SAWQG, Vol. 4 – DWAF, 1996), while Table 16 uses guideline values from other sources because these constituents are not listed in the SAWQG for Irrigation Use. Wherever possible, SAWQG for other, similar uses were used since much thought has been devoted to designing these guidelines relevant to the South African context. Wherever guideline values from other sources have been used, that source is indicated in the table. In both tables, values in excess of the target range and maximum range (or their equivalents) are highlighted as being unsuitable for irrigation use, or suitable only on a site-specific basis, possibly with special consideration given to tolerant plants or to soil type. This allows quick visual identification of the variables likely to pose the largest problems for greywater use in irrigation. It should be borne in mind that, with the exception of the Durban MI (middle income) values, all values represent unsewered communities and hence the "worst case scenario" in terms of greywater use on a quality basis.

In terms of the rationale for SAWQG for irrigation use, the guideline target range represents the best quality for that use and the target to which water authorities and users should aspire. However, the Guidelines also recognise that it is not necessarily always possible to attain this target, hence define a maximum range which is the maximum range which most plants will tolerate, and which will apply best to fine-textured soil of neutral to alkaline pH. Water quality outside this range must be assessed for fitness-for-use on a site by site basis, and should preferably not be used for extended periods of time. The SAWQG for irrigation give lists of plants which are sensitive, moderately tolerant and tolerant of particular water quality variables, *e.g.* sodium. These are not repeated here, but are listed in Appendix 2 to the Guidance Report.

Examination of the two tables below indicates that the following list of greywater constituents are likely to be of concern with respect to use of greywater for irrigation:

- Thermotolerant (faecal) coliforms / *E. coli*
- Total nitrogen
- pH
- Sodium (only three sample sites)
- Selenium (only one sample site)
- Alkalinity
- BOD_5
- COD
- Dissolved oxygen – important where greywater could enter freshwater courses
- EC
- Ammonia – important where greywater could enter freshwater courses
- Oil and grease
- Total phosphorus

These largely reflect the constituents which were identified as potential problems from preceding tables.

Table 15: Comparison of variables measured in site-specific studies to target water quality ranges in the South African Water Quality Guidelines for irrigation (DWAF, 1996).

Constituent	SAWQG Irrigation Target range	Site	Value	Comment
Boron (mg/ℓ)	Up to 0.5	Cato Crest, KZN	3.4	Within max range
		Durban MI, Kitchen	0.10	Within target range
		Durban MI, Bath	0.12	Within target range
		Durban MI, Laundry	0.51	Within max range
Chloride (mg/ℓ)	Up to 100	Cato Crest, KZN	220	Within max range
		Durban MI, Kitchen	78	Within target range
		Durban MI, Bath	7	Within target range
		Durban MI, Laundry	8	Within target range
Chromium (VI) (mg/ℓ)	Up to 0.1	Cato Crest, KZN	0.14	Measured as chromium Within max range for Cr(IV)
Coliforms (faecal) / *E. coli* (counts/100 mℓ)	Up to 1 More realistic guidelines would be ≤1000 faecal coliforms (WHO), General standard: 10^5 counts/ 100 mL	Cato Crest, KZN	Total coliforms 4.2×10^9 *E. coli* 4.0×10^9	Suitable on site-specific basis
Copper (mg/ℓ)	Up to 0.2	Cato Crest, KZN	0.1	Within target range
Lead (mg/ℓ)	Up to 0.2	Cato Crest, KZN	0.5	Within max range
Nickel (mg/ℓ)	Up to 0.2	Cato Crest, KZN	< 0.1	Within target range
Nitrogen (inorganic) (mg/ℓ)	Up to 5	Redhill, WC	20	TKN measured Within max range
		Fairyland, WC	60	TKN measured Site-specific use only
		Kleinmond, WC	110	TKN measured Site-specific use only
		Masiphumelele, WC	130	TKN measured Site-specific use only
		Sweet Home, WC	172	TKN measured Site-specific use only
		KwaShange, KZN	56	TKN measured Site-specific use only
		Emambedwini, KZN	39	TKN measured Site-specific use only
		Emaqedini, KZN	7	TKN measured Within max range
		Boboyi, KZN	20	TKN measured Within max range
		Zolani, KZN	45	TKN measured Site-specific use only
		Cato Manor, KZN	164	TKN measured Site-specific use only
		Mayfield Ext, GP	43	TKN measured Site-specific use only
		Cato Crest, KZN	206	TKN measured Site-specific use only
		Cato Crest, KZN	206	Total N measured Site-specific use only
pH	6-5-8.4	Doornkop, MP	9.6	Site-specific use only

Constituent	SAWQG Irrigation Target range	Site	Value	Comment
		Mashati, LIM	10.4	Site-specific use only
		Manapyane, LIM	9.3	Site-specific use only
		Tlhalampye, LIM	9.3	Site-specific use only
		Leeufontein, LIM	10.9	Site-specific use only
		Jane Furse. LIM	10.3	Site-specific use only
		Winnie Park, LIM	10.1	Site-specific use only
		Seshego Zone 5, LIM	8.6	Site-specific use only
		Mahwelereng, LIM	9.1	Site-specific use only
		Doornkraal, LIM	9.7	Site-specific use only
		New Pietersburg, LIM	8.9	Site-specific use only
		Mothlakaneng, LIM	9.4	Site-specific use only
		Mputhi, EC	8.9	Site-specific use only
		KwaShange, KZN	9.1	Site-specific use only
		Emambedwini, KZN	9.9	Site-specific use only
		Emaqedini, KZN	8.7	Site-specific use only
		Boboyi, KZN	9.5	Site-specific use only
		Zolani, KZN	8.8	Site-specific use only
		Cato Manor, KZN	8.8	Site-specific use only
		Mayfield Ext, GP	9.8	Site-specific use only
		Cato Crest, KZN	8.1-9.8	Site-specific use only
		Durban MI, Kitchen, KZN	6.7	Within target range
		Durban MI, Bath, KZN	7.1	Within target range
		Durban MI, Laundry, KZN	8.1	Within target range
Selenium (mg/ℓ)	Up to 0.02	Cato Crest, KZN	0.08	Site-specific use only
Sodium (mg/ℓ)	Up to 70	Cato Crest, KZN	188	Within max range
		Durban MI, Bath, KZN	41.3	Within target range
		Durban MI, Laundry, KZN	299	Site-specific use only
Zinc (mg/ℓ)	Up to 1.0	Cato Crest, KZN	0.24	Within target range

Table 16: Comparison of variables measured in site-specific studies to target water quality ranges in the South African Water Quality Guidelines (SAWQG – DWAF, 1996) for various uses or, where these were not available, from other guidelines available internationally.

Constituent not in SAWQG for Irrigation	Target range/guideline value	Reference	Site	Variable value	Comment
Ascaris ova	<1 helminth egg/ℓ (WHO)	WHO, Vol. 4 (2006a)	Cato Crest, KZN	ND	Within target
Alkalinity (mg/ℓ $CaCO_3$)	Target range 20-100 Poor production: 0-20; >175	SAWQG, Aquaculture, Vol. 6	Cato Crest, KZN	330	Site-specific use only, not suitable for aquaculture
			Durban MI, Kitchen, KZN	115	Within target range
			Durban MI, Bath, KZN	91	Within target range
			Durban MI, Laundry, KZN	480	Site-specific use only, not suitable for aquaculture
BOD (mg/ℓ)	Uncooked crops Up to 10 Suitable for fruit and forestry Up to 150 Ornamental, fruit and fodder crops Up to 240	WHO, Vol. 1 (2006a) CSBE (2003) WHO, Vol. 1 (2006a)	Cato Crest, KZN	280-310	Likely to be unsuitable for use or site-specific use only
Calcium (mg/ℓ)	Human consumption 0-32 Livestock watering 0-1000	SAWQG, Domestic Use, Vol 1; Livestock Watering, Vol.7	Cato Crest, KZN	7.5-9	Likely to be suitable for use
			Durban MI, Kitchen, KZN	15.7	Likely to be suitable for use
			Durban MI, Bath, KZN	11.3	Likely to be suitable for use
			Durban MI, Laundry, KZN	16.6	Likely to be suitable for use
COD (mg/ℓ)	All uses, including irrigation Up to 250 Does not exceed 5000mg/L after removal of algae	Indian General Standards (1983) SA General Authorisation (DWAF, 2004)	Redhill, WC	1470	Likely to be suitable for use
			Lingelethu, WC	6190	Likely to be unsuitable for use or site-specific use only
			Fairyland, WC	2320	Likely to be suitable for use
			Kleinmond, WC	3510	Likely to be suitable for use
			Masiphumelele,	7850	Likely to be unsuitable

Constituent not in SAWQG for Irrigation	Target range/guideline value	Reference	Site	Variable value	Comment
			WC		for use or site-specific use only
			Khayelitsha RR, WC	3580	Likely to be suitable for use
			Sweet Home, WC	8490	Likely to be unsuitable for use or site-specific use only
			Cato Crest, KZN	280-310	Likely to be suitable for use
			Durban MI, Kitchen, KZN	2056	Likely to be suitable for use
			Durban MI, Bath, KZN	900	Likely to be suitable for use
			Durban MI, Laundry, KZN	393	Likely to be suitable for use
Coliphages (counts/100mℓ)	Human consumption: 0-1 Full contact recreation: 0-20	SAWGQ, Domestic Use, Vol. 1; Recreational Use, Vol. 2	Cato Crest, KZN	ND	Within target range
DO (mg/ℓ)	Aquatic ecosystems: 80-120% of saturation For these purposes, saturation at 20˚C and normal pressure, 9.1mg/L is taken to represent 100% saturation; 80% approx. 7.3mg/L, 120% approx. 10.9mg/L		Khayelitsha RR, WC	3.7	Too low to support aquatic life. Likely to be unsuitable for use or site-specific use only
			Mputhi, EC	0.2	Too low to support aquatic life. Likely to be unsuitable for use or site-specific use only
			KwaShange, KZN	0.1	Too low to support aquatic life. Likely to be unsuitable for use or site-specific use only
			Emambedwini, KZN	0.6	Too low to support aquatic life. Likely to be unsuitable for use or site-specific use only
			Emaqedini, KZN	0.6	Too low to support aquatic life. Likely to be unsuitable for use or site-specific

Constituent not in SAWQG for Irrigation	Target range/guideline value	Reference	Site	Variable value	Comment
					use only
			Boboyi, KZN	0.6	Too low to support aquatic life. Likely to be unsuitable for use or site-specific use only
			Zolani, KZN	1.2	Too low to support aquatic life. Likely to be unsuitable for use or site-specific use only
			Cato Manor, KZN	0.6	Too low to support aquatic life. Likely to be unsuitable for use or site-specific use only
			Mayfield ext., GP	0.6	Too low to support aquatic life. Likely to be unsuitable for use or site-specific use only
Electrical conductivity (mS/m)	Non-saline 0-200 Very slightly saline 200-400 Moderately saline 800-1600 Strongly saline > 1600 Discharge 200mS/m	CSBE (2003) SA General Standards (DWAF, 2004a)	Redhill, WC	155	Suitable for use
			Masakhane, MP	1040	Likely to be unsuitable for use or site-specific use with tolerant plants only
			Doornkop, MP	126	Suitable for use
			Mashati, LIM	289	Likely to be suitable for use with tolerant plants
			Manapyane, LIM	112	Suitable for use
			Tlhalampye, LIM	461	Likely to be unsuitable for use or site-specific use with tolerant plants only
			Leeufontein, LIM	770	Likely to be unsuitable for use or site-specific use with tolerant plants only
			Jane Furse, LIM	389	Likely to be suitable for use with tolerant plants
			Winnie Park, LIM	234	Likely to be suitable for use with tolerant plants
			Seshego Zone 5, LIM	140	Suitable for use

Constituent not in SAWQG for Irrigation	Target range/guideline value	Reference	Site	Variable value	Comment
			Mahwelereng, LIM	90	Suitable for use
			Doornkraal, LIM	489	Likely to be unsuitable for use or site-specific use with tolerant plants only
			New Pietersburg, LIM	1530	Likely to be unsuitable for use or site-specific use with tolerant plants only
			Mothlakaneng, LIM	196	Suitable for use
			Emahobeni, EC	381	Likely to be suitable for use with tolerant plants
			Mputhi, EC	783	Likely to be unsuitable for use or site-specific use only
			Phakamisa Park, EC	514	Likely to be unsuitable for use or site-specific use only
			Bongweni, EC	916	Likely to be unsuitable for use or site-specific use only
			New Payne, EC	113	Suitable for use
			Silvertown, EC	189	Suitable for use
			Orange Grove, EC	764	Likely to be unsuitable for use or site-specific use with tolerant plants only
			KwaShange, KZN	59	Suitable for use
			Emambedwini, KZN	567	Likely to be unsuitable for use or site-specific use with tolerant plants only
			Emaqedini, KZN	70	Suitable for use
			Boboyi, KZN	128	Suitable for use
			Zolani, KZN	199	Suitable for use
			Cato Manor, KZN	54	Suitable for use
			Mayfield Ext., GP	653	Likely to be unsuitable for use or site-specific use with tolerant plants only
			Cato Crest, KZN	267	Likely to be suitable for use with tolerant plants
			Durban MI, Kitchen	59	Suitable for use
			Durban MI, Bath	31	Suitable for use
			Durban MI, Laundry	207	Likely to be suitable for use with tolerant plants
Magnesium (mg/ℓ)	Human consumption: 0-30	SAWQG for Domestic Use, Vol. 1;	Cato Crest, KZN	7.5	Likely to be suitable for use

Constituent not in SAWQG for Irrigation	Target range/guideline value	Reference	Site	Variable value	Comment
	Livestock watering: 0-500	Livestock Watering, Vol. 5			
			Durban MI, Kitchen	9.0	Likely to be suitable for use
			Durban MI, Bath	4.1	Likely to be suitable for use
			Durban MI, Laundry	8.5	Likely to be suitable for use
Nitrogen as Ammonia (mg/ℓ)	Target range, unionised: 0.7mg/L Chronic effects 15 mg/L N Acute effects 100mg/L	SAWQG for Aquatic Ecosystems, Vol. 7	Masakhane, MP	> 3	Likely to be unsuitable for use or site-specific use only
			Doornkop, MP	> 3	Likely to be unsuitable for use or site-specific use only
			Mashati, LIM	> 3	Likely to be unsuitable for use or site-specific use only
			Manapyane, LIM	3.0	Likely to be unsuitable for use or site-specific use only
			Tlhalampye, LIM	> 3	Likely to be unsuitable for use or site-specific use only
			Jane Furse, LIM	2.0	Likely to be unsuitable for use or site-specific use only
			Winnie Park, LIM	> 3	Likely to be unsuitable for use or site-specific use only
			Seshego Zone 5, LIM	> 3	Likely to be unsuitable for use or site-specific use only
			Mahwelereng, LIM	0.5	In target range
			Doornkraal, LIM	> 3	Likely to be unsuitable for use or site-specific use only
			New Pietersburg, LIM	> 3	Likely to be unsuitable for use or site-specific use only
			Mothlakaneng, LIM	> 3	Likely to be unsuitable for use or site-specific use only
			Emahobeni, EC	> 3	Likely to be unsuitable for use or site-specific use only
			Mputhi, EC	2.0	Likely to be unsuitable for use or site-specific use only
			Phakamisa Park, EC	> 3	Likely to be unsuitable for use or site-specific use only

Constituent not in SAWQG for Irrigation	Target range/guideline value	Reference	Site	Variable value	Comment
			Bongweni, EC	3.0	Likely to be unsuitable for use or site-specific use only
			New Payne, EC	2.6	Likely to be unsuitable for use or site-specific use only
			Silvertown, EC	> 3	Likely to be unsuitable for use or site-specific use only
			Orange Grove, EC	2.2	Likely to be unsuitable for use or site-specific use only
			KwaShange, KZN	12.5	Likely to be unsuitable for use or site-specific use only
			Emambedwini, KZN	8.5	Likely to be unsuitable for use or site-specific use only
			Emaqedini, KZN	5.7	Likely to be unsuitable for use or site-specific use only
			Boboyi, KZN	3.0	Likely to be unsuitable for use or site-specific use only
			Zolani, KZN	> 3	Likely to be unsuitable for use or site-specific use only
			Cato Manor, KZN	7.6	Likely to be unsuitable for use or site-specific use only
			Mayfield Ext., GP	21.8	Likely to be unsuitable for use or site-specific use only
			Durban MI, Kitchen	4.7	Likely to be unsuitable for use or site-specific use only
			Durban MI, Bath	0.6	In target range
			Durban MI, Laundry	3.1	Likely to be unsuitable for use or site-specific use only
Nitrogen as (Nitrite + Nitrate) (mg/ℓ)	Aquaculture: 0.5 NO_3 Livestock watering: 0-10 NO_2 0-100 NO_3	SAWQG Aquaculture, Vol 5; Livestock Watering, Vol. 7	Cato Crest, KZN	88	Likely to be suitable for selected or site-specific uses only
			Durban MI, Kitchen	0.14	In target range
			Durban MI, Bath	0.17	In target range
			Durban MI, Laundry	0.21	In target range
Oil and grease (mg/ℓ)	10	Indian General Standards (1983)	Redhill, WC	176	Likely to be unsuitable for use, or for site-specific use only

Constituent not in SAWQG for Irrigation	Target range/guideline value	Reference	Site	Variable value	Comment
			Fairyland, WC,	30	Likely to be unsuitable for use, or for site-specific use only
			Kleinmond, WC	29	Likely to be unsuitable for use, or for site-specific use only
			Masiphumelele, WC	242	Likely to be unsuitable for use, or for site-specific use only
			Sweet Home, WC	30	Likely to be unsuitable for use, or for site-specific use only
Phosphorus as orthophosphate (mg/ℓ)			Cato Crest, KZN	40	Suitability for use unclear
Phosphorus, total (mg/ℓ)	Aquaculture: 0.1 Aquatic ecosystems 5-25 (but see guide) Low risk, combined with appropriate irrigation and crop growing practices Up to 5 Moderate risk 5-10 High risk combined with appropriate irrigation and crop growing practices >10	SAWQG, Aquaculture, Vol. 6; Aquaculture, Vol. 7 Standen and McGuckian (2000)	Redhill, WC	27	Likely to be unsuitable for use or site-specific use only
			Fairyland, WC	88	Likely to be unsuitable for use or site-specific use only
			Kleinmond, WC	146	Likely to be unsuitable for use or site-specific use only
			Masiphumelele, WC	98	Likely to be unsuitable for use or site-specific use only
			Sweet Home, WC	144	Likely to be unsuitable for use or site-specific use only
			Masakhane, MP	> 5	Level uncertain, so suitability for use difficult to ascertain
			Doornkop, MP	> 5	Level uncertain, so suitability for use difficult to ascertain
			Mashati, LIM	> 5	Level uncertain, so suitability for use difficult to ascertain
			Manapyane,	5	Likely to be suitable for

Constituent not in SAWQG for Irrigation	Target range/guideline value	Reference	Site	Variable value	Comment
			LIM		use
			Tlhalampye, LIM	5	Likely to be suitable for use
			Jane Furse, LIM	1.6	Likely to be suitable for use
			Winnie Park, LIM	> 5	Level uncertain, so suitability for use difficult to ascertain
			Seshego Zone 5, LIM	> 5	Level uncertain, so suitability for use difficult to ascertain
			Mahwelereng, LIM	> 5	Level uncertain, so suitability for use difficult to ascertain
			Doornkraal, LIM	> 5	Level uncertain, so suitability for use difficult to ascertain
			New Pietersburg, LIM	> 5	Level uncertain, so suitability for use difficult to ascertain
			Mothlakaneng, LIM	> 5	Level uncertain, so suitability for use difficult to ascertain
			Emahobeni, EC	2.9	Likely to be suitable for use
			Mputhi, EC	1.3	Likely to be suitable for use
			Phakamisa Park, EC	1.9	Likely to be suitable for use
			Bongweni, EC	3.5	Likely to be suitable for use
			New Payne, EC	4.5	Likely to be suitable for use
			Silvertown, EC	> 5	Level uncertain, so suitability for use difficult to ascertain
			Orange Grove, EC	> 5	Level uncertain, so suitability for use difficult to ascertain
			KwaShange, KZN	57.4	Likely to be unsuitable for use or site-specific use only
			Emambedwini, KZN	112.4	Likely to be unsuitable for use or site-specific use only
			Emaqedini, KZN	115.6	Likely to be unsuitable for use or site-specific use only
			Boboyi, KZN	34.4	Likely to be unsuitable for use or site-specific use only
			Zolani, KZN	37.6	Likely to be unsuitable for use or site-specific use only
			Cato Manor, KZN	7.5	Likely to be suitable for use

Constituent not in SAWQG for Irrigation	Target range/guideline value	Reference	Site	Variable value	Comment
			Mayfield Ext., GP	240	Likely to be unsuitable for use or site-specific use only
			Cato Crest, KZN	69	Likely to be unsuitable for use or site-specific use only
			Durban MI, Kitchen	8.8	Likely to be suitable for use
			Durban MI, Bath	0.5	Likely to be suitable for use
			Durban MI, Laundry	91.1	Likely to be unsuitable for use or site-specific use only
Potassium (mg/ℓ)	Human consumption: 0-50	SAWQG, Domestic Use, Vol. 1	Cato Crest, KZN	31	Likely to be suitable for use
			Durban MI, Bath	3.6	Likely to be suitable for use
			Durban MI, Laundry	10.3	Likely to be suitable for use
Sulphate (mg/ℓ)	Human consumption: 0-200 Livestock watering: 0-1000	SAWQG, Domestic Use, Vol. 1; Livestock Watering, Vol. 5	Cato Crest, KZN	576	Likely to be suitable for use, site-specific factors may need to be considered
			Durban MI, Kitchen	41	Likely to be suitable for use
			Durban MI, Bath	10	Likely to be suitable for use
			Durban MI, Laundry	542	Likely to be suitable for use, site-specific factors may need to be considered

WC – Western Cape, MP – Mpumalanga, LIM – Limpopo, EC – Eastern Cape,
KZN – KwaZulu-Natal, GP – Gauteng
MI = Middle Income sewered households

Based on the comparison of measured greywater quality to available guidelines, the following list of greywater quality variables was identified for guideline development:

- Total coliforms
- Thermotolerant (faecal) coliforms / *E. coli*
- pH
- Electrical conductivity
- COD
- Boron
- Chloride
- Total nitrogen
- Nitrite/nitrate – important for assessing potential groundwater contamination
- Ammonia – important where greywater could enter freshwater courses
- Total phosphorus

- Potassium
- Sulphur
- NPKS ratio
- Sodium
- Calcium
- Magnesium
- SAR
- Alkalinity
- Oil and grease
- Total suspended solids
- Dissolved oxygen – important where greywater could enter freshwater courses

This list was too long for practical application because of cost and logistical barriers. Peer review via the Reference Group was used to identify those variables of greatest relevance specifically to irrigation use of greywater. These variables were:

- EC
- SAR
- *E. coli*
- pH
- Boron
- COD
- Oil and grease
- Suspended solids
- Total inorganic nitrogen
- Total phosphorus

4. Acknowledgements

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Case Study 4
Greywater Treatment

1. Aims

This case study aimed to evaluate greywater treatment systems which have been implemented and evaluated in South Africa

2. Introduction

This case study report consists of two parts. A qualitative study reviews a series of interventions for treatment of greywater at Moshoeshoe EcoVillage and at the Hull Street Project, both in Sol Plaatjies Municipality, Kimberley. A quantitative study follows, in which a biological system is evaluated. This system is based on experience with the systems in Sol Plaatjies Municipality, and is intended for implementation in Buffalo City Municipality.

The rationale behind the inclusion of a case study on greywater treatment systems is that in areas generating greywater of a quality not directly suitable for use, it may be possible to introduce relatively simple on-site systems which make it possible to use the treated greywater for beneficial purposes or simply to improve the quality of greywater prior to release into the environment. Where feasible, use for beneficial purposes is considered, for the purposes of this report, as the preferred option. This report builds on the overview of greywater treatment systems presented in the main body of the Technical Report.

3. Qualitative study: Sol Plaatjies Municipality (Kimberley)

3.1 Moshoeshoe EcoVillage, Sol Plaatjies Municipality (jointly developed and implemented by Sol Plaatjies Municipality and SIDA): Sedimentation and flotation tanks, sand filter and storage pond

The Moshoeshoe EcoVillage in Sol Plaatjies Municipality was developed as a pilot project for the Hull Street development in the same Municipality (the latter also jointly developed with the Swedish International Development Corporation, SIDA). The EcoVillage is served by dry sanitation (UD toilets) and hence requires provision for treatment and disposal of greywater.

The EcoVillage was built in 1999 and occupied in 2000. The initial greywater treatment system designed for the development of 11 households comprised a series of four serial compartments for grease trapping, followed by a sand filter. Greywater was treated at household level. Water from the sink and shower was led via a pipe with diameter 50 mm to a treatment system comprising four small serial compartments for grease trapping and then to a larger compartment containing a sand filter. The size of the whole unit was 1.95 m × 1.3 m × 0.84 m, corresponding to a volume of approximately 2.2 m^2. From there, a 100 mm pipe on the ground surface led treated greywater to a central storage pond, which also received stormwater from the surrounding area (Ridderstolpe, 2007). This was to be used to irrigate food gardens and the gardens of the associated Housing Support Centre (Schoeman, pers. comm., 2009; Van der Molen, pers. comm., 2009).

Initially, the system functioned and community gardening on the land adjacent to the pond was implemented successfully. However, the positioning of the outlet pipe resulted in the greywater treatment system becoming saturated with water. As a result, the sand filter became anaerobic instead of aerobic as planned. Investigation of the sand filters showed them to be clogged with a slimy anaerobic biofilm (Ridderstolpe, 2007). Conversations with the manager of the Sol Plaatjies Housing Company, which is responsible for the daily operations of the EcoVillage, and with the Stockholm Environment Institute (SEI) planning consultant responsible for liaison with SIDA, indicated that user abuse of the system played a significant role in its failure. Users flushed too much grease, fat and particulate matter into the system, resulting in clogging of the sand filter. Rice and other particulate matter also clogged the filters and stagnant water began to smell (Schoeman, pers. comm., 2009; Van der Molen, pers. comm., 2009). Consequently, all units were blocked several times, and some units became almost permanently blocked, with stagnant water of bad odour overflowing into the yard (Ridderstolpe, 2007).

Presently, the greywater treatment system is not functioning and cultivation of the land surrounding the pond has been abandoned. Greywater is discharged directly to the storage pond, together with stormwater from the surrounding area. This therefore functions as a form of waste stabilisation pond. It is not ideally suited to this purpose since it varies in depth from 1 m to 4 m, *i.e.* it is too deep for a stabilisation pond and also lacks an initial anaerobic pond.

The failure of the community gardening initiative was attributed both to the bad odour of the greywater and to changes in the community. While members of the community were initially willing to save water by using greywater, they were unwilling to use water which smelled bad and which they perceived as being unhealthy (Ridderstolpe, 2007). Members of the surrounding community became more economically stable, entered into jobs which left them too little time for cultivation of food gardens, and developed aspirations to a more urban lifestyle with convenience foods replacing home-grown produce (Schoeman, pers. comm., 2009; Van der Molen, pers. comm., 2009).

3.1.1 Conclusions

It is difficult to determine how well the system could have functioned had the outlet pipe been positioned such that the sand filter had operated as an unsaturated vertical flow aerobic filter. It is possible that surface ponding of greywater with unpleasant odours may not have occurred, had the system operated in accordance with the original design principles. Therefore, while the original design cannot be verified as functional for greywater treatment, it also cannot be fully rejected on the basis of experiences at Moshoeshoe Village. What can be concluded is that it is vital for construction and implementation of treatment designs be monitored closely to ensure that the original design principles are met.

This failure of this project also emphasises the importance of managing user involvement. Users became disillusioned with the system, failed to maintain it correctly and did not want to reuse the water for irrigation. Changes in community structure and aspirations were also not catered for in the plans for irrigation re-use.

3.2 Hull Street Project, Sol Plaatjies Municipality (jointly developed and implemented by Sol Plaatjies Municipality and SIDA)

3.2.1 History of greywater treatment and disposal at Hull Street

This project comprises an urban development of 114 households, served by dry sanitation (urine diversion toilets). Each household has a small private plot, and the units are arranged around a common area of ground. The design provided for on-site pre-treatment and subsequent use of greywater. The 114 units currently in existence represent the first phase of a larger project intended to provide 2 500 units. However, the project implementation did not progress beyond the first phase. The present housing units were built and occupied in 2002.

The topography of the land on which the Hull Street development is flat. The development is built on land previously belonging to a diamond mine. In parts of the development, soil has been removed and filled back with residuals from mining. The bedrock is covered by a thin (0.3 to 1.5 m) layer of top soil. This soil has a clayey nature, and is rich in calcareous and weathered material. The soil also shows a tendency to swell when wetted. The combination of thin soil layer and clayey nature of the soil makes the soil very impermeable for infiltration (Ridderstolpe, 2007).

Initial provisions for greywater (and urine from urine diversion toilets) encompassed leading the liquid into a soakaway of approximately 1 m^3 in the private plot associated with each unit. This was said to be temporary until a better solution was found (Ridderstolpe, 2007).

Soon after the soakaways went into operation, it became apparent that they were not adequate. By April 2004, some pits were found to have filled with water. Infiltration capacity was greatly reduced by swelling of the soil and formation of an anaerobic biofilm. By the beginning of 2006, the soakaways required emptying by a pump. The water was carried in a container by wheelbarrow to the central common land and was used to irrigate young trees (Ridderstolpe, 2007).

Temporary solutions implemented to counteract the reduction in infiltration from soakaways included the introduction of infiltration trenches (shallow trenches lined with plastic and filled with gravel and small stones) for disposal of greywater; grease traps (filled with plastic media to support biofilm) installed for kitchen water; and use of biocultures to improve degradation of entrapped sludge. None of the interventions was successful (Ridderstolpe, 2007; Schoeman, pers. comm., 2009; Van der Molen, pers. comm., 2009).

It had also originally been intended that the common ground be used to grow food crops, with irrigation use of some of the greywater fraction. Once again, this failed because of the community demographics. Most of the adult members of households in Hull Street were employed and worked long hours. This left little time for cultivation of crops. In addition, as commented for Moshoeshoe Village, there was an aspiration towards convenience foods rather than homegrown ones. Thus cultivation of the common ground never occurred (Schoeman, pers. comm., 2009; Van der Molen, pers. comm., 2009).

A small proportion of the residents used greywater from washing machines to water their gardens. These gardens were easily distinguishable from the other gardens at Hull Street by their lush vegetation (own observation).

3.2.2 Demonstration greywater treatment facility – mulch filter and resorption trench

The problems with stagnant ponding greywater on the surface caused frustration to Hull Street residents and to the management of the Sol Plaatjies Housing Company, to the extent that connection of greywater outlets to sewers was planned for 2007. In 2006, an intensive intervention was initiated at one household to attempt to solve the problem of on-site treatment of greywater and its disposal by infiltration and evapotranspiration. The intervention was designed by Peter Ridderstolpe and implemented by a team led by Michelle van der Molen (SEI, consultant on site in Kimberley), all under the guidance of Prof. Håkan Jonssen of SEI. It was based on experience gained with similar greywater treatment units in Sweden, taking into account the local soil profile and topography at Hull Street (Ridderstolpe, 2007).

A lesson learned from the history of greywater treatment at Hull Street was that blockages were to be expected if the greywater was led to infiltration without being sufficiently pre-treated to reduce SS and BOD significantly. This could be achieved by an above-ground biofilter, which would allow both microorganisms and macro-fauna such as earthworms to contribute to biodegradation of organic matter in the greywater. It would also make water and nutrients in the water more readily available for plant uptake (Ridderstolpe, 2007).

The treatment process proposed involved:
1) Removal of SS by straining through mulch in a mulch tower.
2) Degradation of organics (BOD) by soil fauna within the mulch tower, resulting in conversion of fats, oils, proteins and carbohydrates to humics.
3) Removal of water by infiltration and transpiration via a resorption bed (Ridderstolpe, 2007).

This combination of treatment processes had been applied previously in other situations, notably in Sweden, but required some modification for the specific requirements of the Hull Street situation. In particular, the system had to be extremely robust and efficient with respect to resorption since the topography did not allow for surface discharge and since the soil was shallow and impermeable (Ridderstolpe, 2007).

It should be noted that in soils with little capacity for infiltration, such as those in Hull Street, it is essential that SS and BOD are removed *prior* to infiltration so that clogging of the soil and subsequent development of anaerobic biofilm (causing even further clogging) can be avoided. For this reason, the proposed system separated the processes of straining, degradation of organics and resorption into separate treatment units. These were as follows:

1) A mulch tower (as above), for straining and degradation of particulates, and fats and grease (Unit A in Figure 26)
2) An artificial infiltration unit (Infiltra®), which provided a large surface area for biofilm formation, the purpose of which was BOD removal (Unit B in Figure 26)
3) A gravel-filled trench which acted as a resorption bed, directing the treated greywater to the surrounding soil (Unit C in Figure 26) (Ridderstolpe, 2007).

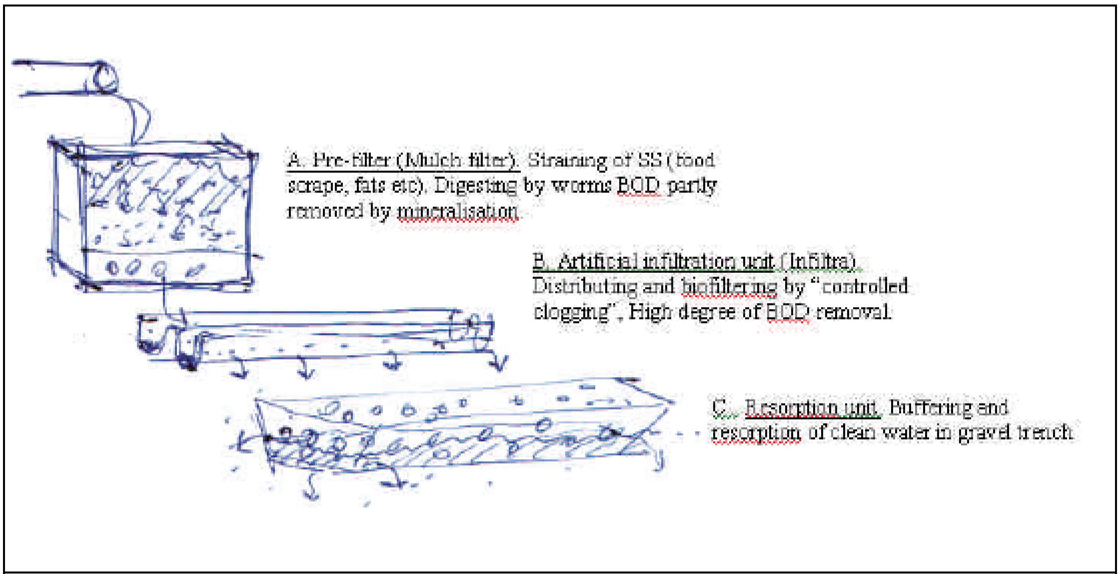

Figure 26: System of three treatment units suggested for treatment of greywater in Hull Street (from Ridderstolpe, 2007 – used with permission).

Mulch tower
The requirement for this unit was that it should have a high capacity for drainage while simultaneously providing adequate capacity for straining of particulates and a favourable environment for the growth of macro- and micro-fauna capable of aerobic degradation of organic matter. Introduction of earthworms to add a vermicomposting function is a possible extension of this concept (Ridderstolpe, 2007).

Infiltra
This was an adaptation of the Infiltra® concept originally developed by Ridderstolpe. It comprised a corrugated surface providing a total surface area of 6 m^2 for biofilm formation. This estimate was based on an assumption of minimal BOD removal in the mulch filter, which represents a worst case scenario (Ridderstolpe, 2007).

Resorption bed
This took the form of a long, narrow gravel trench which provided a large surface area for resorption. The pore volume in the gravel under the Infiltra layer was

calculated to provide 1 m^3 storage, corresponding to a four to five day worst case load. The resorption rate of the site was estimated at 40-50 mm per day. Planting of shrubs above the trench would provide for most of the necessary water removal by transpiration (Ridderstolpe, 2007).

The overall design load was:

Flow: 180 ℓ/d (maximum 200 ℓ/d for short periods)
TS: 350 g/d
COD: 300 g/d
BOD: 70 g/d

This design was implemented in January 2006 at one house in the Hull Street housing project, intended as a demonstration unit. In March 2006 earthworms were added to the mulch tower. The system functioned satisfactorily for a 10 month period until November 2006, when it was decommissioned. During this period, water consumption of the household ranged from 50 ℓ/d to 300 ℓ/d. A return rate of 75% as greywater has been estimated by Carden *et al*. (2007), although it may have been less in this case since the homeowner used greywater to water his garden. The system was able to absorb the additional load from extremely high rainfall in January to June 2006 when Kimberley received 2 000 mm of rain, ten times the average rainfall for the area. During the high rainfall period, greywater and stormwater ponded in all surrounding yards, but not in the yard of the demonstration greywater treatment unit. Monitoring of the mulch tower and of the Infiltra showed no sign of development of anaerobic conditions. Upon decommissioning, the gravel of the resorption bed and the geotextile lining the resorption bed looked unchanged, indicating that the SS and BOD loads were successfully removed before the resorption bed (Ridderstolpe, 2007).

3.2.3 Conclusions

The on-site greywater system, comprising a mulch tower, Infiltra and resorption bed, worked according to design and could have been more widely implemented. Unfortunately, the intervention came too late to change plans for connecting greywater outlets from the entire Hull Street to a central sewer. However, the system demonstrated that successful on-site (household-based) treatment of greywater is possible, even in areas of flat topography and impermeable soil.

An important observation which arises out of this experience is the necessity to have both the manager of any greywater treatment/management project and all members of households served by the project committed to its success. Part of this commitment depends on community education and a pro-active community involvement plan, which were in place at Hull Street. Part is dependent on thorough design and testing of the intended greywater intervention prior to full-scale implementation. In this instance, a number of interventions had been tested and had failed before the successful demonstration system described here was implemented. By that time, many of the residents of the Hull Street housing project, and most importantly its manager, had lost interest and faith in the greywater management system. This, and not failure of the greywater treatment itself, ultimately led to decommissioning of on-site greywater management at Hull Street.

4. Quantitative study: An evaluation of an on-site biological greywater treatment system exposed to different loading scenarios

4.1 Introduction

This section of the report describes a quantitative experimental study to evaluate a combination of primary and secondary treatment processes for treatment of greywater. It is conceptually derived from the treatment system implemented as a demonstration facility in the Hull Street Project, as described in the preceding section. The specific combination of components tested in this investigation was designed for implementation in a low-cost ecological housing pilot project in Buffalo City Municipality, South Africa (Ridderstolpe, 2004; Whittington-Jones, 2007). The system comprised a mulch tower as primary treatment and a subsurface resorption bed with embedded infiltration zone (Infiltra) as secondary treatment. The mulch tower was designed to serve a dual function as a filter, in removing the suspended solids of greywater, and as a site for biodegradation, where the filtrate could be broken down by aerobic micro- and macro-organisms (Ridderstolpe, 2007; Whittington-Jones, 2007). Effluent from the mulch tower drained into the resorption bed with Infiltra, which comprised the below-ground secondary treatment stage. Water travelling through the resorption bed permeated through the geotextile lining the resorption bed and entered the environment.

The aim of the quantitative study was to determine the treatment efficiency of the mulch tower, Infiltra and the resorption bed individually, and of the treatment system overall, when subjected to different loading scenarios. These loading scenarios were intended to represent typical household greywater generation scenarios. Variations in loadings could be a factor affecting the overall performance of household level greywater treatment systems. Since effluent from the treatment system was released into the environment, the study also aimed to determine if the effluent complied with the South African standards for effluent discharge.

4.2 Materials and methods

4.2.1 Experimental protocol

The greywater treatment system was constructed at the Pollution Research Group (PRG) experimental site at the Howard College Campus of the University of KwaZulu-Natal. Greywater for the study was sourced from 5 low-income households in the Cato Manor informal settlement in close proximity to the University. Greywater was collected on a daily basis (week days) and delivered to the University by eThekwini Water and Sanitation Services. All greywater was thoroughly mixed on site prior to use. The study comprised a stabilizing stage and an experimental stage. Results for the stabilising stage are not reported here.

4.2.2 Treatment system design

The greywater treatment system consisted of a mulch tower (Figure 27), and a sand biofilter encapsulated with geo-textile (Infiltra) with a sub-surface resorption bed and was dimensioned to biologically treat 200 ℓ of greywater per a day. (Figure 28 and

Figure 28; Whittington-Jones, 2007). Effluent left the mulch tower in a 50 mm polypropylene pipe which emptied into the Infiltra. The Infiltra consisted of stone chips encapsulated with geotextile and lay within the resorption bed. The resorption bed also consisted of stone chips, and was lined and enclosed with geotextile. In accordance with Ridderstolpe (2007), biofilm development in the Infiltra was expected to serve as a site for removal of COD and BOD and to facilitate even distribution of the influent on the resorption bed. The base of the resorption bed also allowed for biofilm development, which was expected to remove the bulk of the COD and possibly to contribute to removal of nutrients and waste-derived microorganisms (Ridderstolpe, 2007).

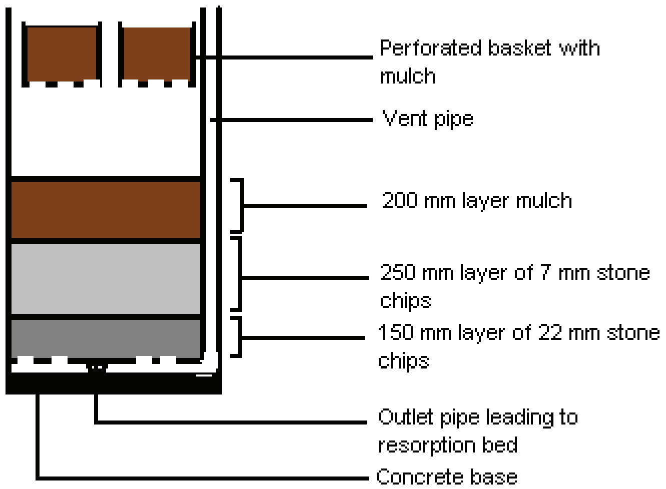

Figure 27: Cross section of mulch tower (not drawn to scale, adapted from Ridderstolpe, 2007, and Whittington-Jones, 2007).

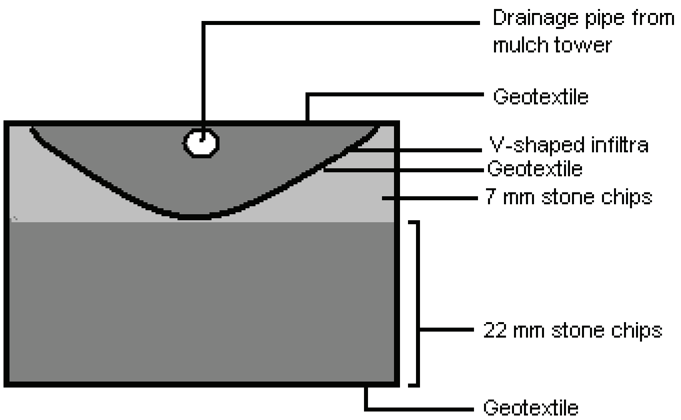

Figure 28: Cross section of sub-surface resorption bed (not drawn to scale, adapted from Whittington-Jones, 2007).

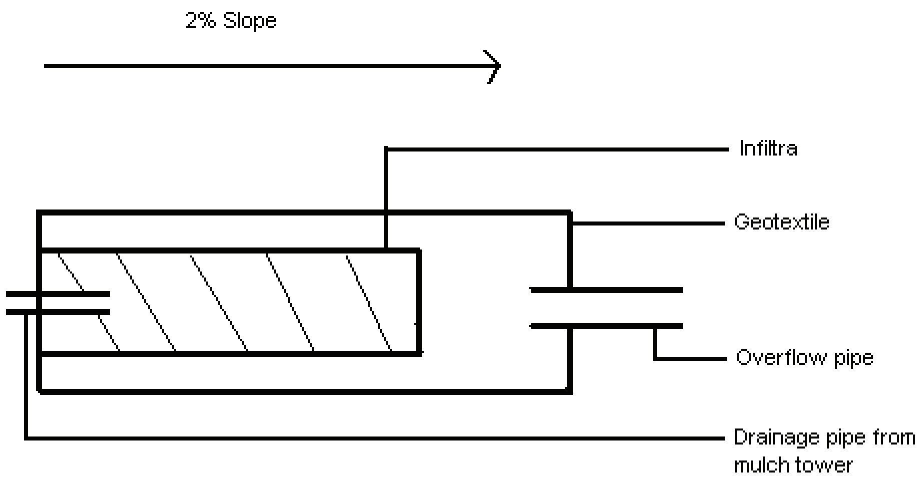

Figure 29: Longitudinal section of sub-surface resorption bed (not drawn to scale, adapted from Whittington-Jones, 2007).

4.2.3 Experimental greywater loading of treatment system

The experimental phase of the study was conducted for seventeen days in total, representing two treatments, each at three greywater loadings. Greywater was fed into the biological system on a daily basis at two times (09h00 and 17h00). Volumes of greywater were varied to represent different operating scenarios (Table 17). Each experiment included three different volumes of application, representing differences in both flow and loading (Table 17).

Table 17: Description of the greywater application and measurement periods in the evaluation of the greywater treatment system as described.

Treatment set	Duration (days)	COD load (%)	Volume (ℓ) of untreated greywater applied daily
1	5	100% COD – The maximum volume of greywater produced by households, using the full free basic water provision as at the time of planning.	200 ℓ – this represented 100% return rate of the free basic water provision at the time of planning the experiment.
1	3	50% COD – The volume of greywater was halved to represent the situation in which some household members were absent.	100 ℓ
1	3	175% COD – Extra greywater was added to represent the situation of additional load on the system.	300 ℓ
2	2	100% COD	200 ℓ
2	2	50% COD	100 ℓ
2	2	175% COD	300 ℓ

Samples of the inflow water to the mulch tower, the outflow from the mulch tower and the outflow from the Infiltra and resorption bed, respectively, were taken on a daily basis in triplicate and analysed. During the experiment, on the first and last day of each loading treatment, pH, EC, COD, SS, ammonia-nitrogen (ammonia-N) and total phosphorous concentrations, and *Escherichia coli* and total coliform counts were determined. Chemical oxygen demand and SS were measured by the open reflux dichromate method and gravimetric method, respectively (Standard Methods, 2005). Total coliform bacteria and *E. coli* were analysed by standard membrane filtration techniques according to Ayres and Mara (1996), with incubation of membrane filters on Chromocult coliform (Merck).

4.2.4 Statistical analysis

Data were captured in Microsoft Excel and analysed using Statistical Package for Social Sciences (SPSS) version 15.0. Data were tested for normality of distribution using the Kolmogorov-Smirnov test. Analysis of variance (ANOVA) with repeated measures was used to test for significance of differences of means in COD, SS, pH, EC, total phosphorous, ammonia-N, *E. coli* (log-transformed) and total coliform (log-transformed) levels amongst the untreated greywater and effluent leaving the mulch tower, Infiltra and resorption bed, and between the two sets of treatments. It should be noted that a limitation of the statistical analysis is that triplicate results are pseudoreplicates, not true replicates, since all were taken from the same treatment system. This limitation was unavoidable since it was not possible to construct more than one pilot treatment system for this study.

4.3 Results and discussion

There were minor fluctuations of pH in untreated greywater and effluent from each treatment stage during the experimental period (Figure 30A). The pH of untreated greywater and of effluent leaving each treatment stage were not significantly different ($p>0.05$). In the present study the pH of effluent leaving the treatment system ranged from 5.9 to 7.8, which falls within the General Limit for discharge of wastewater (DWAF, 2004). This indicates that effluent leaving the treatment system would not be expected to alter the surrounding soil characteristics.

There were relatively greater fluctuations in EC than in pH in untreated greywater and effluent leaving each treatment stage during the experimental period (Figure 30B). The EC of untreated greywater and of effluent leaving each treatment stage were significantly different ($p\leq 0.05$). However, there did not appear to be any clearly observable trend in electrical EC over time and removal of EC was minimal. The EC both before and after treatment was well within the General Limit for discharge of wastewater (150 mS/m) (DWAF, 2004).

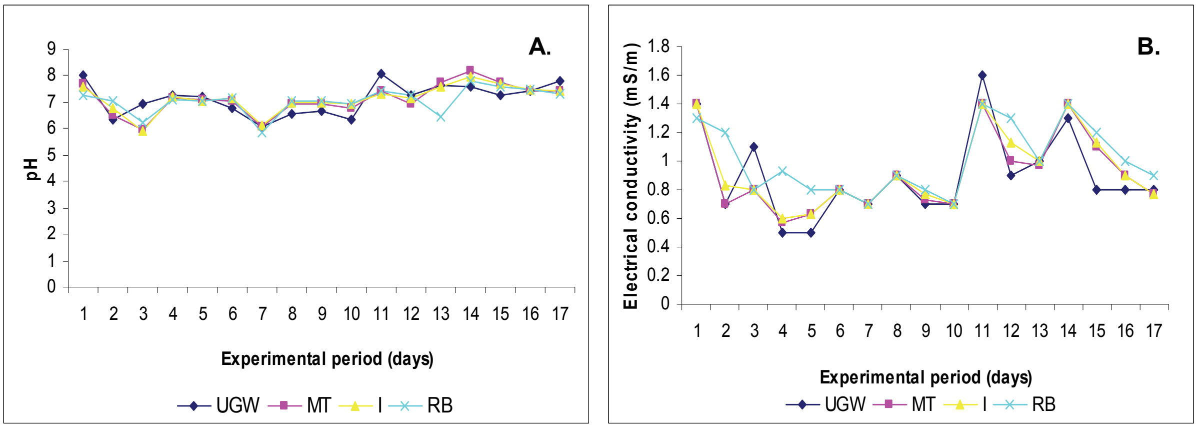

Figure 30: A) Mean pH of untreated greywater and effluent from each treatment stage during the experimental period (1-17 days) (n=3 for each treatment stage) and, B) Mean electrical conductivity of untreated greywater and effluent from each treatment stage during the experimental period (1-17 days) (n=3 for each treatment stage).UGW – untreated greywater, MT – mulch tower, I – Infiltra, RB – resorption bed

According to Eriksson *et al.* (2002), COD of greywater ranges from 5 to 1 460 mg/ℓ and in the current study the COD of untreated greywater used for the experiment varied from 776.5 to 4 984 mg/ℓ. This indicates that the raw greywater which was used during the experimental period represented a high organic load which was moreover highly variable. The COD of the effluent leaving the treatment system during the experimental period ranged from 93.6 to 1 709.9 mg/ℓ, showing 66% removal efficiency (Figure 31). However, COD removal changed over time in response to variation in greywater feed. It also appears that a consistent removal did not exist for a particular loading volume. Assessing removal efficiency amongst the treatment stages, the mulch tower appeared to remove a high concentration of COD particularly at the end of the first set 200 ℓ and 300 ℓ treatments, with minimal contribution from the secondary treatment processes. The COD of untreated greywater and effluent leaving each treatment stage were significantly different ($p \leq 0.05$). The mean COD of effluent leaving the treatment system exceeded the General Limit for wastewater discharge (75 mg/ℓ COD after removal of algae) but fell below the limit specified for irrigation use of no more than 500 m^3 of biodegradable wastewater per day (DWAF, 2004). Thus, on the basis of COD, this system produced effluent quality suitable for small-scale irrigation use.

A study conducted by Gross and Soares (2008), using a small scale on-site recycled vertical flow constructed wetland, showed that that system had a greater COD removal efficiency (80%), with the untreated greywater having a COD of 230 mg/ℓ and effluent leaving the treatment system having a COD of 45 mg/ℓ. Another study conducted by Jefferson *et al.* (1999), using a sand filter system, showed that this system had a similar COD removal efficiency to the small-scale recycled vertical flow constructed wetland. The greater removal efficiency in the small-scale recycled vertical flow constructed wetland may be due to the treated water being circulated continuously into the treatment system. This suggests that contact time of polluted water with the treatment system increases COD removal. Although the mulch tower was apparently the most effective treatment stage in removing chemical oxygen demand, Figure 31 indicates that the secondary process did contribute slightly to COD removal. Therefore, the removal efficiency may be improved at the Infiltra and resorption bed by increasing the contact time of polluted water within these treatment stages.

In the current study, SS in the untreated greywater used during the experimental period ranged from 0.09 to 1.9 mg/ℓ (Figure 32). This suggests that the treatment system was fed with greywater that had very low SS content. Although this makes it difficult to evaluate the capacity of the system to remove SS, indications are that the treatment system did reflect capacity to remove SS, and that most of this removal occurred in the mulch tower. This observation is based on the relatively few occasions when the raw greywater had high SS levels, namely, at the end of the first set 200 ℓ and 300 ℓ treatment and at the end of the second set of 300 ℓ treatment (Figure 32). The SS of untreated greywater and effluent leaving each treatment stage were significantly different ($p \leq 0.05$). Figure 32 indicates that SS in the greywater varied widely and that the treatment system was robust enough to deal with the fluctuating SS load. Suspended solids in effluent leaving the treatment system ranged from 0.03 to 0.28 mg/ℓ (85% SS removal efficiency), which falls below the General Limit for discharge of wastewater (25 mg/ℓ) (DWAF, 2004). However, since SS in the raw greywater also fell below the General Limit, it is difficult to draw conclusions regarding the capacity of the system to treat greywater to within the SS limit.

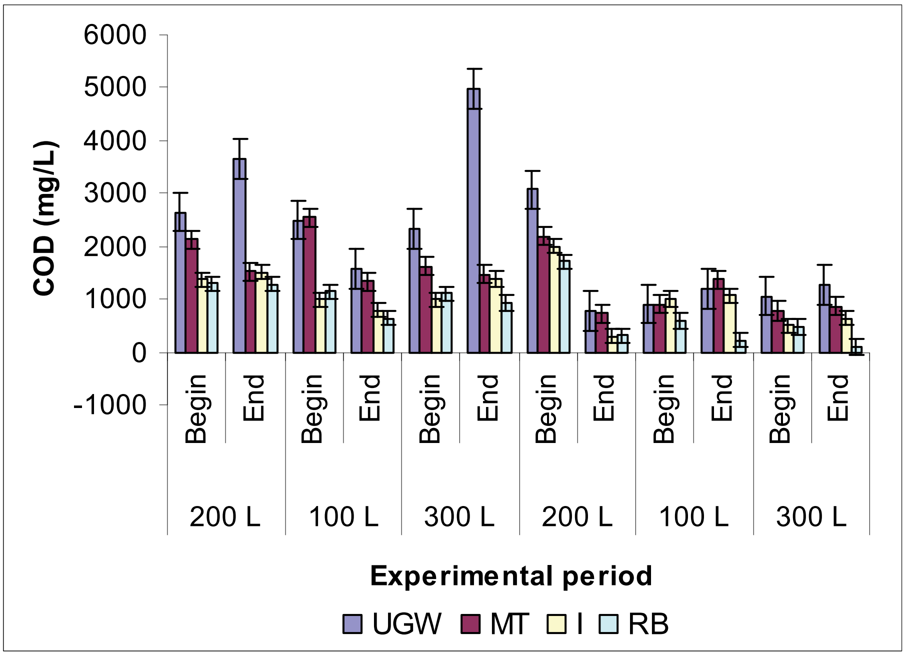

Figure 31: Mean chemical oxygen demand (COD) (mg/ℓ) (± standard error) in untreated greywater and effluent from each treatment stage during the experimental period (n=3 for each treatment stage) .The study consisted of two measurement periods with three treatments each (200 ℓ, 100 ℓ and 300 ℓ greywater feed) and measurements were taken on the first and last day of each treatment. UGW – untreated greywater, MT – mulch tower, I – Infiltra, RB – resorption bed.

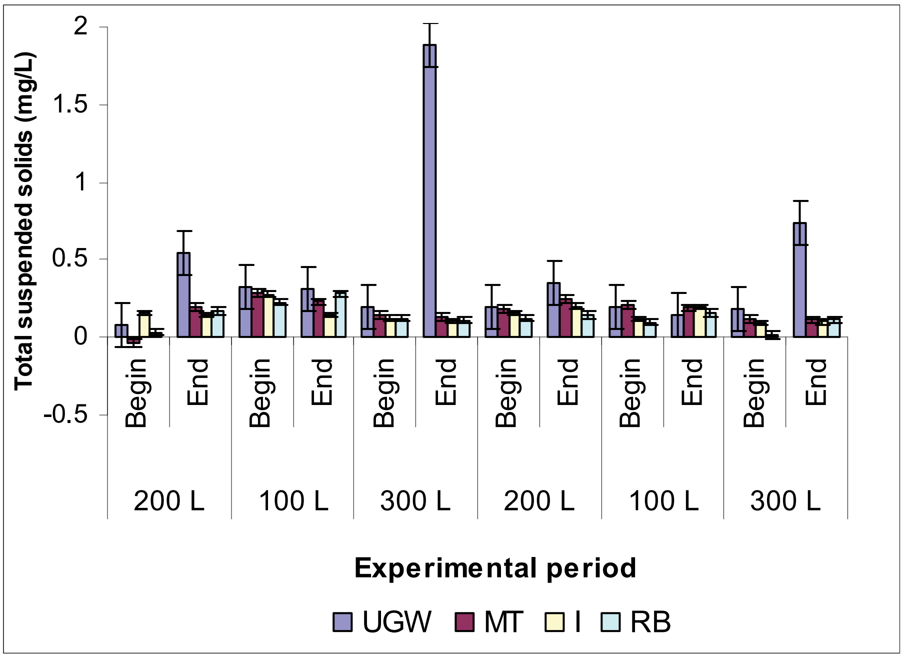

Figure 32: Mean suspended solids (SS) (mg/ℓ) (± standard error) in untreated greywater and effluent from each treatment stage during the experimental period (n=3 for each treatment stage). The study consisted of two measurement periods with three treatments each (200 ℓ, 100 ℓ and 300 ℓ greywater feed) and measurements were taken on the first and last day of each treatment. UGW – untreated greywater, MT – mulch tower, I – Infiltra, RB – resorption bed.

Figure 33 shows ammonia-N removal during the middle of the experimental period and both primary and secondary treatment processes contributing to the removal of ammonia-N at the end of the first set 100 ℓ treatment, during the 300 ℓ treatment and during the second set 200 ℓ treatment. During this period ammonia-N concentration in the untreated greywater ranged from 11.8 to 58.5 mg/ℓ and ammonia concentration in the effluent leaving the treatment system ranged from 13.6 to 40.7 mg/ℓ. This suggests that the steady ammonia-N removal during the middle of the experimental period may be due to the stabilising of biofilm within the secondary stages of the treatment system. The removal efficiency as measured in this study was not sufficient to reduce ammonia-N concentrations to below the General Limit value of 6 mg/ℓ (DWAF, 2004). However, no ammonia-N limit is specified for irrigation use of less than 500 m^3 of biodegradable wastewater per day (DWAF, 2004), so the effluent was potentially suitable for small-scale irrigation use.

Towards the end of the experimental period the ammonia-N concentration in effluent from each treatment stage increased (Figure 33). This suggests that fluctuations of ammonia-N concentrations may have been due to shearing of biofilm that occurred as a result of high peak greywater flow rates or of change in greywater loading volume. The previously quoted study by Gross and Soares (2008) showed that a small-scale recycled vertical flow reed bed could remove both organic and inorganic forms of nitrogen to within most effluent guidelines. Thus the biological system tested here was inferior to that described by Gross and Soares (2008) with respect to nitrogen removal. It remains to be determined whether longer measurement periods and more realistic peak flow rates would have reflected ongoing improvement in ammonia-N removal of the system.

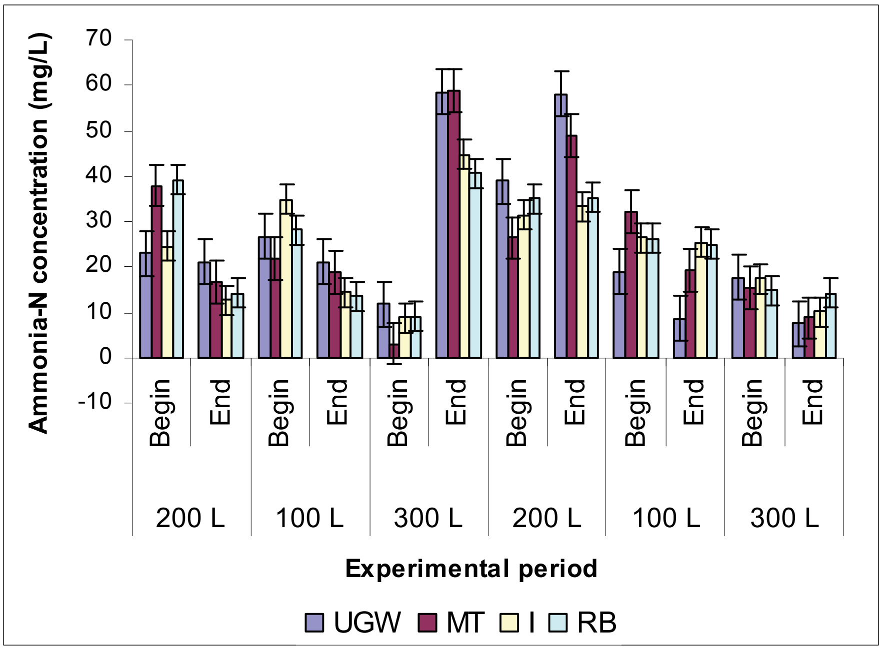

Figure 33: Mean ammonia-N concentration (mg/ℓ) (± standard error) in untreated greywater and effluent from each treatment stage during the experimental period (n=3 for each treatment stage). The study consisted of two measurement periods with three treatments each (200 ℓ, 100 ℓ and 300 ℓ greywater feed) and measurements were taken on the first and last day of each treatment. UGW – untreated greywater, MT – mulch tower, I – Infiltra, RB – resorption bed.

It appeared that that phosphorus removal followed a similar trend to that observed for ammonia-N (Figure 34), although it is less pronounced. Towards the end of the first set of treatments, effluent leaving the treatment system had a lower total phosphorous concentration than the untreated greywater. During this period it appears that the mulch tower removed a large amount of phosphorous with minimal contribution from the secondary treatment processes. Figure 34 also indicates that the phosphorus concentration in greywater varied widely and that the treatment system was sufficiently robust to deal with fluctuating phosphorus load. The total phosphorous concentration in effluent leaving the treatment system during the experimental period ranged from 6.1 to 31.9 mg/ℓ. This exceeds the General Limit value of 10 mg/ℓ (DWAF, 2004); therefore discharge from the treatment system could give rise to various adverse effects such as eutrophication if it entered surface waters. However, there is no limit for phosphorus specified for irrigation use of less than 500 m^3 of biodegradable wastewater (DWAF, 2004); therefore effluent was potentially suitable for small-scale irrigation use.

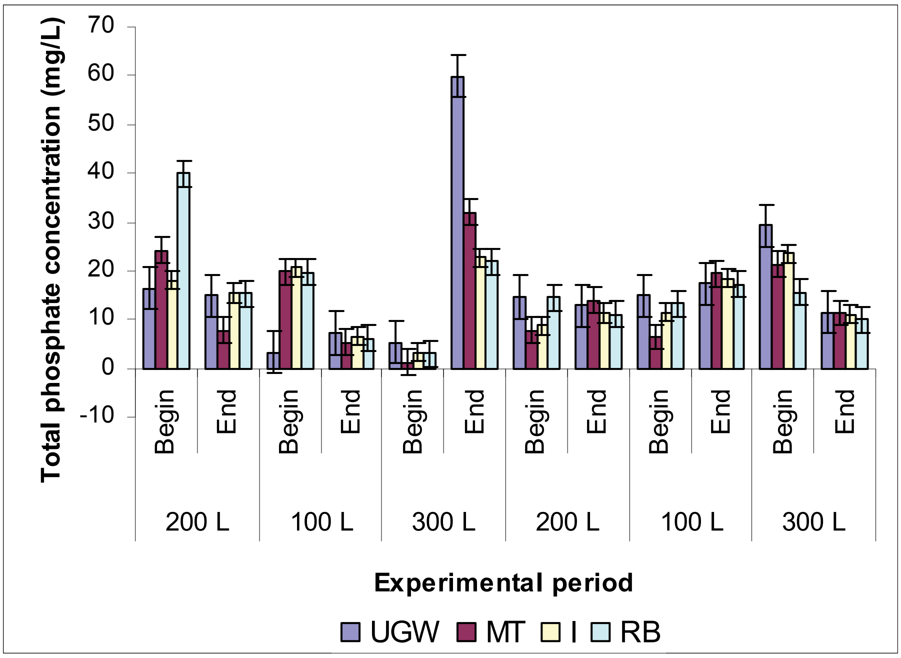

Figure 34: Mean total phosphorus concentration (mg/ℓ) (± standard error) of untreated greywater and effluent from each treatment stage during the experimental period (n=3 for each treatment stage). The study consisted of two measurement periods with three treatments each (200 ℓ, 100 ℓ and 300 ℓ greywater feed) and measurements were taken on the first and last day of each treatment. UGW – untreated greywater, MT – mulch tower, I – Infiltra, RB – resorption bed.

There were high numbers of *E. coli* and total coliform bacteria in the incoming greywater, and the greywater treatment system did not remove these significantly (Figure 35). In the first set of treatments, it appeared that the mulch tower, Infiltra and the resorption bed released *E. coli* into the effluent. This suggests that the high number of colonies in effluent may be due to release from the organic and inorganic media as a result of high peak flow rates. The General Limit for discharge of wastewater specifies 10^3 faecal coliforms/100 mℓ (comparable to *E. coli*, but usually higher) (DWAF, 2004), thus effluent from this treatment system is not suitable for discharge to the environment. However, the limit specified for irrigation use of up to 500 m^3 of biodegradable wastewater per day is 10^5 faecal coliforms/100 mℓ (DWAF, 2004) and this is of the same order as the *E. coli* levels detected in the effluent. It is thus likely that the effluent would be suitable for small-scale irrigation use.

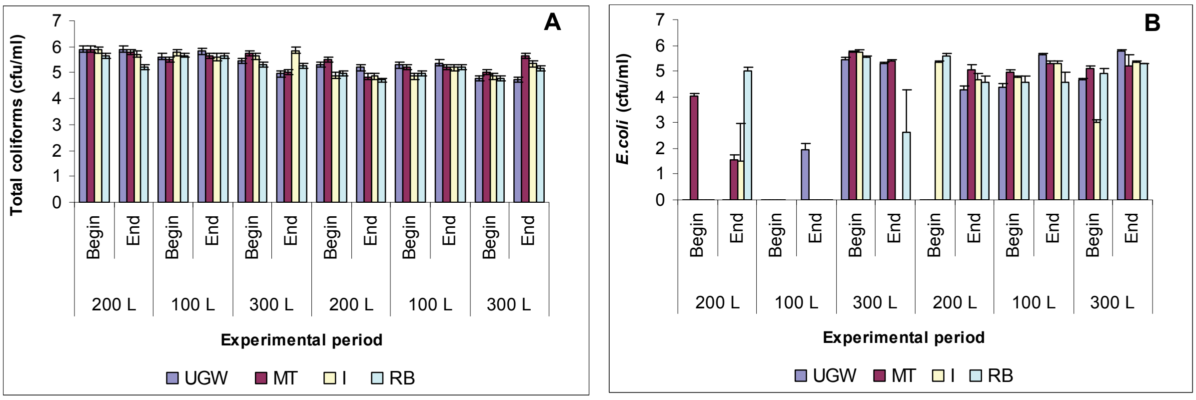

Figure 35: Mean log transformed numbers of A) total coliforms (number of colonies per ml) (± standard error); and B) *E. coli* in untreated greywater and effluent from each treatment stage during the experimental period (n=3 for each treatment stage). The study consisted of two measurement periods with three treatments each (200 ℓ, 100 ℓ and 300 ℓ greywater feed) and measurements were taken on the first and last day of each treatment. UGW – untreated greywater, MT – mulch tower, I – Infiltra, RB – resorption bed

4.4 Conclusions

For most of the measured parameters, removal varied with changes in greywater load and was also not consistent for a particular loading volume tested. Therefore the variation in inflow greywater volume did affect treatment performance over time.

It was also observed that the mulch tower was the most effective treatment stage in removing most of the measured parameters in the minimal time frame. The lag in performance in the secondary treatment stage may indicate that there was insufficient time for biofilm development. Therefore, the system required a longer period to reach pseudo-steady state and this can be achieved in future studies by extending the treatment system stabilising stage. This study also demonstrated that time is indeed a factor that affects the start-up of on-site filter-biofilm systems.

No appreciable removals of health-related indicator bacteria *viz.* total coliforms and *E. coli* was achieved and means to enhance removal should be addressed to prevent potential health risks resulting from contact with the effluent. The effluent from the greywater treatment system did not comply with standards permitting discharge thereof into the environment. However, the potential for re-use for irrigation in small-scale irrigation was noted.

5. Acknowledgements

The qualitative study was funded by the Water Research Commission. The quantitative study was funded by the Stockholm Environment Institute, Sweden, and the Water Research Commission. EThekwini Municipality is thanked for logistical support.

Case Study 5
Impact of Cleaning Products on Greywater Quality

1. Aims

This desk study aimed to determine the contribution of representative South African cleaning products to typical levels of the greywater quality constituents identified in Case Study 3.

2. Methods

Unilever SA provided tables of estimated concentrations of greywater quality variables in greywater, based on proprietary information. The estimation assumed that an average household comprising four to five people utilises 23 000 ℓ water per month. This figure was based on market surveys performed on behalf of Unilever.

The data provided by Unilever were compared to corresponding values in the South African Water Quality Guideline for irrigation (DWAF, 1996), where these were available.

3. Results

Three estimates of concentrations of cleaning products in greywater are presented. Table 18 gives a general overview of the contribution of a range of products to levels of chloride, nitrate/nitrite, phosphorus, sulphur, sodium, and oils and grease in greywater, assuming a water consumption of 23 000 ℓ per month for an average household, as indicated by Unilever consumer surveys. Table 19 and Table 20 present the cumulative monthly contribution of cleaning products which might be expected to be in regular use in a household. Table 19 lists those products expected to be in use in households in the socio-economic groups which represent the majority of the population. This assumes a monthly water consumption of 23 000 ℓ, the household uses soap to bath and dishwashing liquid to wash dishes. Table 20 lists products likely to be used in upper socio-economic groups, using dishwashing powder for dishwashers. Both tables include values in the South African Water Quality Guidelines, for comparison purposes. Only in the case of sodium did cleaning products in greywater represent a major contribution towards the concentration in the target range of the guideline. The greatest contributor to sodium in greywater was laundry powder, followed by dishwashing powder which was much higher in sodium than was dishwashing liquid. Consequently, the total sodium contribution to greywater from cleaning products was greater in households using dishwashers than in households using dishwashing liquids.

Table 18: Estimated contribution of cleaning products to greywater quality, assuming that the average household, comprising 4-5 members, utilises 23 000 ℓ of water per month.

Product	**Chloride (mg/ℓ)**	**Nitrite/Nitrate (mg/ℓ)**	**Total phosphorous (mg/ℓ)**	**Sulphur (mg/ℓ)**	**Sodium (mg/ℓ)**	**Oil and grease (mg/ℓ)**
Dishwashing Liquid (5 mℓ in 5 ℓ = 1.04 g in 1 ℓ)				1.19	0.46	
Dishwashing powder (30 g in 20 ℓ)	0.24	0.14	3.22		14.39	
Laundry powder (high suds) (114 g in 25 ℓ)			6.77	2.15	25.67	
Bath soap, bucket (5 g in 25 ℓ)	0.0016				0.572	3.36
Shower gel (9.50 g in 66.5 ℓ)	0.0038				0.32	
Shampoo (12 g in 6.24 ℓ)	0.038			0.059	0.068	
Conditioner (6 g in 9.21 ℓ)	0.00029	0.00012			0.0012	

Table 19: Estimated contribution of cleaning products to greywater quality, assuming that the average household, comprising 4-5 members, utilises 23 000 ℓ of water per month and assuming that household members use solid soap bars and wash dishes using dishwashing liquid (majority of population).

Product	**Chloride (mg/ℓ)**	**Nitrite/Nitrate (mg/ℓ)**	**Total phosphorous (mg/ℓ)**	**Sulphur (mg/ℓ)**	**Sodium (mg/ℓ)**	**Oil and grease (mg/ℓ)**
Dishwashing liquid				1.19	0.46	
Laundry powder (high suds)			6.77	2.15	25.67	
Bath soap	0.0016				0.572	3.36
Shampoo	0.038			0.059	0.068	
Conditioner	0.00029	0.00012			0.0012	
Total compound generated per litre of water considering the frequency of activities per month	**0.04**	**0.00012**	**6.77**	**3.39**	**26.77**	**3.36**
South African Water Quality Guideline for irrigation (DWAF, 1996) Target range	100	5 mg/ℓ as inorganic N (crop) 0.5 mg/ℓ as inorganic N (irrigation structures)			70	

Table 20: Estimated contribution of cleaning products to greywater quality, assuming that the average household, comprising 4-5 member, utilises 23 000 ℓ of water per month and assuming that household members use solid soap bars and wash dishes using dishwasher powder (small sub-population).

Product	**Chloride (mg/ℓ)**	**Nitrite/Nitrate (mg/ℓ)**	**Total phosphorous (mg/ℓ)**	**Sulphur (mg/ℓ)**	**Sodium (mg/ℓ)**	**Oil and grease (mg/ℓ)**
Dishwashing powder	0.24	0.14	3.22		14.39	
Laundry powder			6.77	2.15	25.67	
Bath soap	0.00				0.572	3.36
Shampoo	0.038			0.059	0.068	
Conditioner	0.00029	0.00012			0.0012	
Total compound generated per litre of water considering the frequency of activities per month	**0.28**	**0.14**	**9.99**	**2.21**	**41**	**3.36**
South African Water Quality Guideline for irrigation (DWAF, 1996) Target range	100	5 mg/ℓ as inorganic N (crop) 0.5 mg/ℓ as inorganic N (irrigation structures)			70	

4. Conclusions

The major contributor of cleaning products to potential adverse effects of greywater use for irrigation is sodium. This affects salinity and sodicity of soil, with impacts on plant growth and yield and on soil structure.

5. Acknowledgements

This study was made possible by Unilever SA.

Case Study 6
Estimating Greywater Volumes for Irrigation

1. Aims

The aim of this desk study was to develop a method for estimating greywater volumes which could be applied in small-scale irrigation and which would reflect varying agroclimatic conditions across South Africa as well as site-specific factors affecting water use such as soil type and recent rainfall. The final product was intended to be simple to use by users with little or no background in irrigation planning.

2. Methods and results

The equation for calculating estimated water use (EWU) as described in the Technical Report, taken from Green (1985) and other similar literature, was used (Equation 7 in the main body of the Technical Report). It is repeated here for convenience, as Equation 2. Other means of estimating plant water use are reviewed in the main body of the Technical Report.

$$EWU = E_0 \times CF \times HA \qquad \textbf{Equation 2}$$

EWU is estimated water use
E_0 is the reference evapotranspiration
CF is a species-specific crop factor
HA is the area to be irrigated, all measures expressed in metric units.

To make the values of EWU relevant to the South African context, local estimates of E_0 were sought.

2.1 Estimating reference evapotranspiration (E_0)

Reference evapotranspiration (E_0) depends on local climatic conditions. Means of measuring E_0 are discussed in the main body of the Technical Report. To simplify the provision of figures for E_0 across the possible climatic variations possible in South Africa, some sub-division of the country into climatic regions was necessary. This was based on a recent classification by Blignaut *et al*. (2009) which clusters geographical regions based on historical temperature and rainfall data for the period 1970 to 2006 (Table 21 and Table 22).

Table 21: Clustering of South Africa's provinces based on temperature and rainfall data, 1970 to 2006 (from Blignaut *et al*., 2009).

Mean annual rainfall by region		Mean annual temperature by region	
<550 mm	Northern Cape North West	>25˚C	Limpopo North West Northern Cape
550-700 mm	Western Cape Free State Limpopo Eastern Cape	24.5-25˚C	Western Cape Free State Mpumalanga
>700 mm	Gauteng Mpumalanga KwaZulu-Natal	<24.5˚C	KwaZulu-Natal Gauteng Eastern Cape

Table 22: Clustering of South Africa's nine provinces by climatic region, based on mean annual rainfall and mean maximum daily temperature, 1970 to 2006 (from Blignaut *et al*., 2009).

Climatic type	Province
Hot and arid	Northern Cape North West
Hot and semi-arid	Limpopo
Temperate and semi-arid	Western Cape Free State Mpumalanga
Temperate and non-arid	Gauteng Eastern Cape KwaZulu-Natal

Values of E_0 (based on pan evaporation) for representative weather stations in each of the climatic regions identified by Blignaut *et al.* (2009) were derived by back-calculation of E_0 values based on values given for ET of pastures and/or lucerne in Green (1985). Data for pasture grass were not available at all stations. For Dohne, Eastern Cape, ET values for both pastures and lucerne were given. The value for ET was the same for both crops. Since $ET = E_0 \times CF$, and since E_0 is the same for different crops at the same location, it follows that CF must be the same too. Lucerne was used as the "reference crop" at sites where no data were given for pastures. Weather stations and crops for which data were extracted are shown in Table 23 and Figure 36. The calculated value of E_0 for summer and winter are summarised for the selected weather stations in Table 24. As a rule of thumb, the drier and hotter the area, the higher the E_0 value. The wetter and more temperate the area, the lower the E_0 value.

An example of the calculation of E_0 for each weather station is shown for Upington in Table 25. The variation of evapotranspiration over the months of the year is shown graphically in Figure 37 to Figure 50. These figures illustrate the dependence of evapotranspiration on changes in localised climatic conditions.

Table 23: List of data items extracted from Green (1985) and used for back-calculation of E_0.

Weather Station	**Region**	**Crop**
Upington	Northern Cape	Lucerne
Okiep	Northern Cape	Lucerne
Calvinia	Northern Cape	Lucerne
Mafikeng	North West	Lucerne
Pietersburg (Polokwane)	Limpopo	Lucerne
Elgin	Western Cape	Pastures
Oudtshoorn	Western Cape	Lucerne
Vredendal	Western Cape	Lucerne
Bloemfontein	Free State	Lucerne
Loskopdam-Groblersdal	Mpumalanga	Lucerne
Jan Smuts (OR Tambo) Airport	Gauteng	Pastures
Dohne	Eastern Cape	Pastures
Mount Edgecombe	KZN	Pastures
Vryheid	KZN	Pastures

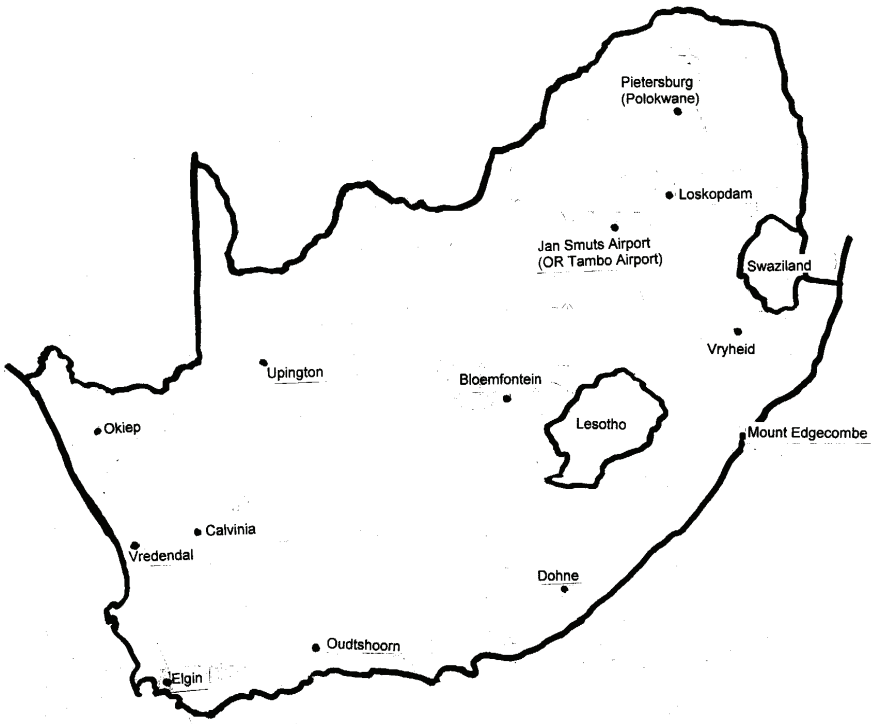

Figure 36: Map of South Africa, showing weather stations for which data was used in deriving evapotranspiration data (adapted from Green, 1985).

Table 24: Calculated values of E_0 for summer and winter at representative weather stations in each of the climatic regions of South Africa (based on Green, 1985, and Blignaut *et al*., 2009).

Climatic Region	Province	Weather Station	E_0 Summer (mm/day)	E_0 Winter (mm/day)
Hot and arid	Northern Cape	Upington	12.7	5.0
		Okiep	10.7	5.3
		Calvinia	6.2	2.0
	North West	Mafikeng	9.4	6.0
Hot and semi-arid	Limpopo	Pietersburg (Polokwane)	8.0	5.5
Temperate and semi-arid	Western Cape	Elgin	5.8	3.0
		Oudtshoorn	8.1	3.4
		Vredendal	7.9	3.6
	Free State	Bloemfontein	8.2	3.1
	Mpumalanga	Loskopdam-Groblersdal	7.9	4.0
Temperate and non-arid	Gauteng	Jan Smuts (OR Tambo) Airport	7.1	4.9
	Eastern Cape	Dohne	6.1	4.9
	KwaZulu-Natal	Mount Edgecombe	5.3	3.0
		Vryheid	6.6	4.9

Table 25: Calculation of E_0 from evapotranspiration (ET) of lucerne, using data from the Upington weather station (based on Green, 1985).

Climatic region; Province; Weather station	Crop	Month	ET (mm)	Days per month	ET (mm/day)	Calculated E_0 (mm/day)
Hot and arid; Northern Cape; Upington	Lucerne	Jul	58	31	1.9	3.7
		Aug	81	31	2.6	5.2
		Sep	144	30	4.8	8.0
		Oct	267	31	8.6	12.3
		Nov	327	30	10.9	13.6
		Dec	366	31	11.8	14.8
		Jan	363	31	11.7	14.6
		Feb	275	28	9.8	12.3
		Mar	213	31	6.9	8.6
		Apr	111	30	3.7	5.3
		May	76	31	2.5	4.1
		Jun	57	30	1.9	3.8

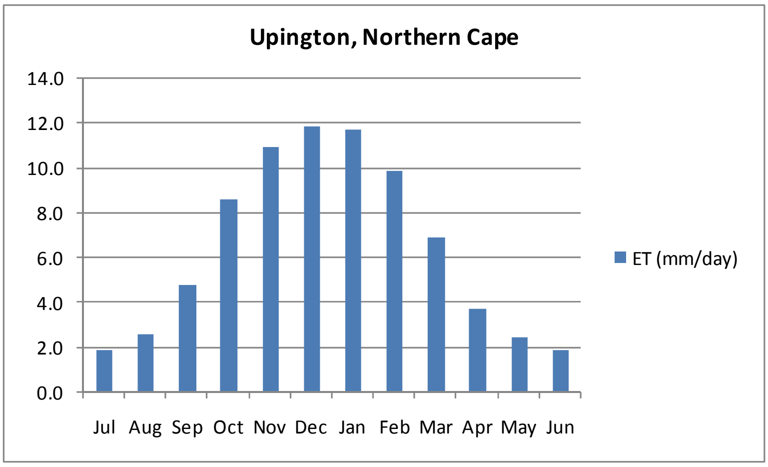

Figure 37: Monthly variation in evapotranspiration (mm/day) of lucerne at Upington, Northern Cape (based on Green, 1985).

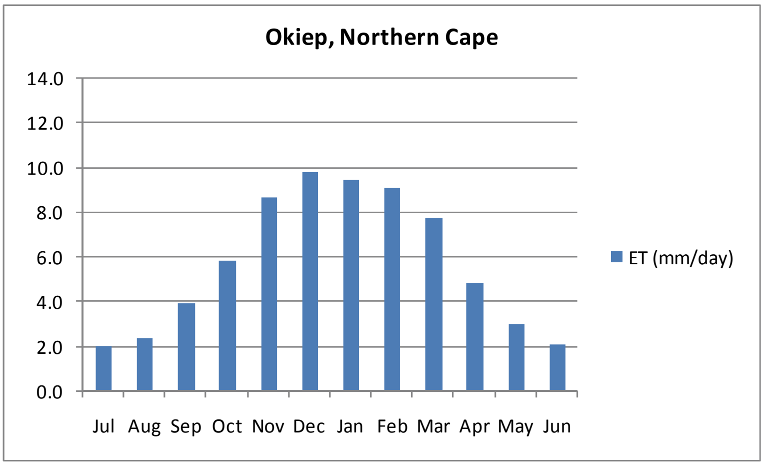

Figure 38: Monthly variation in evapotranspiration (mm/day) of lucerne at Okiep, Northern Cape (based on Green, 1985).

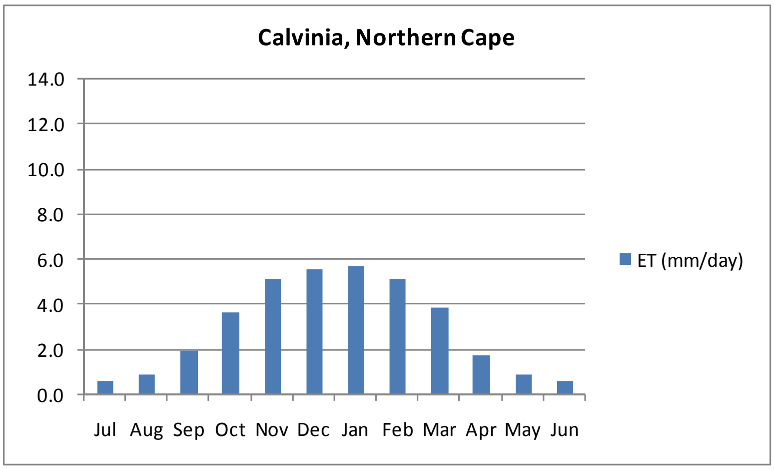

Figure 39: Monthly variation in evapotranspiration (mm/day) of lucerne at Calvinia, Northern Cape (based on Green, 1985).

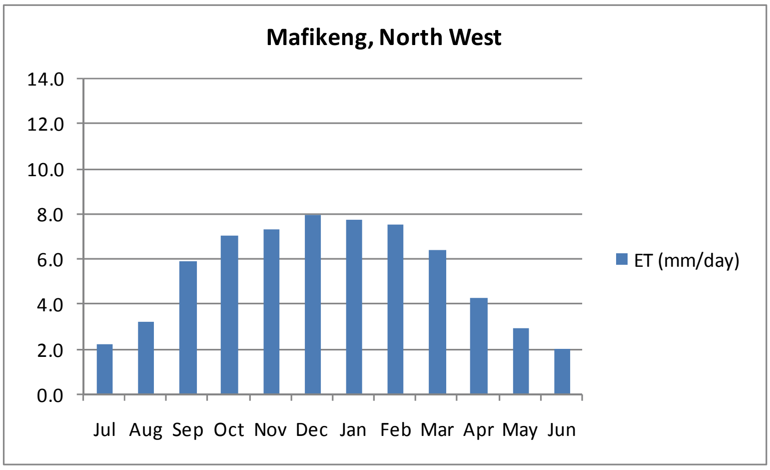

Figure 40: Monthly variation in evapotranspiration (mm/day) of lucerne at Mafikeng, North West (based on Green, 1985).

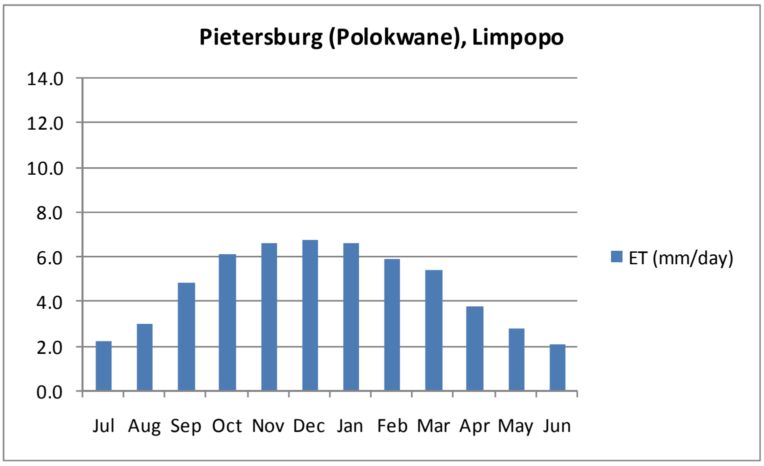

Figure 41: Monthly variation in evapotranspiration (mm/day) of lucerne at Pietersburg (Polokwane), Limpopo (based on Green, 1985).

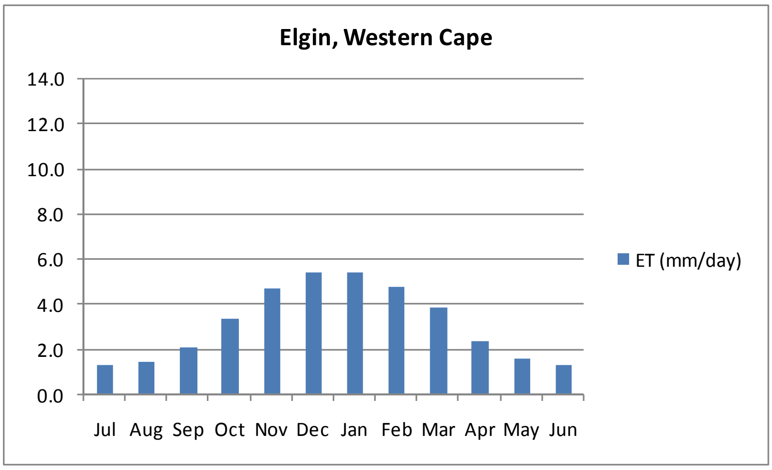

Figure 42: Monthly variation in evapotranspiration (mm/day) of pastures at Elgin, Western Cape (based on Green, 1985).

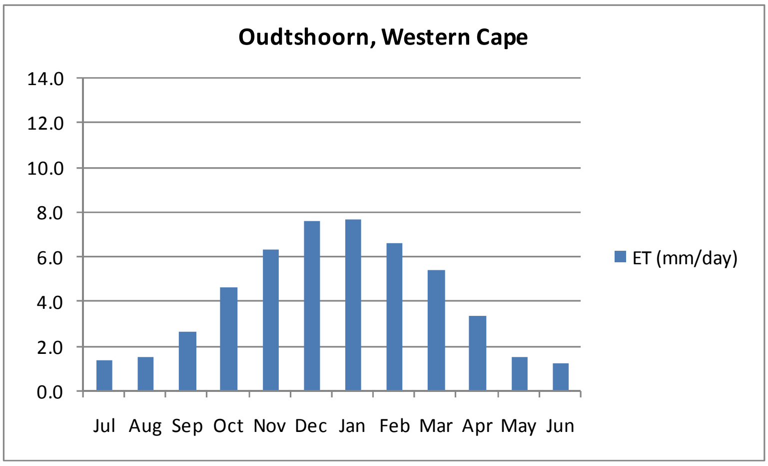

Figure 43: Monthly variation in evapotranspiration (mm/day) of lucerne at Oudtshoorn, Western Cape (based on Green, 1985).

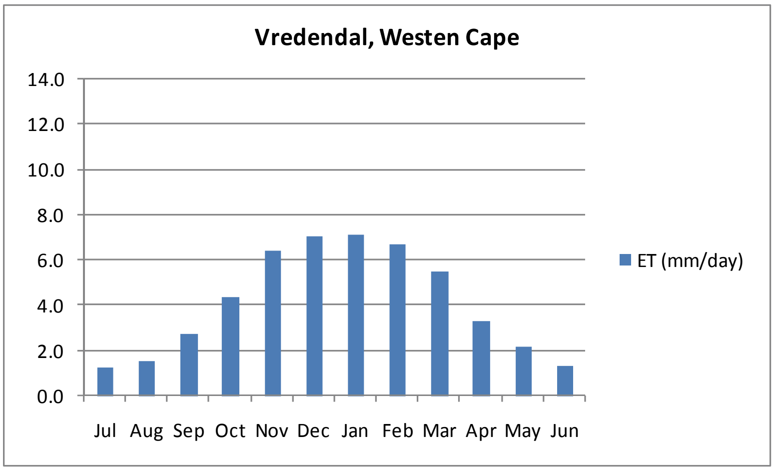

Figure 44: Monthly variation in evapotranspiration (mm/day) of lucerne at Vredendal, Western Cape (based on Green, 1985).

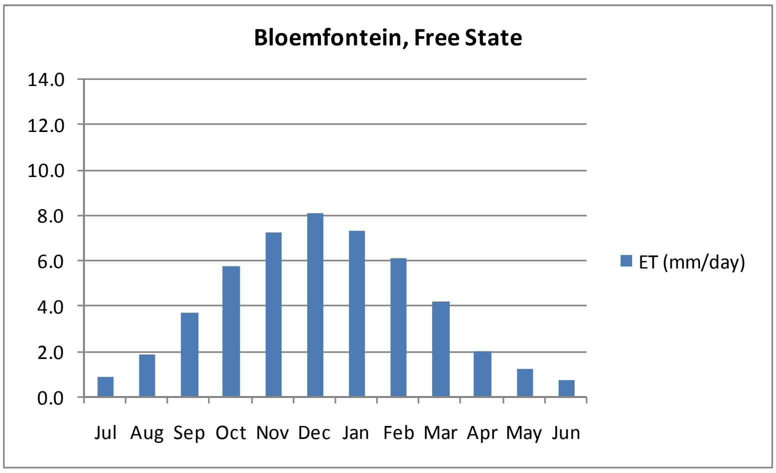

Figure 45: Monthly variation in evapotranspiration (mm/day) of lucerne at Bloemfontein, Free State (based on Green, 1985).

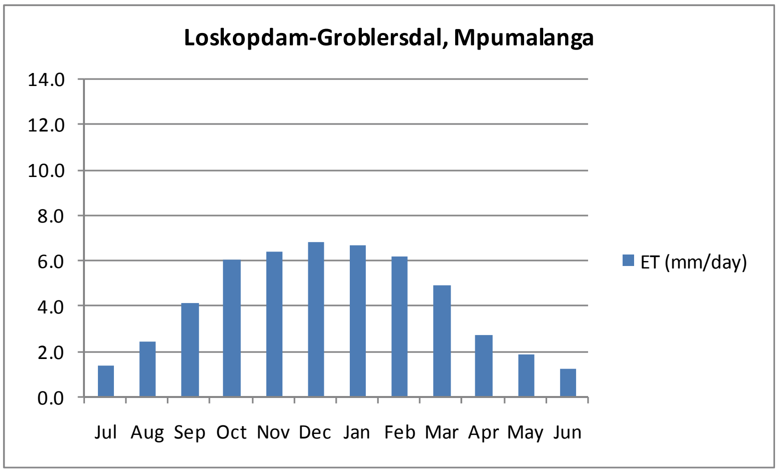

Figure 46: Monthly variation in evapotranspiration (mm/day) of lucerne at Loskopdam-Groblersdal, Mpumalamga (based on Green, 1985).

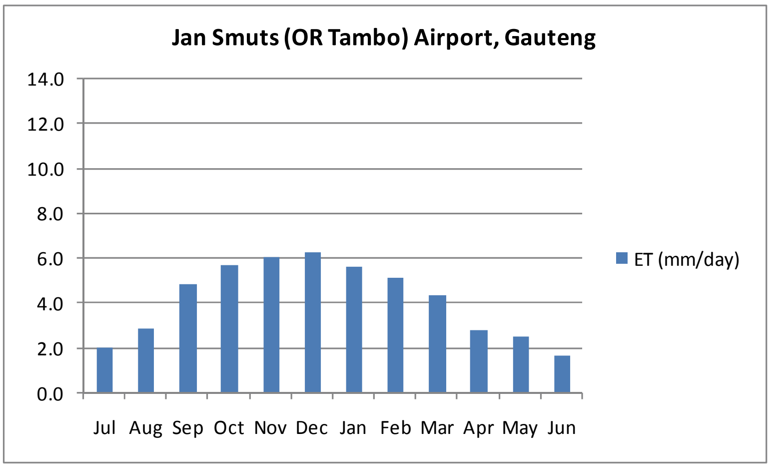

Figure 47: Monthly variation in evapotranspiration (mm/day) of pastures at Jan Smuts (OR Tambo) Airport, Gauteng (based on Green, 1985).

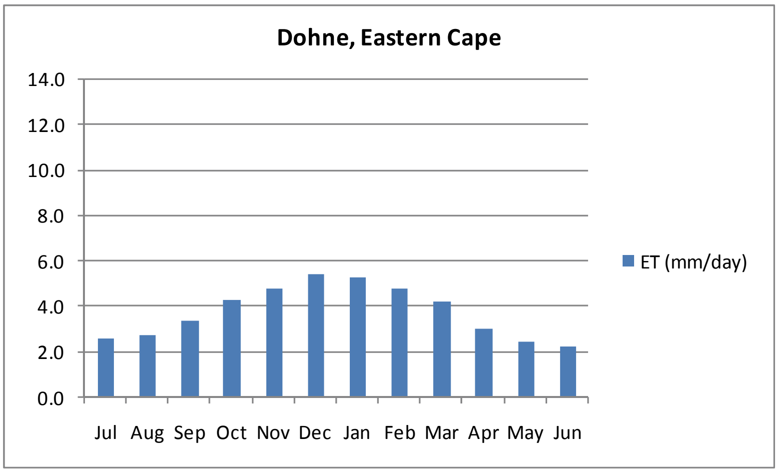

Figure 48: Monthly variation in evapotranspiration (mm/day) of pastures at Dohne, Eastern Cape (based on Green, 1985).

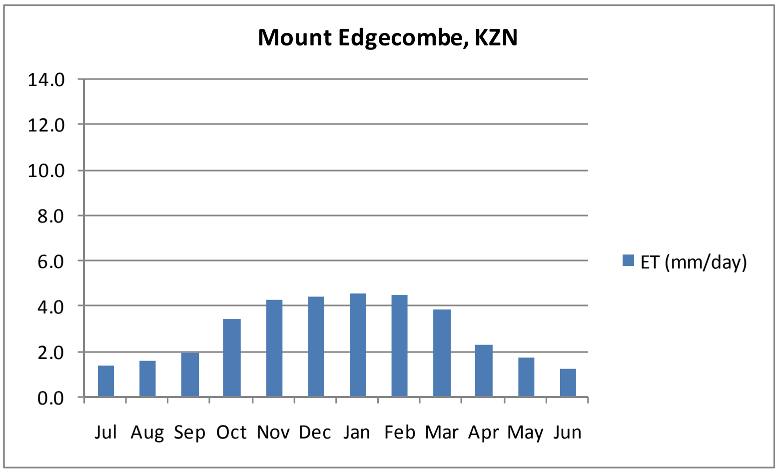

Figure 49: Monthly variation in evapotranspiration (mm/day) of pastures at Mount Edgecombe, KwaZulu-Natal (based on Green, 1985).

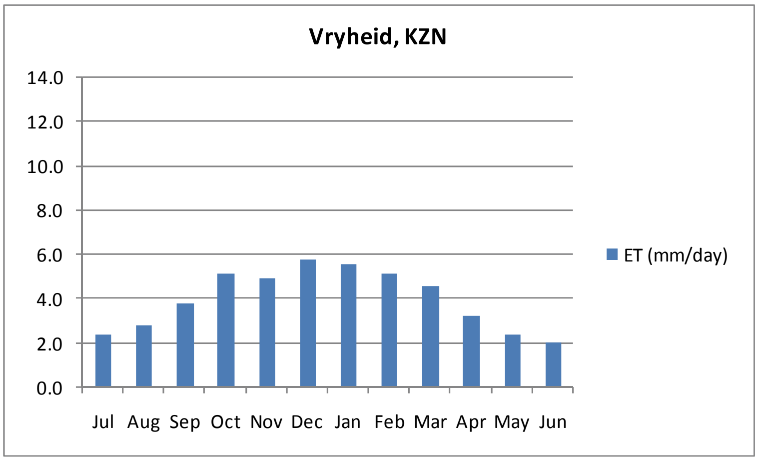

Figure 50: Monthly variation in evapotranspiration (mm/day) of pastures at Vryheid, KwaZulu-Natal (based on Green, 1985).

2.2 Crop factors (CF)

Crop factors are used in the calculation of EWU. In South Africa, crop factors are used rather than plant factors used in other countries. The crop factor (CF) is conceptually the same as the plant factor (PF), being defined as the ratio of actual evapotranspiration for the crop (ET) to the reference evaporation for a particular location and time of year (E_0). The difference is that, in South Africa, E_0 is the value for pan evaporation rather than evapotranspiration for a reference crop (usually turf grass). Thus the definition for CF, as used in South Africa, is as given in Equation 3.

$$\mathbf{CF = ET/E_0} \qquad \textbf{Equation 3}$$

CF = crop factor
ET = crop evapotranspiration
E_0 = reference evapotranspiration, as measured by pan evaporation.

Examples of crop factors listed by Green (1985) for a range of crops are listed in Table 26 to Table 28 below. It can be noted that crop factors vary with the time of year and the part of the crop growing season of the crop.

Table 26: Crop factors for vegetable crops (from Green, 1985).

Crop	Proportion of growing season				
	0-20%	20-40%	40-60%	60-80%	80-100%
Beans	0.3	0.4	0.6	0.7	0.7
Brassicas	0.4	0.6	0.7	0.7	0.7
Cucurbits	0.3	0.4	0.6	0.7	0.7
Green peas	0.3	0.3	0.4	0.7	0.6
Onions (sown)	0.3	0.4	0.6	0.7	0.7
Onions (transplanted)	0.3	0.4	0.6	0.7	0.7
Tomatoes	0.3	0.4	0.7	0.7	0.7

Table 27: Crop factors for citrus and subtropical fruit. Constant crop factors are regarded appropriate for all seasons (from Green, 1985).

Crop	Crop factor
Citrus (except Eastern and Western Cape)	0.67
Avocado	0.65
Banana	0.75
Litchi	0.75
Macadamia	0.65
Mango	0.65

Table 28: Crop factors for citrus and subtropical fruit (from Green, 1985).

Crop and period	Crop factor
Citrus (Eastern and Western Cape	
July-November	0.45
December	0.50
January	0.55
February	0.60
March	0.65
April	0.70
May	0.65
June	0.60
Pecans	
July	0.35
August-April	0.65
May-June	0.35

Because of the difficulty of selecting a crop factor appropriate for a given crop and season, generic crop factors were chosen in implementing Equation 2 for the calculation of EWU, as per Bennet (1995) and described in the section below.

2.3 Derivation of look-up tables for Estimated Water Use (EWU)

The equation for EWU was used by Bennet (1995), with subsequent adaptation by Murphy (2006), to derive a table of suggested irrigation volumes under a number of assumed agroclimatic conditions. Bennet's table was derived for use in California. Murphy (2006) converted units for ET and irrigation volume per week to metric units from the original US units, but did not further adapt the information in the table to South African conditions. The approach used by Bennet (1995) and Murphy (2006) was used to develop tables of EWU, calculated using the E_0 values derived as described in the preceding section.

Water use for average summer and winter conditions (Table 29 for summer; Table 30 for winter) were estimated using Equation 2 and E_0 values for weather stations representative of the climatic regions as proposed by Blignaut *et al*. (2009). Three crop factors (representative of plants with low water use, CF 0.3, medium water use, CF 0.5, and high water use, CF 0,8) were used to calculate their daily and weekly water use (water requirement) over representative areas of 5, 10 and 20 m^2. These figures provide guidance to the potential users of greywater to estimate the area that can be irrigated with the greywater available. These figures represent long-term mean values, since there is considerable variation in E_0 values. Actual irrigation requirements will be determined by the actual E_0 values and actual rainfall, since rain helps to supply the water use requirement of plants. Other factors influencing the volume applied and method of application are planting density (crop coverage) and soil type. These are addressed in the next section.

Table 29: Estimated water use, EWU (hence maximum volume of greywater to be applied) for crops with low water use (crop factor, CF, 0.3), moderate water use (CF 0.5) and high water use (CF 0.8) for various climatic regions in South Africa in **summer** and for illustrative areas of land to be irrigated, HA. EWU calculated as per Equation 2 in the text.

			EWU in Litres Per Day, Summer; Applicable to irrigated area (HA) of:			EWU in Litres Per Week, Summer Applicable to irrigated area (HA) of:		
Climatic region, Province, Representative weather station	**Summer E_0**	**Crop Factor (CF)**	**5 m^2**	**10 m^2**	**20 m^2**	**5 m^2**	**10 m^2**	**20 m^2**
Hot and arid								
Northern Cape Upington	12.7	0.3	19	38	76	133	267	533
	12.7	0.5	32	64	127	222	445	889
	12.7	0.8	51	102	203	356	711	1422
Okiep	10.7	0.3	16	32	64	112	225	449
	10.7	0.5	27	54	107	187	375	749
	10.7	0.8	43	86	171	300	599	1198
Calvinia	6.2	0.3	9	19	37	65	130	260
	6.2	0.5	16	31	62	109	217	434
	6.2	0.8	25	50	99	174	347	694
North West Mafikeng	9.4	0.3	14	28	56	99	197	395
	9.4	0.5	24	47	94	165	329	658
	9.4	0.8	38	75	150	263	526	1053
Hot and semi-arid								
Limpopo Pietersburg (Polokwane)	8.0	0.3	12	24	48	84	168	336
	8.0	0.5	20	40	80	140	280	560
	8.0	0.8	32	64	128	224	448	896
Temperate and semi-arid								
Western Cape Elgin	5.8	0.3	9	17	35	61	122	244
	5.8	0.5	15	29	58	102	203	406
	5.8	0.8	23	46	93	162	325	650
Oudtshoorn	8.1	0.3	12	24	49	85	170	340
	8.1	0.5	20	41	81	142	284	567
	8.1	0.8	32	65	130	227	454	907
Vredendal	7.9	0.3	12	24	47	83	166	332
	7.9	0.5	20	40	79	138	277	553
	7.9	0.8	32	63	126	221	442	885
Free State Bloemfontein	8.2	0.3	12	25	49	86	172	344
	8.2	0.5	21	41	82	144	287	574
	8.2	0.8	33	66	131	230	459	918
	7.9	0.5	20	40	79	138	277	553

			EWU in Litres Per Day, Summer; Applicable to irrigated area (HA) of:			EWU in Litres Per Week, Summer Applicable to irrigated area (HA) of:		
Climatic region, Province, Representative weather station	**Summer E_0**	**Crop Factor (CF)**	**5 m^2**	**10 m^2**	**20 m^2**	**5 m^2**	**10 m^2**	**20 m^2**
	7.9	0.8	32	63	126	221	442	885
Temperate and non-arid								
Gauteng Jan Smuts (OR Tambo) Airport	7.1	0.3	11	21	43	75	149	298
	7.1	0.5	18	36	71	124	249	497
	7.1	0.8	28	57	114	199	398	795
Eastern Cape Dohne	6.1	0.3	9	18	37	64	128	256
	6.1	0.5	15	31	61	107	214	427
	6.1	0.8	24	49	98	171	342	683
KZN Mount Edgecombe	5.3	0.3	8	16	32	56	111	223
	5.3	0.5	13	27	53	93	186	371
	5.3	0.8	21	42	85	148	297	594
Vryheid	6.6	0.3	10	20	40	69	139	277
	6.6	0.5	17	33	66	116	231	462
	6.6	0.8	26	53	106	185	370	739

Table 30: Estimated water use, EWU (hence maximum volume of greywater to be applied) for crops with low water use (crop factor, CF, 0.3), moderate water use (CF 0.5) and high water use (CF 0.8) for various climatic regions in South Africa in **winter** and for illustrative areas of land to be irrigated, HA. EWU calculated as per Equation 2 in the text.

			EWU in Litres Per Day, Winter; Applicable to irrigated area (HA) of:			EWU in Litres Per Week, Winter; Applicable to irrigated area (HA) of:		
Climatic region, Province, Representative weather station	**Winter E_0**	**Crop Factor (CF)**	**5 m^2**	**10 m^2**	**20 m^2**	**5 m^2**	**10 m^2**	**20 m^2**
Hot and arid								
Northern Cape Upington	5.0	0.3	8	15	30	53	105	210
	5.0	0.5	13	25	50	88	175	350
	5.0	0.8	20	40	80	140	280	560
Okiep	5.3	0.3	8	16	32	56	111	223
	5.3	0.5	13	27	53	93	186	371
	5.3	0.8	21	42	85	148	297	594
Calvinia	2.0	0.3	3	6	12	21	42	84
	2.0	0.5	5	10	20	35	70	140
	2.0	0.8	8	16	32	56	112	224
North West Mafikeng	6.0	0.3	9	18	36	63	126	252
	6.0	0.5	15	30	60	105	210	420
	6.0	0.8	24	48	96	168	336	672
Hot and semi-arid								
Limpopo Pietersburg (Polokwane)	5.5	0.3	8	17	33	58	116	231
	5.5	0.5	14	28	55	96	193	385
	5.5	0.8	22	44	88	154	308	616
Western Cape Elgin	3.0	0.3	5	9	18	32	63	126
	3.0	0.5	8	15	30	53	105	210
	3.0	0.8	12	24	48	84	168	336
Oudtshoorn	3.4	0.3	5	10	20	36	71	143
	3.4	0.5	9	17	34	60	119	238
	3.4	0.8	14	27	54	95	190	381
Vredendal	3.6	0.3	5	11	22	38	76	151
	3.6	0.5	9	18	36	63	126	252
	3.6	0.8	14	29	58	101	202	403
Free State Bloemfontein	3.1	0.3	5	9	19	33	65	130
	3.1	0.5	8	16	31	54	109	217
	3.1	0.8	12	25	50	87	174	347
Mpumalanga Loskopdam Groblersdal	4.0	0.3	6	12	24	42	84	168
	4.0	0.5	10	20	40	70	140	280
	4.0	0.8	16	32	64	112	224	448

			EWU in Litres Per Day, Winter; Applicable to irrigated area (HA) of:			EWU in Litres Per Week, Winter; Applicable to irrigated area (HA) of:		
Climatic region, Province, Representative weather station	**Winter E_0**	**Crop Factor (CF)**	**5 m^2**	**10 m^2**	**20 m^2**	**5 m^2**	**10 m^2**	**20 m^2**
Temperate and non-arid								
Gauteng Jan Smuts (OR Tambo) Airport	4.9	0.3	7	15	29	51	103	206
	4.9	0.5	12	25	49	86	172	343
	4.9	0.8	20	39	78	137	274	549
Eastern Cape Dohne	4.9	0.3	7	15	29	51	103	206
	4.9	0.5	12	25	49	86	172	343
	4.9	0.8	20	39	78	137	274	549
KZN Mount Edgecombe	3.0	0.3	5	9	18	32	63	126
	3.0	0.5	8	15	30	53	105	210
	3.0	0.8	12	24	48	84	168	336
Vryheid	4.9	0.3	7	15	29	51	103	206
	4.9	0.5	12	25	49	86	172	343
	4.9	0.8	20	39	78	137	274	549

2.4 Adjusting for planting density (crop cover)

The equation for EWU (Equation 2) assumes 100% crop cover. Where water is applied directly to the base or root zone of plants to be irrigated, as proposed for greywater irrigation, and the area to be irrigated is not completely covered by the crop or plant type, the amount of water to be applied is reduced accordingly. The factors to be applied are shown in Table 31. Thus the equation for estimated water use (EWU) becomes:

$$\mathbf{EWU_{adjusted} = EWU \times CC} \qquad \textbf{Equation 1}$$

CC = crop coverage factor from Table 31.

Table 31: Factors for adjusting irrigation volume for proportion of crop coverage (from Green, 1985).

Proportion of area covered by crop (%)	Reduction in water requirement (%)	Additional factor by which to multiply EWU (denoted CC – crop coverage – in equation below)
10	60	0.4
30	40	0.6
50	20	0.8
≥70	0	1.0

2.5 Adjusting for soil type

The estimates for water use depicted in Table 29 and Table 30 provide guidance about the *amount* of water that should be applied during a certain period to replenish water use during that period. However they do not provide guidance concerning the *frequency* with which water should be applied or the *rate* at which it should be applied. This is largely determined by the soil type.

Sandy soils generally have high infiltration rates, but a low capacity to hold/store water. Because they absorb water easily, the risk is high that more water will be applied than they can hold, leading to percolation and potential pollution of groundwater. Because of their low capacity to hold water they require more frequent water applications to replenish their limited storage. As a rule of thumb, sandy soils require that the water use by plants be replenished more frequently and in smaller quantities.

In contrast to sandy soils, clay soils generally have low infiltration rates, but a high capacity to hold/store water. Because of their slow intake rate, they may quickly display surface ponding and runoff before sufficient water can infiltrate to replenish the water taken up by plant water use. Continued water application to replenish the water used may cause further run-off, ponding and surface water contamination. All these effects are undesirable. It is therefore necessary to apply water at a reduced rate for longer periods of time to clayey soils. Alternatively, soil surface storage (to prevent run-off) can be increased by basins around trees or mini-basins within beds.

2.6 Adjusting for recent rainfall

Recent rainfall also increases the risks of percolation to groundwater in sandy soils and of run-off and saturation in clay soils, respectively. For this reason, greywater should not be applied to soils which are obviously moist, as in the case of recent rainfall. Estimated water application, EWU (Table 29 and Table 30) should be adjusted for rainfall in the 24 hours preceding greywater application. To determine the reduction in greywater volume, it is generally accepted that 1 mm of rainfall is equivalent to 1 ℓ of water per square meter. Thus, for 10 mm rain in the 24 hours preceding greywater application, the water application on a five square meter area should be reduced by 50 ℓ.

If rainfall has fallen continuously for a period of more than 24 hours, as may occur in some areas in the rainy season, then the *total* rainfall for the period in which it has rained continuously should be used instead. The reason for this is that, for example, 10 mm of rain in 24 hours on wet soil (as would occur if rain has fallen continuously for more than 24 hours) is more likely to cause the soil to saturate than would 10 mm of rain falling on dry soil over the same period.

Thus the overall equation for determining the amount of greywater to be applied is as follows:

$$\mathbf{EWU_{adjusted} = (EWU \times CC) - (mm\ rainfall\ in\ preceding\ 24\ hours \times HA)} \qquad \textbf{Equation 2}$$

$EWU_{adjusted}$ is the estimated water use, adjusted for site-specific factors affecting water use.
EWU is estimated water use as per Equation 3 and Table 29 and Table 30.
CC is crop coverage factor from Table 31.
HA is area to be irrigated (measured in m^2), as in Equation 2.
mm rain is subject to the considerations in the paragraph above.
Greywater application rate and frequency are adjusted for soil type as described above.

3. Acknowledgements

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Appendix 2

Examples of Commercially Available Greywater Treatment Systems from Outside South Africa

1. Commercially available greywater treatment systems

Commercially available systems for household-level treatment of greywater were reviewed comprehensively in Appendix B of Carden *et al.* (2007). In the interests of collating available greywater irrigation-related information in a single document, the content of that Appendix is largely repeated here, with some updating (all web site references are correct as at June 2010). These systems are not directly available in South Africa. However, the concepts used are similar throughout and have been reviewed. Thus, similar systems could be designed and tested locally.

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1.1 Biological Sand Filters

Biological filters of various sorts are available for treatment of drinking water and a similar concept can be applied to treatment of greywater. Construction of a typical sand filter is described on the website http://www.reuk.co.uk. Greywater should be screened for removal of hair, lint and other large particles by passing it through a coarse filter, such as a fabric bag (Figure 51).

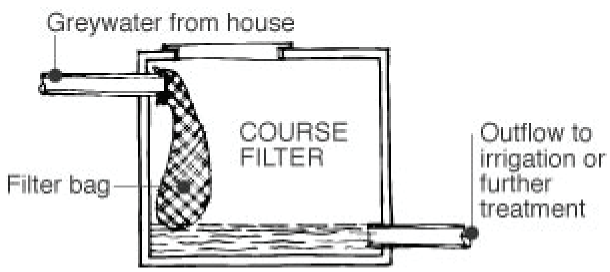

Figure 51: Screening of greywater by passing it through a coarse filter (from http://www.reuk.co.uk**).**

Screened greywater can then be passed through either a fast sand filter or a slow sand filter. Both types of sand filter comprise a thin layer of gravel overlaid with a much thicker layer of sand. In the rapid sand filter, the water is passed through the filter rapidly, with most of the removal of unwanted greywater constituents occurring by filtration through the sand (Figure 52). The filter must be washed regularly to remove accumulated particulate matter.

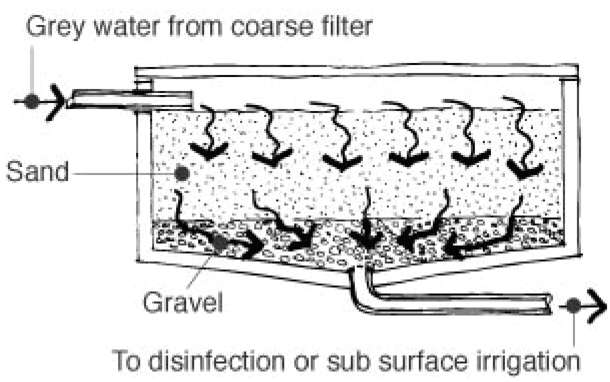

Figure 52: Screened greywater treated by filtration through a rapid sand filter (from http://www.reuk.co.uk).

A slow sand filter requires water to be applied continuously at a relatively slow rate, such that a biofilm is allowed to develop at the top of the sand layer. This layer assists in breaking down organic matter and additionally entraps very small particles like micro-organisms (Figure 53).

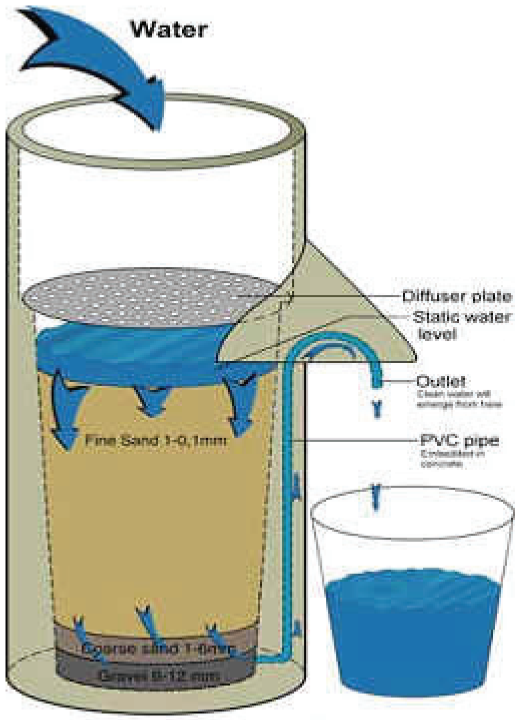

Figure 53: Screened greywater treated by filtration through a slow sand filter (from http://www.reuk.co.uk)**.**

1.2 Greywater Drywell

(http://www.thenaturalhome.com; based in the USA)

This is a passive (gravity drainage) greywater disposal system for situations when greywater use may not be an option. It consists of a self-cleaning filter and settling tank with all the relevant plumbing fittings plus a drywell kit, which consists of vent and fabric wrap for direct disposal of household greywater. Drywells are designed to provide alternate water management solutions which reduce the need for costly labour-intensive concrete and pipe-in-trench leaching systems. Top loading of effluent (greywater) ensures maximum surge capacity for the drywell. Irrigation of an orchard is often the typical use of greywater from a system such as this. The drywell acts as "emergency overflow" leaching pit and the majority of the water is delivered directly to the trees in the orchard. Figure 54 shows a typical greywater drywell filter / settling tank and Figure 55 is an example of the self-cleaning filter.

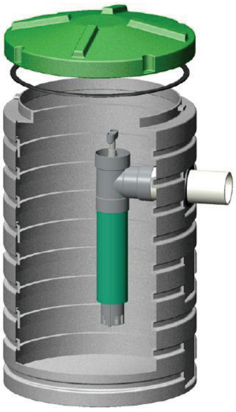

Figure 54: Greywater Drywell filter and settling tank (from http://www.thenaturalhome.com).

Figure 55: Self-cleaning filter for Greywater Drywell (from http://www.thenaturalhome.com).

The following instructions are given when purchasing this system. They apply to greywater treatment in general:

- Never store "treated" greywater in a large holding tank, cistern, lagoon or pond for future use.
- Never allow greywater to drain on top of bare ground – the irrigation area needs to be below soil and/or mulch.
- Never use unlabeled, unsealable or unvented containers for a filter basin – settling tanks need easy access.
- Always vent the plumbing fixtures, filter basin, planter-bed, leach field and or leach pit to allow air into the system.
- Always drain containers & planter-bed bases so as to allow oxygen to get into the soil.

1.3 Alternating Intermittent Recirculating Reactor (AIRR)

(http://wwwgreenwisdom.us; based in the USA)

The AIRR system consists of a septic/dosing tank, a biological reactor with both secondary and tertiary sections, a cover structure, a recirculating tank and a discharge tank or pipe. The septic tank needs to be pumped regularly, and visual inspections need to be carried out on the pipes with routine maintenance on the cover structure. This system works for both single family residences and entire communities. It is energy-efficient, has low construction costs and can be upgraded. The AIRR system is classified as a recirculating sand gravel filter (biological activity is controlled on the surface area of media in combination with high oxygenation). It delivers treated effluent that is suitable for recycling and re-use in non-potable applications (may be discharged underground into drainfields, or into salt water, streams and rivers, or can be used to irrigate golf courses, parks, forests or farm land). A typical layout of an AIRR system is shown in Figure 56.

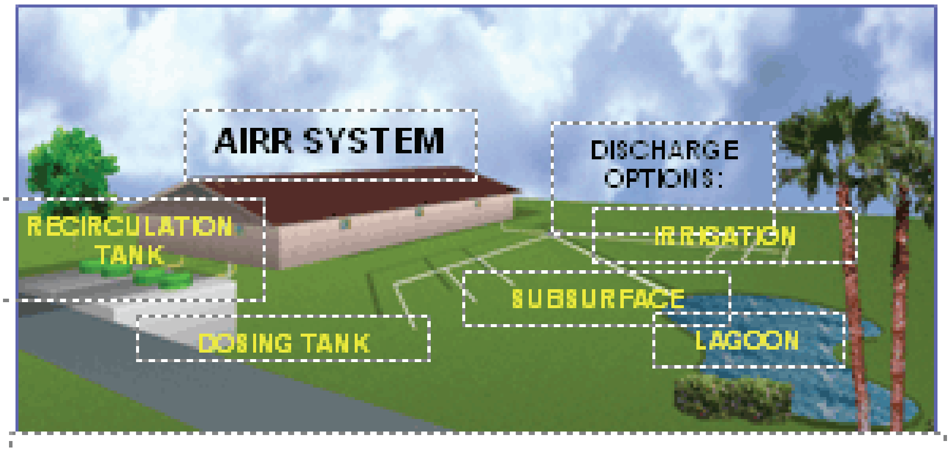

Figure 56: Schematic diagram of an alternating intermittent recirculating reactor (AIRR) system (from http://wwwgreenwisdom.us).

1.4 AquaCycle 900

(http://freewateruk.co.uk; based in the UK)

This system cleans water from baths and showers with claims of potential savings of up to 90 000 ℓ of water per annum for a family of four. It is easy to install, is odourless and maintenance is kept to a minimum, with low energy requirements (approximately 0.6 kWh per day). The Aquacycle system (Figure 57) makes use of the patented SmartClean system and operates as follows:

- Prefiltration – larger particles like hair and textile fragments are collected. A spray pump automatically flushes the filter and sediments are washed away into the main wastewater drain.
- Two-fold biological treatment – in the main and secondary recycling chambers the dirt particles are decomposed by bio-cultures. The water is pumped to the next station at three-hour intervals.

- Sediment disposal – the organic sediments, which are produced during the recycling process, are regularly sucked out from the chambers and diverted into the wastewater drain.
- Ultraviolet-Sterilisation – on the way to the storage chamber the recycled water flows through a UV-light lamp, which disinfects it. The high quality of the water now conforms to the E.U. Directive for Recreational Water and can be utilised for a variety of non-potable uses around the home.

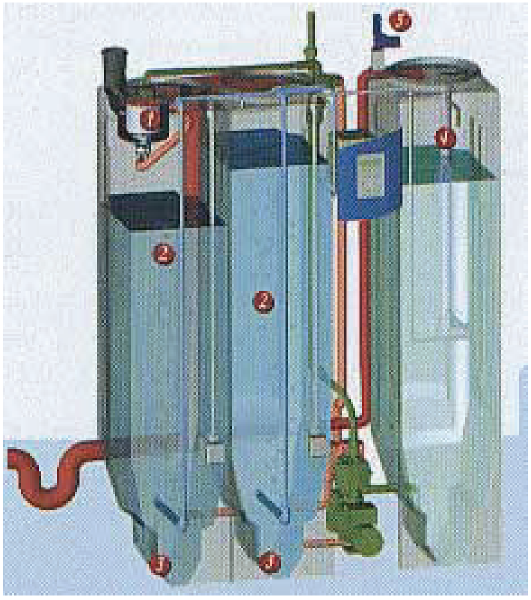

Figure 57: A cross section view of the AquaCycle 900 greywater treatment system (from http://freewateruk.co.uk).

1.5 Ecomax

(http://www.ecomax.com.au; based in Australia)

The Ecomax system (Figure 58) consists of a sedimentation/septic tank connected to a "dual disposal field" via sealed pipes and a manual diverter valve for rotation of flow between fields. The greywater from the sedimentation tank flows into pervious geotextile-encased pipework which is laid beneath lawns or garden beds and is surrounded by specially prepared nutrient-removing modified soil. Bauxite residue is also used in the filter bed, which has good absorptive properties for some minerals and metals and also works as a good bacterial filter. Below-ground disposal ensures that the greywater is already at root access without losses to evaporation, and also provides better protection of public health. A typical Ecomax cell for greywater removal from a three-bedroomed home would be 9 m long and 4.4 m wide.

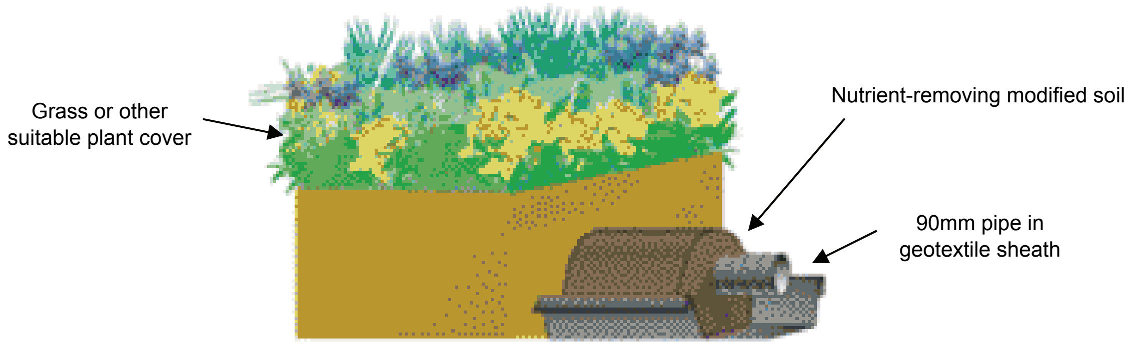

Figure 58: Oblique section through an Ecomax system (from http://www.ecomax.com.au).

1.6 ReWater® distribution cone greywater system

(http://www.rewater.com; based in USA)

This system captures, filters and reuses shower, bath, wash-basin, and laundry greywater water from domestic residences and disposes of it in the ReWater's patented underground drip system, which is reported to be at least 30% and up to 60% more efficient than sprinklers. The system consists of a tank, pump, automatic on/off switch, automatic filter, backflow and switching valves and is generally connected to the most regularly-used showers and washing machine in the home as it has been found that about 95% of the reusable water comes from these few sources.

When the pump turns on during the irrigation cycle, water is sent to the top of the filter canister and forced down through the sand filter media where hair, lint, and other debris are trapped in the sand medium. Water then travels out to a series of irrigation valves for use in the garden. To keep the filter clean, when the controller has accumulated a certain (programmable) amount of run time, it begins a self-cleaning cycle after that day's irrigation has been completed by using fresh water, and diverting the backwash to waste. The fresh water is rapidly forced up into the sand filter media, causing sand particles to rise and separate from each other, releasing the trapped debris. Lighter than the sand, the debris rises to the top and flows out to the waste line. When the process is over, the valves return to their irrigation position.

The system is shown in Figure 59.

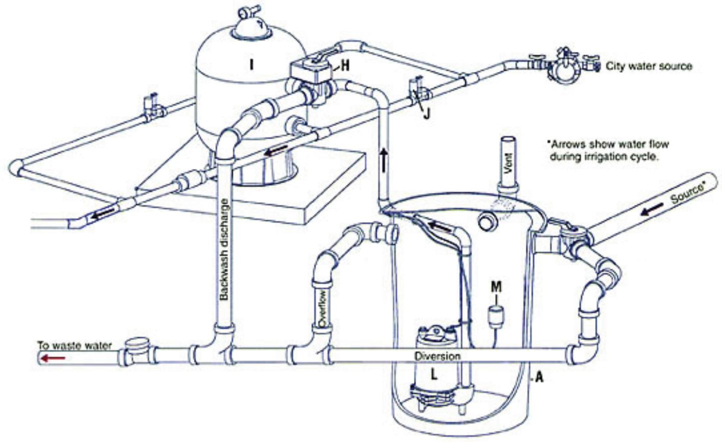

Figure 59: A schematic representation of the ReWater® filter system (from http://www.rewater.com).

1.7 Greywater-irrigated greenhouses

(http://www.greywater.com; based in US and Canada)

These greenhouses are constructed in such a manner that the fertilized growing beds provide efficient greywater treatment. The beds are automatically irrigated using household greywater. One such greenhouse in New Hampshire (USA) uses a fish pool as the final treatment after the soil beds, which stays clear by means of a biological treatment technique involving a waterfall and bio-filter plates on the pool-bottom. These greenhouses have been reported as providing a family of four to six people with more than enough vegetables throughout the winter season. A schematic view of the layout of a greywater-irrigated green house is shown in Figure 60.

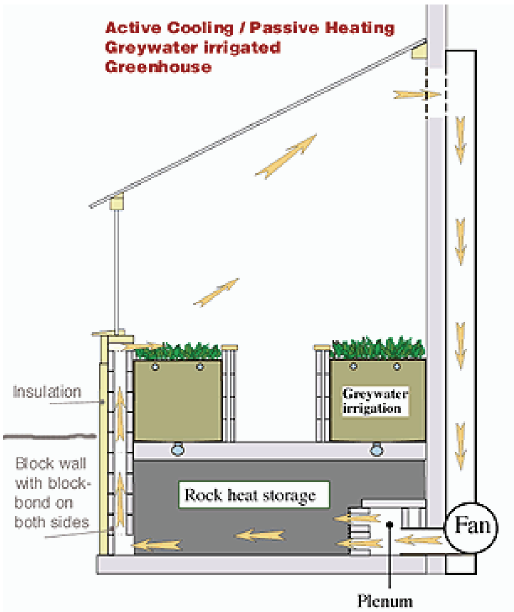

Figure 60: Schematic view of a greywater-irrigated greenhouse (from http://www.greywater.com.

1.8 Outdoor planters

(http://www.greywater.com; based in US and Canada)

These are masonry soil boxes which effectively serve to build up the soil profile of a site. Greywater is led into the planter box in such a way that it is forced to pass through the greater soil profile before draining away, by use of an impermeable liner which directs the passage of the greywater (Figure 61). An example of a planter is shown in Figure 62. Such boxes act as retarding mechanisms within sandy soils to slow down the greywater so that sufficient treatment can be accomplished in the soil. Within moderately dense settlements, it is suggested that two adjacent neighbours build a large mound on their properties which acts as a property divider. In so doing they would also be able to plant hedges or evergreens on the leaching area.

Both aerobic and anaerobic pre-treatment of the greywater are possible before discharging it to the soil planters which can be used to improve the quality of the final effluent (Figure 63).

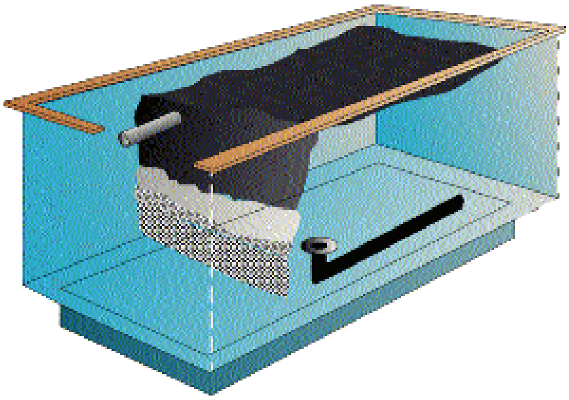

Figure 61: Schematic of a greywater planter box (from http://www.greywater.com).

Figure 62: Example of a greywater planter in British Columbia (from http://www.greywater.com).

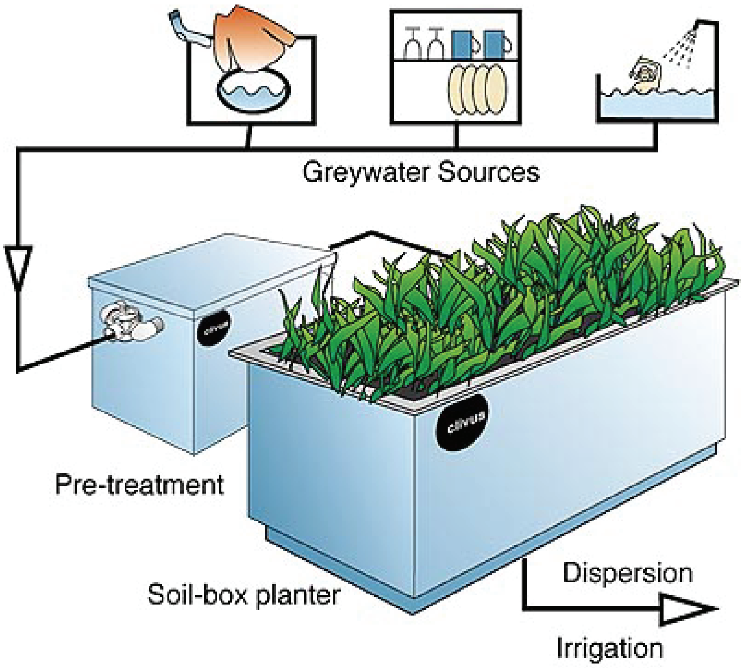

Figure 63: Greywater treatment system with a planter box (from http://www.greywater.com).

1.9 Aerobic pre-treatment

(http://www.greywater.com; based in US and Canada)

An aerobic treatment system for greywater typically starts with some form of filter treatment which removes large particles and fibres to protect the subsequent treatment stages from clogging. The filter allows the rest of the organic matter to travel through to the next stage of processing. Directly after this primary filtration, the greywater is transferred into a biologically active, aerobic soil-zone environment where both macro- and micro-organisms thrive, *e.g.* some form of sub-surface soil infiltration. This type of filter system is suitable for either private or public facilities where the principal source of greywater is hand-washing and showers without significant amounts of food waste (food wastes may accumulate in the filter causing it to become anaerobic and resulting in odours).

1.10 Anaerobic to aerobic pre-treatment

(http://www.greywater.com; based in US and Canada)

This system usually consists of a three-stage septic tank that caters for sludge and grease separation, resulting in effluent that is anaerobic. Following the septic tank is a sand filter which serves to stimulate aerobic conditions, after which the greywater is routed to a planter bed (Figure 64). This results in purified water of "near potable-quality". Such systems are reported to be among the most effective, simple-to-maintain on-site treatment techniques and are recommended where there are significant quantities of food waste in the greywater to be treated.

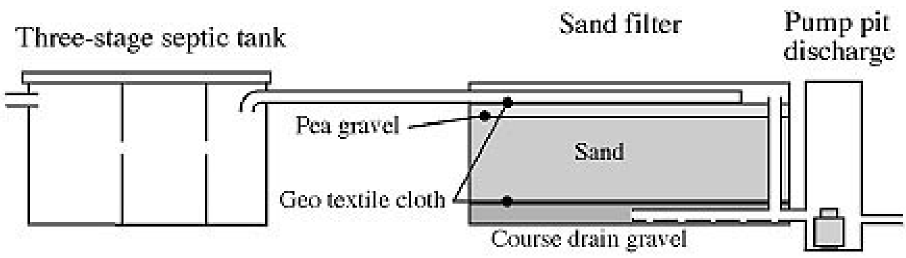

Figure 64: Schematic representation of an anaerobic to aerobic pre-treatment system (from http://www.greywater.com).

1.11 The Greywater Recycling System (GRS)

(http://www.waterinstallations.com; based in Australia)

This is a greywater diversion device that is a gravity-fed primary treatment, distribution and irrigation system which uses greywater for watering gardens. The system does not store the greywater in any form and is used for immediate disposal of the greywater. The GRS can recycle up to 2 000 ℓ of greywater per day using irrigation areas 70 m^2 in size. Since it operates on a gravity system, the irrigation beds need to be lower than the greywater source points. The system consists of distribution pipes and connectors, outlet housings, an aerobic grease filter and "H" nozzle components. It is illustrated diagrammatically in Figure 65.

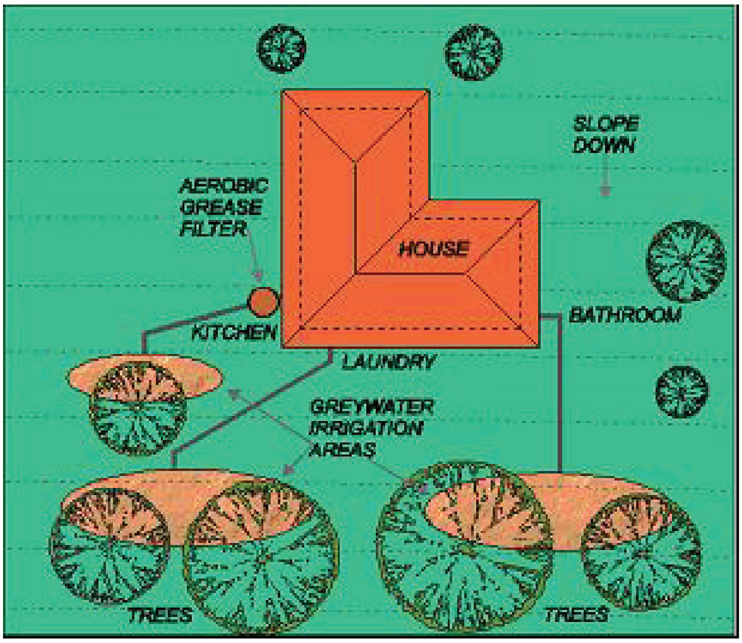

Figure 65: Schematic representation of a Greywater Recycling System (GRS), as viewed from above (from http://www.waterinstallations.com)

1.12 Wattworks Greywater Treatment System

(http:///www.wattworks.com.au; based in Australia)

The SmartPit system from Wattworks (Australia) uses greywater generated from the household for subsurface irrigation of lawns and gardens, after filtering. It stores water from the shower or bathroom in a holding tank which discharges excess water to sewer every 24 hours so as to not to cause any offensive smells. The installation is shown in Figure 66.

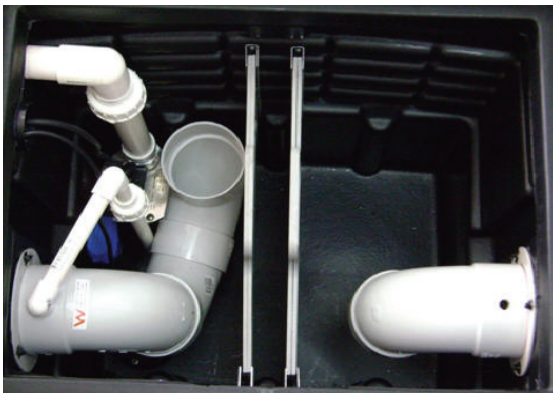


Figure 66 Example of a SmartPit system from Wattworks (from http:///www.wattworks.com.au).

1.13 Earthstar Greywater Systems

(http://realgoods.com; based in the USA)

The Earthstar system essentially consists of a 250 ℓ holding tank coupled to a simple sand filter with backwash cleaning (Figure 67). The irrigation cycle begins once the greywater reaches a certain level in the tank and a float switch activates a centrifugal pump. A simple five minute backwash cleaning process every two months is included in the design to keep the filter operating efficiently.

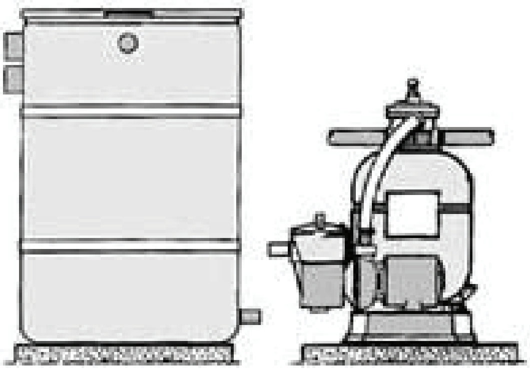

Figure 67: Simple schematic of Earthstar greywater system (from http://realgoods.com).

1.14 Casa Juliana Kitchen Greywater System

(http://www.omick.net; based in the USA)

This system was designed to treat kitchen greywater. It consists of a distribution hub from a 25 ℓ cement bucket and a 15 mm PVC pipe which distributes the greywater to six small infiltration chambers. The kitchen greywater first passes through an interceptor which traps grease and fats before it is used for irrigation purposes. An example is shown in Figure 68.

A

B

C

D

Figure 68: Example of a Casa Juliana greywater treatment and distribution system. A) Grease interceptor. B) Six pipes to distribute greywater. C) Distribution hub. D) Infiltration chamber at the end of a pipe. (From http://www.omick.net.)

1.15 Niimi Absorption Trench System

(http://www.rotaloo.com; based in Australia)

Greywater is led through a pipe to a collection tank where a distribution box feeds the distribution trenches (Figure 69). The trenches are lined with 0.2 mm thick heavy duty polyethylene and consist of inert mediums such as coarse gravel, shells, plastic, etc. which are used for biological treatment of the greywater (Figure 70). The lengths of the trenches are designed to accommodate the volumes of greywater generated by the household as well as the soil type in the area. These trench systems should not be used where the water table is less than 1.3 m below surface level.

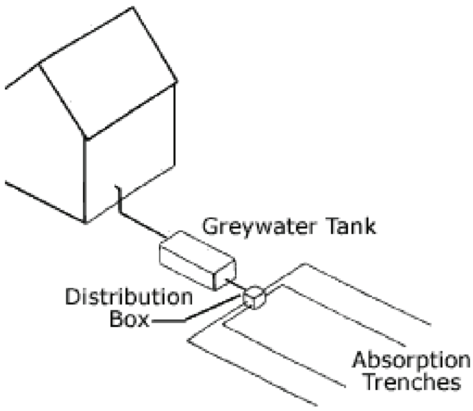

Figure 69: Typical layout of a Niimi system (from http://www.rotaloo.com).

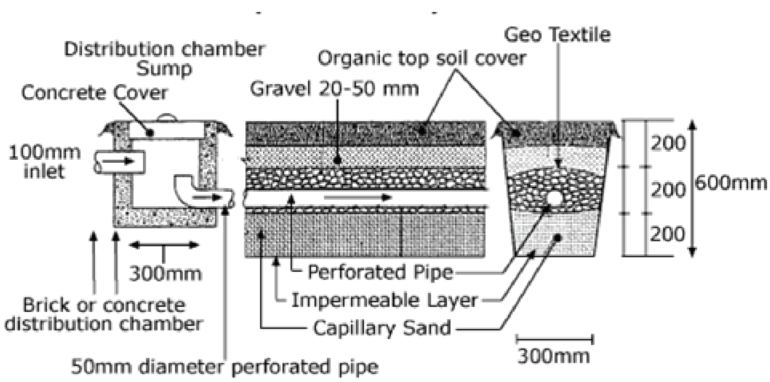

Figure 70: Section through a Niimi absorption trench system (from http://www.rotaloo.com).