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

GUIDANCE REPORT

Nicola Rodda, Kirsty Carden & Neil Armitage

WATER RESEARCH COMMISSION

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

GUIDANCE 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 of this document

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

The aims and objectives of the project as a whole, and the background literature and case studies, are presented in the Technical Report.

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 of this Guidance Report is as follows:

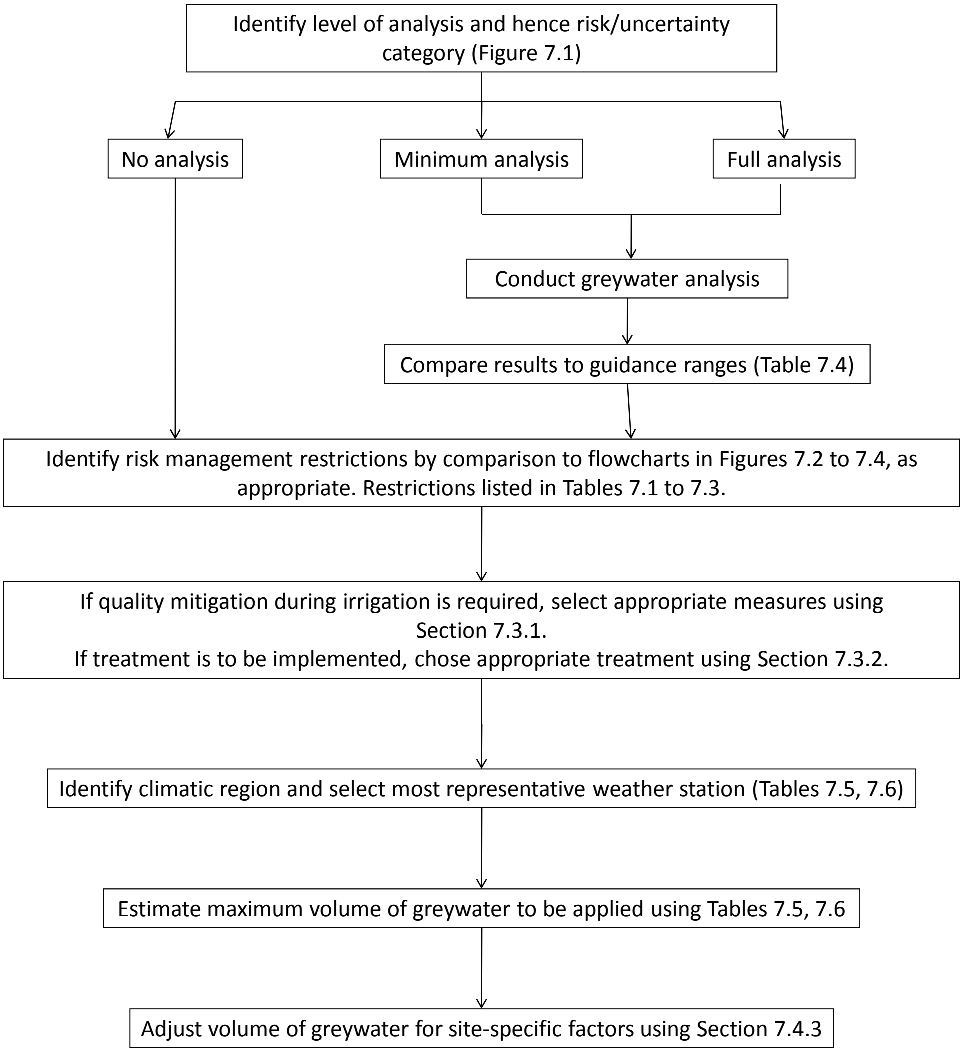
What is greywater?
Why use greywater for irrigation?
Concerns about the use of greywater for irrigation
    Health considerations
    Plant growth and yield
    Ability of soil to support plant growth
Purpose of the Guidance Report
    Intended users of the Guidance Report
    Focus of the Guidance Report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

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

The use of the different sections of this Guidance Report in practice is summarised in the flow diagram on the following page.



This approach should yield an integrated greywater irrigation implementation addressing greywater quality, risk management strategies, greywater treatment (if desired), and appropriate greywater application planning.

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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
Mr JP Nell	Agricultural Research Council
Mr R Plumbley	Unilever (Pty) Ltd
Mr KP Taylor	Department of Agriculture
Mr L Ramashala	Department of Water Affairs
Mr Z Zituta	Department of Water Affairs

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Abbreviations and Acronyms

BOD Biological oxygen demand

CC Crop coverage factor

CF Crop factor

CFU Colony-forming units

COD Chemical oxygen demand

DWAF Department of Water Affairs and Forestry

DWA Department of Water Affairs

E_0 Reference evapotranspiration

EC Electrical conductivity

EWU Estimated water use

HA Area irrigated (m^2)

NBR National Building Regulations

NGO Non-governmental organisation

NWA National Water Act

pH Negative logarithm to the base 10 of the concentration of hydrogen ions ($-\log_{10}[H+]$)

SAR Sodium adsorption ratio

WHO World Health Organisation

WRC Water Research Commission

Glossary

Blackwater	Domestic wastewater from toilet use and toilet flushing.
Evapotranspiration	The sum of evaporation and plant transpiration, representing movement of water from the surface of the Earth to the atmosphere.
Greywater	Domestic wastewater from all non-toilet household uses (*i.e*. excluding blackwater).
Hardsetting	A condition of a soil in which the surface is dry and compacted. Such soils are not disturbed or indented by the pressure of the forefinger. Hardsetting soils typically have high runoff.
Imbibition	The absorption or adsorption of a liquid by a solid or a gel, here the absorption or adsorption of water by soil.
Leaching	The loss of water-soluble plant nutrients from the soil as a result of rain and irrigation. It is also used to refer to the practice of applying excess irrigation water where water has a high salt content to avoid build-up of salts in the soil (see soil salinity).
Soil salinity	The salt content of the soil. The ions responsible for soil salinity are sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}) and chloride (Cl^-).
Soil sodicity	The percentage of the soil cation exchange capacity that is occupied by sodium (Na^+) ions. This affects the structure and physical characteristics of soil. Sodic soil is usually recognised as having an exchangeable sodium percentage greater than 15%.

1 What is Greywater?

Greywater is untreated household effluent from baths, showers, kitchen and hand wash basins, and laundry (*i.e*. all non-toilet uses). More than half of indoor household water use is normally used for these purposes – estimates range from approximately 50% to 80%. This percentage represents a large fraction of household wastewater which can potentially be intercepted by the householder and used for additional beneficial uses.

Some authors (*e.g.* Alcock, 2002) exclude kitchen water from the definition of greywater which can be used since this fraction contains the highest levels of many contaminants such as bacteria, suspended solids, and oil and grease. However, in this document kitchen water is included in the greywater fraction considered for further use in small-scale irrigation applications.

2 Why Use Greywater for Irrigation?

South Africa is a water-scarce country, with average annual rainfall of approximately 500 mm, well below the world average of 860 mm. Moreover, much of this rainfall is seasonal. The Western Cape region has a Mediterranean climate, receiving most of its rainfall in winter while the rest of the country has predominantly summer rainfall. The distribution of rainfall is also uneven, with some regions in the North West receiving less than 200 mm per year while much of the eastern Highveld receives 500 to 900 mm. There is a large area in the centre of the country which receives 400 mm. A ‘400 mm rainfall line’ can be identified, to the east of which rainfall is sufficient to grow crops and to the west of which land is suitable only for grazing or irrigated agriculture (Byrnes, 1996).

Furthermore, South Africa has decreasing sources of fresh water which means that new sources of water need to be sought. Using greywater sustainably for irrigation in small-scale agriculture and in gardens is one possible way of alleviating water stress.

It should be borne in mind that inland areas differ from coastal ones in terms of possibilities for indirect water re-use. Inland, treated wastewater from sewered settlements is discharged into receiving water bodies which usually form the source for abstraction of domestic water supplied downstream. Thus there is indirect re-use of water which is disposed of via sewers, albeit at the cost of treatment firstly of the wastewater and secondly of domestic water supplies after abstraction. However, in coastal areas there is no possibility for downstream re-use; hence water savings via greywater use may be of particular significance in this context.

Since greywater also contains nitrogen and phosphorus, it is furthermore a potential source of nutrients for plant growth, particularly for those users who cannot afford fertiliser. In the same vein, the soapy nature of greywater means it has some pest repellent properties, again of particular significance to potential users who cannot afford pesticides.

Examples of beneficial use of greywater are:

- For irrigation of food gardens at a household or communal level, where water and plant nutrient supplementation would not usually be available. This would improve food security in low income and informal settlements.
- For irrigation of gardens where water and plant nutrient supplements would not usually be available. This would make it possible to establish gardens where it might otherwise not be possible and to improve productivity of such gardens, thereby improving quality of life.
- For irrigation of gardens or small-scale crop cultivation in times of water shortage, *e.g.* drought. This would improve sustainability of gardens and food production without placing limited water sources under further pressure.
- For use in irrigation of gardens in place of usual fresh water supplies. This would reduce water costs for the user and reduce pressure on fresh water sources on the level of local water authorities.

3 Concerns about the Use of Greywater for Irrigation

Concerns about the use of greywater for small-scale irrigation applications fall into four groups:

1. Possible adverse effects on human health
2. Possible adverse effects on plant growth and yield
3. Possible adverse effects on the environment, especially on the continued ability of the soil to support plant growth.
4. Increased potential for blockages in sewerage systems and for increased loads at wastewater treatment plants, as a result of reduced flows when greywater flow is removed from the system.

The first three concerns are dealt with explicitly in this Guidance Report.

An obvious omission appears to be explicit mention of contamination of surface water bodies under the third point, 'possible adverse effects on the environment'. This is because greywater irrigation is intended to retain all greywater use ***within the boundaries of the irrigated property*****.** For this reason, the broader environment beyond the irrigated property is not explicitly mentioned in the Guidance Report. However, to guard against the possibility that greywater does escape from the property, greywater quality guidance ranges have been set in such a way as to provide protection of the surrounding environment, particularly other water bodies.

The last concern is considered to be an issue which lies beyond the scope of this Guidance Report and should be addressed by local authorities in their planning of greywater irrigation implementations.

3.1 Human Health Considerations

Greywater contains micro-organisms from skin surfaces and dirt, from small amounts of urine and faeces (*e.g.* from washing of soiled nappies or bedclothes), and from the washing and preparation of food. Standing greywater also provides an environment in which micro-organisms can survive and proliferate. As a result, greywater usually contains significant numbers of micro-organisms, some of which may be capable of causing disease in those who come in contact with the greywater or with plants and crops irrigated with greywater.

3.2 Plant Growth and Yield

In addition to containing substances which are beneficial to plants (mainly nitrogen and phosphorus), greywater also contains substances that can reduce plant growth or crop yield if present at sufficiently high concentrations. Some of these are salts, sodium and boron. Extreme pH can also be damaging to plants.

3.3 Ability of Soil to Support Plant Growth

Some constituents of greywater can change soil properties so that it becomes progressively less productive (*i.e.* less able to support plant growth). Because soil properties change slowly, these tend to be long-term effects, while effects on plant growth and yield are more short-term. The major concerns with regard to soil are salinity and sodicity, both of which are related to the increased concentration of sodium in greywater. Other greywater constituents which may affect soil adversely are oil and grease, and suspended solids.

Many of these concerns can be overcome by adequate management of greywater irrigation in terms of measures taken to reduce risks, and to control the quality and quantity of greywater applied. The aim of this Guidance Report is to assist potential greywater users in identifying and implementing such measures.

4 Purpose of the Guidance Report

4.1 Intended Users of the Guidance Report

This Guidance Report is intended for two main groups of users:

- Municipalities or non-governmental organisations (NGOs) who wish to initiate greywater use applications or wish to support users in developing greywater use initiatives.
- Informed users who wish to use greywater for small-scale irrigation and need guidance.

4.2 Focus of the Guidance Report

This Guidance Report for small-scale irrigation use of greywater focuses on minimising the following risks:

- Risk of illness in handlers of greywater and greywater-irrigated produce, and in consumers of crops irrigated with greywater.
- Risk of reduction in plant growth or in yield of plants and crops irrigated with greywater.
- Risk of long-term degradation of the environment receiving the greywater, especially the soil environment.

For the purposes of this Guidance Report, irrigation is interpreted as the ***beneficial use of greywater to support plant growth within the boundaries of the irrigated property only***. It is important for the reader 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 therewith.

The primary focus of this Guidance Report is on ***beneficial use of greywater only***, and ***not*** on greywater disposal. Although use of greywater for irrigation may well decrease the amount of greywater which is disposed of in an uncontrolled manner, the reduction of greywater volumes entering the environment is ***not*** the primary intent of this Document. Where minimising the risks listed above conflicts with an opportunity for irrigation use as a potential disposal route of greywater, the focus on risk management as outlined above is always given precedence.

4.3 Major Sources Used

Four documents provide the major sources for this Guidance Report for greywater use in small-scale irrigation:

- 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 non-sewered 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, have provided the background for the principles and content of the present document. The full supporting background is provided in the Technical Report which supports and expands on the Guidance Report, and which is available from the Water Research Commission.

5 Legislative Context of Greywater Use for Irrigation

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 would be considered a “controlled activity”. Discharge or use of water containing waste requires that the use is listed in a general authorisation 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. Greywater irrigation is most likely to fall into the category specifying irrigation of up to 500 m^3 of “domestic or biodegradable industrial wastewater” per day, for which quality limits are prescribed. 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). 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, 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 pollution or health hazards. The authorisation for this is considered to be implicitly provided under permitted water uses as specified in Schedule 1 of the NWA. Although greywater use for small-scale irrigation is not mentioned specifically, it is within the spirit of the law. For larger scale use, either the requirements under the general authorisations apply as mentioned above, or a licence for this use would have to be obtained (Gravele’t-Blondin, pers. comm.)

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 (wastewater including toilet waste). These need to be resolved to clarify the legal position of use of greywater for irrigation. In particular, input from the relevant legislative bodies is required to clarify the ***legal position*** with respect to:

- ***The status of greywater use for small-scale irrigation in terms of the NWA***
- ***The building regulations, in terms of the NBR, which apply to storage and use of greywater within the boundaries of a property.***

Until such clarity is achieved and any necessary additions or modifications of existing legislation are made, greywater use for small-scale irrigation cannot be unequivocally stated to be a legally permitted water use.

The guidance provided by this document should thus be considered as provisional until clarity is provided by the relevant authorities. However, it does provide guidance to potential users of greywater for irrigation about how to maximise the benefits and minimise the disadvantages associated with the practice.

6 Special Considerations for Informal Settlements

Special mention needs to be made of the situation of greywater in informal settlements. Winter *et al.* (in press), reporting on WRC project No**. K5/1654,** 'Sustainable Options for Community-Level Management of Greywater in Settlements Without On-Site Waterborne Sanitation', make the following observations:

> "Greywater is defined broadly as the wastewater that is generated from a variety of household activities without input from toilets. It accounts for virtually all water consumption in non-sewered areas except for that which is used for drinking purposes, cooking and that which remains on the surfaces of washed articles. However, the problem in non-sewered informal shack settlements in South Africa, and those with limited waterborne services and drainage, is that greywater often merges with toilet water and other effluent flows thus creating a toxic mix of contaminated water that poses a danger to human health and the environment. Although the *per capita* volume of greywater disposed on the ground in the vicinity of shack dwellings is low, greywater runoff often carries solid and liquid waste contaminants that collects in ponds and is frequently discharged via stormwater systems into wetlands and rivers."

A number of factors contribute to the situation described by Winter and co-authors. The primary factor 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 a lack of communication or miscommunication between official bodies and settlement representatives.

The next factor 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 defecate, disposing of solid waste, and managing mixed waste and water flows during 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.

Thus additional precautions need to be taken if use of greywater for irrigation in informal settlements is to be considered. Aside from the precautions with respect to greywater management, quality and quantity, as outlined in the remainder of this Guidance Report, the creation of a sense of community and the engaging of such a community with the concept of greywater use are critical pre-requisites for any greywater irrigation implementation. Specifically, it is crucially important to inform potential users that any greywater intended for irrigation use must be:

- limited in terms of the number of uses within the household prior to use for irrigation
- isolated at source.

Greywater which has been used multiple times or which is collected after discharge into the environment should not be considered as suitable for irrigation use.

Greywater surveys at household level in both sewered and unsewered settlements, conducted partially as part of WRC project K5/1524 and partially as part of the present project, have offered further insight into the nature of water use and greywater generation in these two types of settlements. In sewered settlements, water use and greywater generation are broadly similar so general guidance can be developed, with some site-specific modification as necessary. By contrast, unsewered settlements (including both informal settlements and settlements with formal sanitation provision by way of on-site systems) vary widely in the volumes of water used and in greywater generation. This means that greywater use in such settlements must be considered on a case-by-case basis. More detail about these studies can be obtained from the Technical Report.

Examples of how greywater use has been addressed as part of integrated water and sanitation interventions in rural and urban environments are presented in the Technical Report.

7 Guidance for Greywater Use in Small-Scale Irrigation in South Africa

The following section presents guidance for the use of greywater for irrigating gardens or for small-scale crop cultivation in South Africa. It should be noted that it is assumed that ***guidance provided here will be used in the context of existing guidelines and best practice for irrigation, both nationally and locally***. Thus the intention of this document is not to provide a catch-all manual for general irrigation water quality, treatment processes, irrigation methods, plant water requirements, soil selection, *etc*. Although reference is made to many of these issues, it is assumed that suitable source water quality (*i.e.* before use in the home which renders the water 'grey') and suitable plants, cultivation and irrigation practices are already available or known for successfully irrigated plants in a given agroclimatic zone, or that this knowledge will be developed using existing procedures. This Guidance Report has been developed specifically to provide guidance for managing the ***additional*** risks and uncertainty associated with using greywater in place of conventional irrigation water sources.

More information regarding the rationale underlying the development of the Guidance Report and the choice of water quality constituents included is presented in the Technical Report.

7.1 Guide to Managing Risk and Uncertainty

Risk, whether expressed qualitatively or quantitatively, indicates the probability of a defined adverse effect occurring in an exposed population. Within the context of this Guidance Report, the adverse effects and exposed 'populations' are as follows:

- Illness in human handlers of greywater and greywater-irrigated produce, or human consumers of greywater-irrigated produce.
- Reduction in plant growth or yield in plants / crops irrigated with greywater.
- Environmental degradation, specifically reduction in ability of the soil irrigated with greywater to support plant growth in the long term.

Uncertainty refers to the degree of confidence associated with the estimate of risk. In the context of greywater quality, this relates largely to the degree of confidence associated with knowledge of water quality, as once the quality of the greywater is known, suitable steps can be taken to address the risks described above. It should however be noted that the baseline of uncertainty associated with greywater use is inherently higher than that associated with, *e.g.* domestic water use or recreational water use, since:

- Greywater is inherently highly variable in quality, further complicated by the fact that the quality of various greywater sources in a household vary considerably.
- Greywater irrigation implementations are most likely to occur on a small scale, where frequent monitoring of greywater quality is likely to be both economically and logistically difficult.

Within this context, three risk and uncertainty categories can be identified among potential users of greywater for irrigation:

1. Users unable / unwilling to conduct any analyses to characterise greywater quality prior to planning irrigation use and during its implementation.
2. Users willing and able to conduct limited analyses (minimum analysis) to characterise greywater quality prior to planning irrigation use and during its implementation.
3. Users willing and able to conduct more extensive analyses (full analysis) to characterise greywater quality prior to planning irrigation use and during its implementation.

The reason for identifying these risk and uncertainty categories is that risk can only be said to exist where human users, plants or soil are exposed to a potential hazard. Where there is no exposure, there is no risk. Thus risk can be managed by managing either the magnitude of the hazard (the quality of greywater) or the extent of exposure to the hazard. The higher the magnitude of the hazard (*i.e*. the poorer the quality of the greywater), the more stringent the required risk management interventions to protect human health, plants and soil. Risk management interventions related to exposure take the form of barriers which minimise the exposure of human users, plants or soil to a given hazard. As the extent of analysis increases from Category 1 to Category 3 – and, by implication, as greywater quality improves as it complies with the quality guidance associated with the analysis (see Section 7.2) – so the magnitude of the hazard decreases, and hence so do the risk management requirements.

Risk for Category 1 is unknown and uncertainty is high. Thus this category of use faces the greatest restrictions in the anticipated greywater irrigation implementation. These restrictions are necessary to manage the potentially high risks associated with irrigation use of greywater of unknown quality.

Risk for Category 2 is moderate (assuming compliance with guidance for greywater quality subject to minimum analysis, Section 7.2), as is uncertainty. Analytical results for broad indicators of risk to human health, plants and soil are available. Thus restrictions for this category are less than for Category 1, being aimed at providing barriers to specific classes of risk and thereby managing those risks.

Category 3 carries the lowest risk (assuming compliance with guidance for greywater quality subject to full analysis, Section 7.2) and the lowest uncertainty. The quality of greywater with respect to human health, plants and soil is relatively well characterised and necessary barriers to risks can be identified with relatively little uncertainty. Risks in this category are therefore the easiest to manage.

Figure 7.1 depicts identification of the three categories of irrigation use, as determined by risks and uncertainty concerning greywater quality.

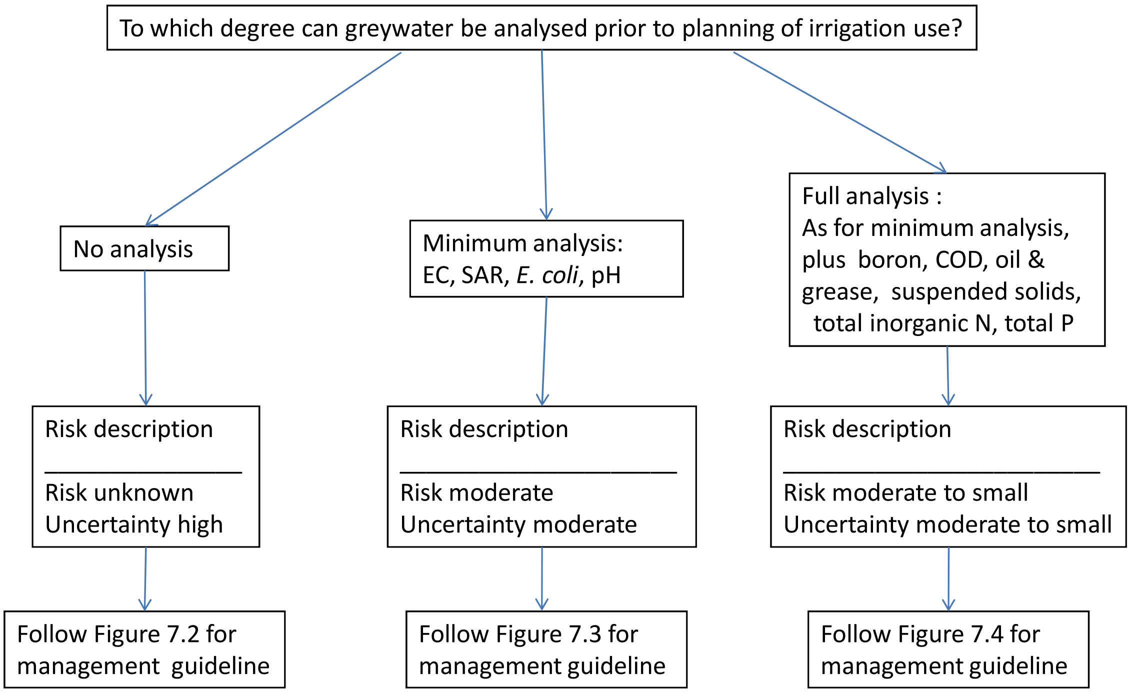


Figure 7.1: Division of potential greywater use into three categories according to risk and risk management options.

7.1.1 Category 1: No greywater analysis (Figure 7.2)

This is the simplest use scenario, but perhaps the most complex to manage because users (both human and environmental) must be protected from essentially unknown risks. There is no quantitative assessment of greywater quality and no treatment of greywater prior to use. Greywater use without any prior assessment of the quality of the greywater should be considered for household level use only, where users are exposed only to wastes generated on the property. The reason for this is that, within a household, other routes of exposure to potential pathogens are likely to be more significant as exposure routes than those associated with greywater. When greywater is used by someone not from the household of origin, exposure to greywater increases in significance as an exposure route. Thus no communal gardening initiative should be undertaken in this category. Kitchen greywater should not be considered for use because it typically carries the highest loads of micro-organisms, COD, oil and grease, and suspended solids. Laundry wash water should also not be used because of potentially high pH and high salt levels. **Only laundry rinse water and bath greywater can be used in accordance with restrictions R1 in Table 7.1.** This set of restrictions is the most stringent of those presented. All restrictions in Table 7.1 are intended to minimise: (1) risks to human health, (2) risks to plant growth and yield, and (3) risks to the environment, specifically to the ability of soil to support plant growth. Note that cognisance must be taken of the volume of greywater which can be applied to land (see Section 7.4). An example of a user information leaflet, based on Table 7.1, is presented in Appendix A.

Table 7.1: Risk management restrictions for use of greywater for irrigation without analysis of greywater.

Restrictions R1, applicable to greywater use in Category 1
Restrictions relating to health impact **Do:** ✓ Wash hands and arms well with soap after handling greywater. ✓ Use bathwater water and laundry rinse water only. ✓ Use all greywater within 24 hours of collection. ✓ Grow only non-food plants or food plants with crops that will be cooked before consumption. ✓ Use irrigation methods that minimise contact of greywater with above-ground plant parts. ✓ If using on lawns, avoid direct human contact for 8 hours after irrigation. ✓ If using on crops, stop irrigating with greywater 2 weeks before harvesting. ✓ Reduce volume of greywater per application if ponding occurs on surface of irrigated ground, or if water runs off the surface. ✓ Wash all crops well in soapy water after harvest and dry in sunlight. ✓ Peel and cook crops prior to consumption. **Do not:** ✗ Do not use greywater falling in this category of use restrictions for any form of communal gardening. ✗ Do not use greywater if someone in the household has an infectious disease. **Restrictions relating to impacts on plant growth and yield** **Do:** ✓ Use irrigation methods that minimise contact of greywater with above-ground plant parts. ✓ Switch to salt-tolerant plants, if plants show symptoms of salt stress. **Do not:** ✗ Do not plant or irrigate plants prone to boron toxicity. **Restrictions relating to soil and environmental deterioration** **Do:** ✓ Use bathwater water and laundry rinse water only. ✓ Increase greywater application or alternate with freshwater, in order to leach out salts, if plants show symptoms of salt stress. ✓ Apply agricultural gypsum and compost to ameliorate soils if infiltration rate decreases and it is suspected that this is related to high sodium content of greywater. **Do not:** ✗ Do not irrigate with kitchen greywater or with laundry greywater except rinse water. ✗ Do not use greywater falling in this category of restrictions if the soil is very clayey, if the ground has a steep slope, or if the irrigation site is close to a river or borehole. ✗ Do not use greywater if the irrigated land is close to sensitive environments which may be adversely affected by greywater runoff or infiltration, *e.g.* high water table, wetlands.

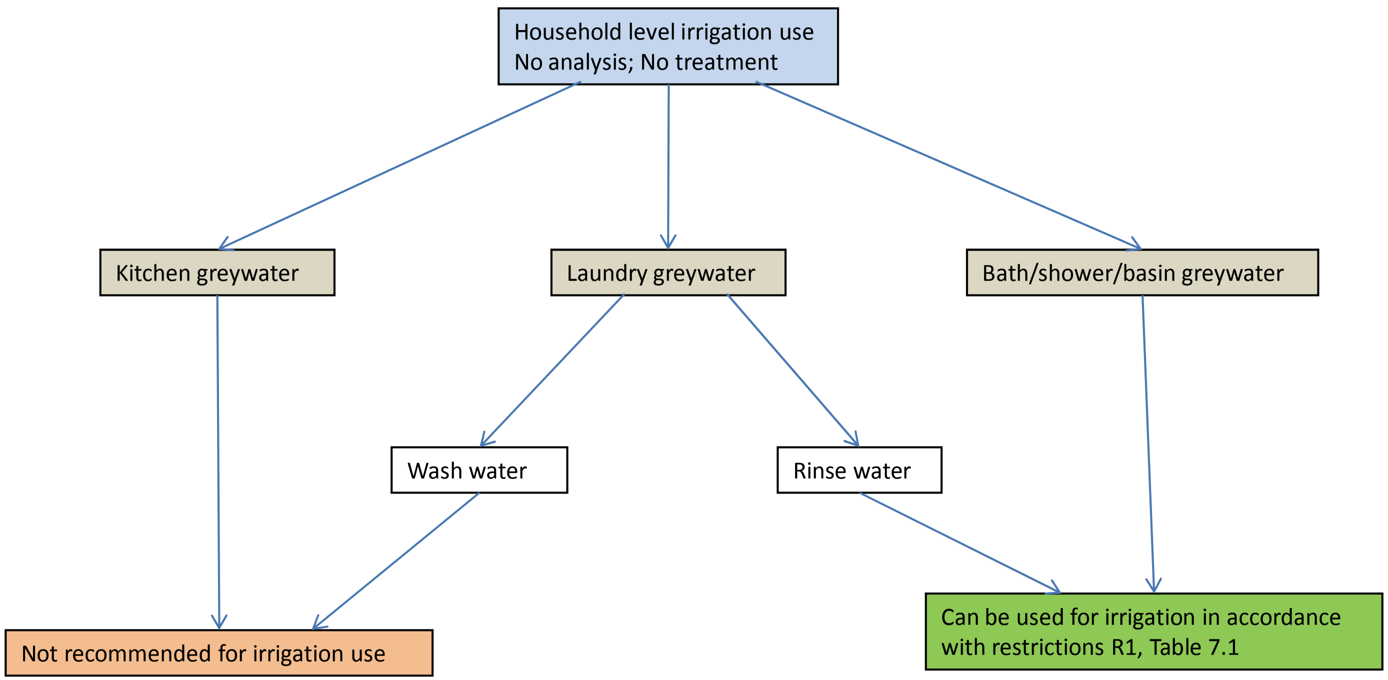


Figure 7.2: Decision flow chart for management of risks associated with greywater use in Category 1 (no analysis).

7.1.2 Category 2: Minimum greywater analysis (Figure 7.3)

This is the first category in which a quantitative assessment of greywater quality is made, and thus the first in which greywater use can be considered at either household or communal level.

Special considerations for communal use of greywater for irrigation

If greywater use is at a communal level, *i.e.* either for a communal garden or for a number of households situated in close proximity to each other all wishing to practice greywater use on their own properties, then cognisance must be taken of the capacity of the available land to absorb the volume of greywater generated. This may be estimated by calculating the ***greywater generation rate*** (Carden *et al*., 2007). The greywater generation rate is particularly important in planning greywater irrigation implementations in unsewered settlements. In sewered settlements it is unlikely that the total fraction of greywater will be considered for irrigation and any water in excess of the estimated volume required for irrigation (see Section 7.4, Greywater Quantity: Guide to Irrigation Volumes) can be easily disposed of to the sewer. However, in unsewered settlements careful planning is required to ensure responsible disposal of greywater which is in excess of irrigation requirements (as also of greywater which is of a quality not suitable for irrigation).

The greywater generation rate is calculated as follows:

$$\mathbf{G_G = Q \times D} \qquad \textbf{Equation 1}$$

G_G is the greywater generation rate, ℓ/ha.day
Q is the approximate volume of greywater produced per household (water consumption x 75%), ℓ/dwelling unit (du).day
D is the density of households per hectare, du/ha (Carden *et al*., 2007).

- If this value is below 500 ℓ/ha.day, then irrigation use of greywater is not constrained by the availability of land to absorb the volume of greywater generated. If it is between 500 and 2 500 ℓ/ha.day, then careful attention needs to be paid to site-specific factors (*e.g.* nearby surface water bodies, slope of the land, type of soil, rainfall, depth to the water table) before a decision is taken to use greywater for irrigation.

- If this value is above 2 500 ℓ/ha.day, then greywater use should preferably be avoided unless adequate provision for disposal of excess greywater is available.

- If greywater use is to be undertaken despite a high greywater generation rate, then all users of greywater must understand clearly that it is likely that only a fraction of the total volume of greywater generated can be used for irrigation and that the remainder of available greywater cannot be disposed of to land. The fraction which could potentially be used would need to be evaluated on a site-specific basis, taking into account the area to be irrigated and the estimated water use (see Section 7.4). In such instances, it is advisable that the best quality greywater is reserved for irrigation use.

Considerations applicable to both household level and communal use of greywater for irrigation
Kitchen greywater should be treated with a minimum of a mulch filter prior to irrigation use (see Section 7.3.2, Greywater treatment systems). If this is not possible, then use of this greywater fraction should be avoided.

All greywater to be used for irrigation under this category is analysed for the greywater constituents specified as per ***minimum analysis***, *viz*. electrical conductivity (EC), sodium adsorption ratio (SAR), pH and *Escherichia coli*. These constitute the minimum indicators of risk to human health (*E. coli*), plant growth and yield (EC, SAR, pH) and soil structure (EC, SAR). A distinction is drawn between ***minimum analysis*** and ***full analysis*** so that water consumers who wish to use greywater productively but do not have the resources to support full analysis, can still take advantage of better evaluation of potential risks and hence less restrictive greywater uses than those for whom no analysis is performed.

If greywater complies with at least the maximum range for the specified greywater constituents, as given in Section 7.2, then irrigation with greywater can be performed in accordance with restrictions R2 in Table 7.2.

If greywater does not meet these greywater quality ranges, then some form of treatment must be considered, as described in Section 7.3. Where a treatment option is chosen for which it is possible to monitor the treated greywater, this should again be tested to determine whether the greywater quality after treatment falls within the target range (preferably) or the maximum range. Integrated treatment and irrigation options, and mitigation, treatments should not be applied if greywater quality before treatment / mitigation falls beyond the ranges for short-term use.

Note that cognisance must be taken of the volume of greywater which can be applied to land (see Section 7.4).

Table 7.2: Risk management restrictions for irrigation use of greywater after minimum analysis of greywater (as defined), and assuming compliance with quality guidance for minimum analysis (see Section 7.2).

Restrictions R2, applicable to greywater use in Category 2
Restrictions relating to health impact **Do:** ✓ Wash hands and arms well with soap after handling greywater. ✓ Use all greywater within 24 hours of collection. ✓ Use irrigation methods that minimise contact of greywater with above-ground plant parts. ✓ If using on lawns, avoid direct human contact for 8 hours after irrigation. ✓ If using on crops, stop irrigating with greywater 2 weeks before harvesting. ✓ Reduce volume of greywater per application if ponding occurs on surface of irrigated ground, or if water runs off the surface. ✓ Wash all crops well in soapy water after harvest and dry in sunlight. ✓ Preferably, peel and cook crops prior to consumption. **Do not:** × Do not use kitchen greywater unless treated with minimum of a mulch filter. × Do not use greywater if someone in the contributing household(s) has an infectious disease. **Restrictions relating to impacts on plant growth and yield** **Do:** ✓ Use irrigation methods that minimise contact of greywater with above-ground plant parts. ✓ Switch to salt-tolerant plants, if plants show symptoms of salt stress. **Do not:** × Do not plant or irrigate plants prone to boron toxicity. **Restrictions relating to soil and environmental deterioration** **Do:** ✓ Increase greywater application or alternate with freshwater, in order to leach out salts, if plants show symptoms of salt stress. ✓ Apply agricultural gypsum and compost to ameliorate soils if infiltration rate decreases and it is suspected that this is related to high sodium content of greywater. **Do not:** × Do not use kitchen greywater unless treated with minimum of a mulch filter. × Do not use greywater falling in this category of restrictions if the soil is very clayey, if the ground has a steep slope, or if the irrigation site is close to a river or borehole. × Do not use greywater if the irrigated land is close to sensitive environments which may be adversely affected by greywater runoff or infiltration.

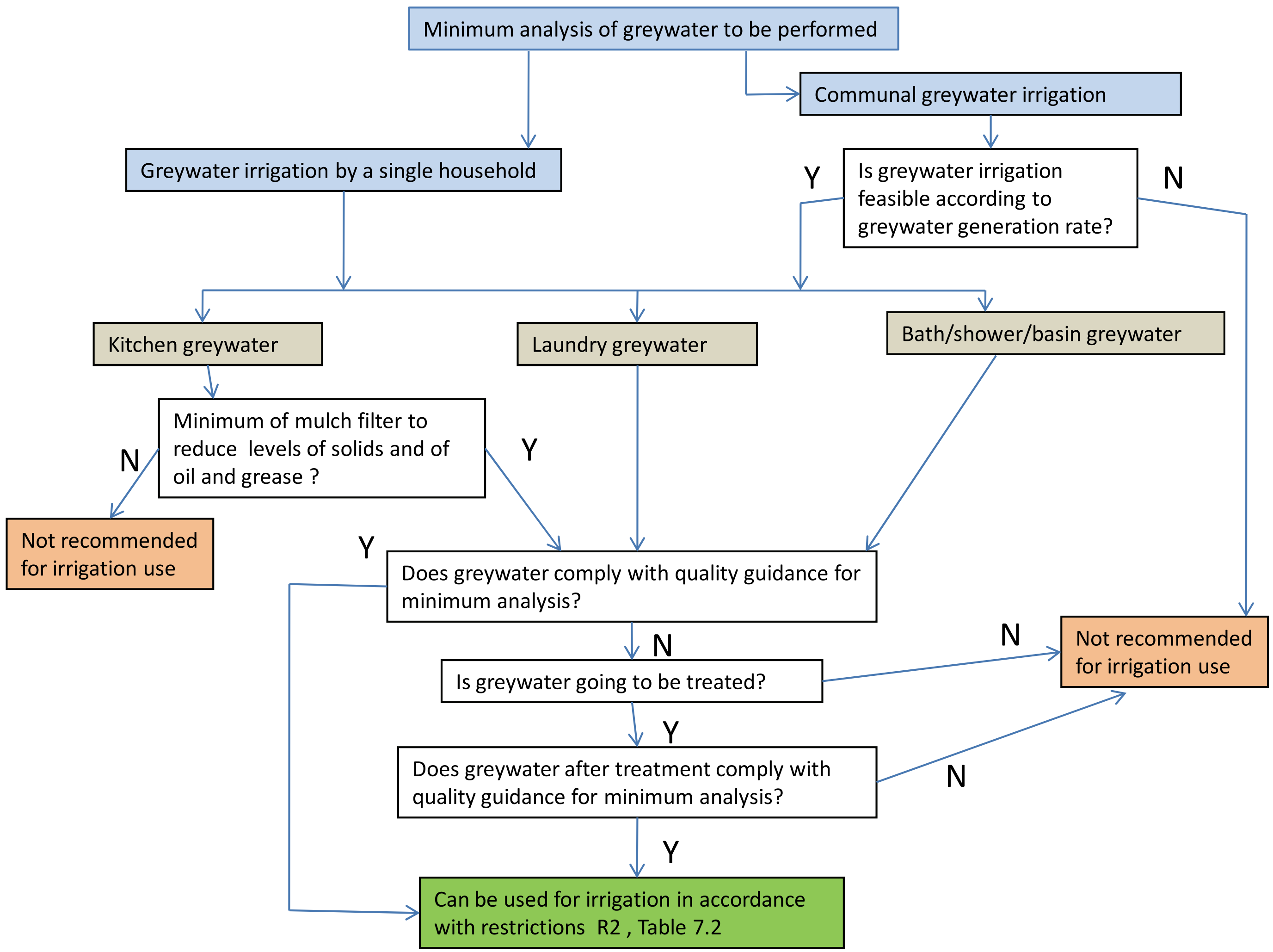


Figure 7.3: Decision flow chart for management of risks associated with greywater use in Category 2 (minimum analysis).

7.1.3 Category 3: Full greywater analysis (Figure 7.4)

The decision-making process for greywater use in this category follows essentially the same flow as described for Category 2, except that greywater is subjected to full analysis in place of minimum analysis.

If greywater falls within the target range (preferably) or the maximum range for all constituents in the full analysis, either before or after treatment, then it can be used in accordance with restrictions R3 in Table 7.3.

If this cannot be achieved, but greywater quality can be improved so that constituents for minimum analysis fall within the desired ranges, then greywater can be used in accordance with restrictions R2 in Table 7.2.

It may be observed that there are few differences between the recommendations listed in Table 7.2 and those in Table 3. The main difference in irrigating with greywater complying with the quality guidance associated with full analysis, *vs.* that associated with minimum analysis, is that remedial interventions, *e.g.* to manage salt or boron toxicity or to counteract biological growth, are less likely to be necessary if greywater complies with the quality guidance recommended for full analysis.

Note that cognisance must be taken of the volume of greywater which can be applied to land (see Section 7.4).

Table 7.3: Risk management restrictions for irrigation use of greywater after full analysis of greywater (as defined), assuming compliance with quality guidance for full analysis (see Section 7.2).

Restrictions R3, applicable to greywater use in Category 3
Restrictions relating to health impact **Do:** ✓ Use all greywater within 24 hours of collection. ✓ Use irrigation methods that minimise contact of greywater with above-ground plant parts. ✓ If using on lawns, avoid direct human contact for 8 hours after irrigation ✓ If using on crops, stop irrigating with greywater 1 week before harvesting. ✓ Reduce volume of greywater per application if ponding occurs on surface of irrigated ground, or if water runs off the surface. ✓ Wash all crops well in soapy water after harvest and dry in sunlight. ✓ Preferably cook crops prior to consumption. ✓ Wash hands and arms well with soap after handling greywater. **Do not:** ✗ Do not use kitchen greywater unless treated with minimum of a mulch filter. ✗ Do not use greywater if someone in the contributing household(s) has an infectious disease. **Restrictions relating to impacts on plant growth and yield** **Do:** ✓ Use irrigation methods that minimise contact of greywater with above-ground plant parts. ✓ Be aware of possible need to switch to boron or salt tolerant plants, although this should not be necessary if guidance present here is used as indicated. **Restrictions relating to soil and environmental deterioration** **Do:** ✓ Be aware of possible need to flush soils to prevent accumulation of salts, especially in hot and/or dry areas where evaporation is high. ✓ Apply agricultural gypsum and compost to ameliorate soils if infiltration rate decreases and it is suspected that this is related to high sodium content of greywater. ✓ Be sensitive to the proximity of sensitive environments which may be adversely affected by greywater runoff or infiltration. **Do not:** ✗ Do not use kitchen greywater unless treated with minimum of a mulch filter.

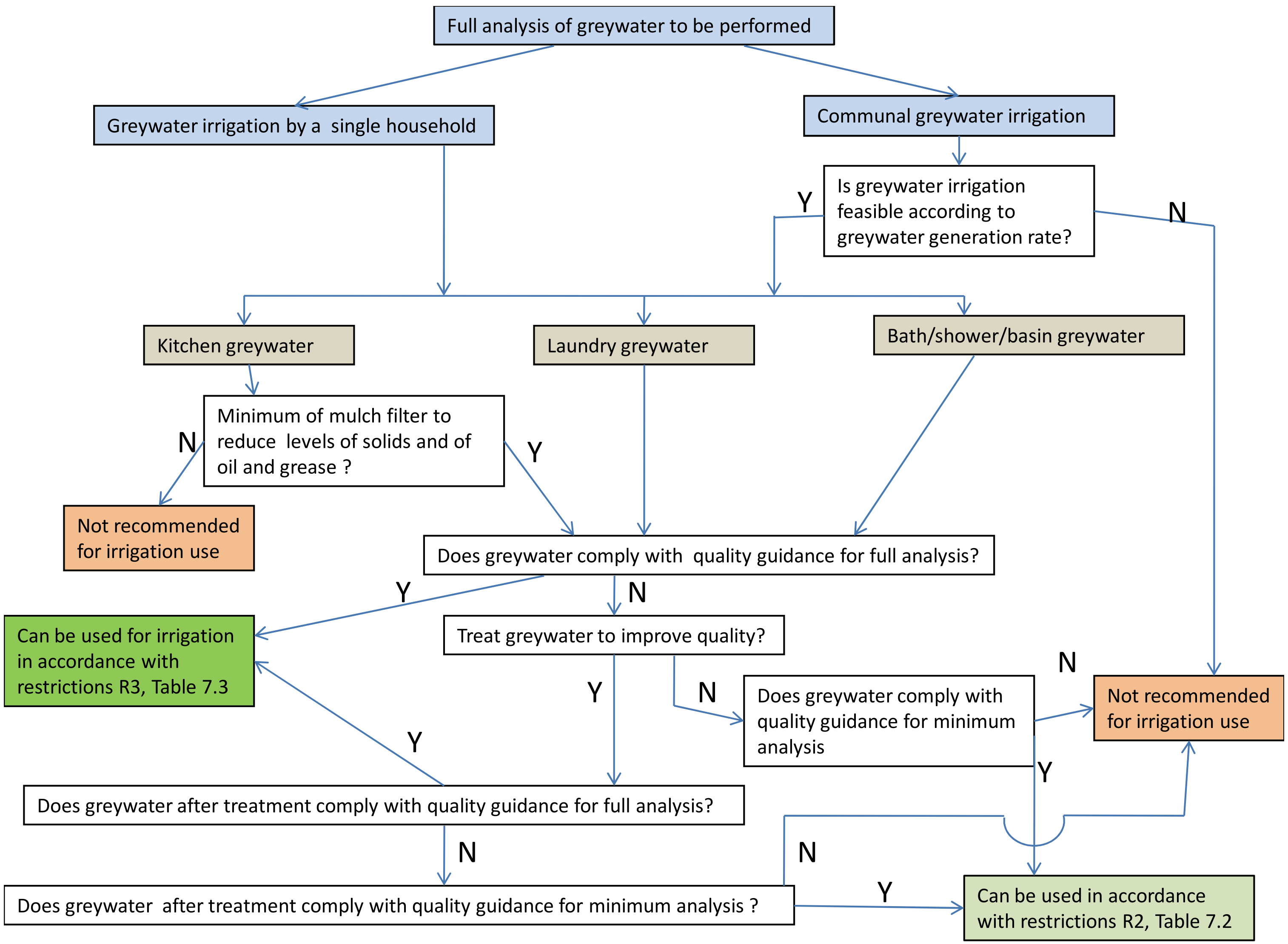


Figure 7.4: Decision flow chart for management of risks associated with greywater use in Category 3 (full analysis).

7.2 Greywater Quality: Guide to Greywater Constituents

7.2.1 Rationale underlying choice of constituents

The constituents included here for quality of greywater to be used for small-scale irrigation reflect the aims and scope of the overall Guidance Report, *viz*.

- Protection of human health.
- Protection of irrigated plants.
- Protection of the environment, specifically the irrigated soil.

Thus the constituents included are related to human health, plant growth and yield, and soil quality.

As explained in Section 7.1, distinction is made between ***minimum analysis*** and ***full analysis***. Water users who wish to use greywater productively but do not have the resources to support full analysis, can still take advantage of better evaluation of potential risks and hence less restrictive greywater uses than those for whom no analysis is performed, by performing a defined minimum set of analyses, termed ***minimum analysis*** here. For larger greywater irrigation implementations, the number of potentially exposed users, and hence the risk, increases. In these situations, or where users can afford a wider analysis and wish to manage risks primarily through control of the quality of the greywater used for irrigation, a wider analysis, termed ***full analysis*** here, is recommended.

7.2.2 Greywater constituents and greywater quality guidance ranges

In keeping with the South African Water Quality Guidelines (DWAF, 1996), the properties of greywater included in the Guidance Report are referred to as ***constituents***. Based on a review of available greywater quality studies in South Africa and comparison to the South African Water Quality Guidelines (SAWQG), and on peer review of the resultant list of greywater constituents, the following physical constituents, chemical constituents and microbiological constituent were chosen for inclusion in this Guidance Report:

Minimum analysis

- Electrical Conductivity (EC)
- Sodium Adsorption Ratio (SAR)
- *E. coli*
- pH

Full analysis

Minimum analysis

- Electrical Conductivity (EC)
- Sodium Adsorption Ratio (SAR)
- *E. coli*
- pH

In addition

- Boron
- Chemical Oxygen Demand (COD)
- Oil and grease
- Suspended solids

- Total inorganic nitrogen
- Total phosphorus

An explanation of the rationale underlying the inclusion of each of the above greywater characteristics in this Guidance Report is presented in Appendix B.

Greywater quality guidance ranges for the indicator greywater constituents were derived wherever possible from the SAWQG for irrigation. 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 the present guidance for the use of greywater in small-scale irrigation. This includes a graded series of greywater quality ranges, indicating preferred quality (***target range*** in Table 7.4), tolerable quality (***maximum range*** in Table 7.4), 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*** in Table 7.4), or quality which is not suitable for irrigation use unless treated (***not recommended for irrigation use*** in Table 7.4). These ranges correspond to minimal excess risks to human health, plants and soil associated with the target range, followed by increasing risks, up to excessive and hence unacceptable risks associated with the range which is not recommended for irrigation use.

Table 7.4 shows only the numeric range of each constituent. The effects associated with each range, and the source of the ranges for each constituent, are shown in Appendix B, which presents essentially the same table but gives additional information for the ranges of each constituent.

Water quality should preferably comply with the target quality guidance range, but certainly be within the maximum guidance range.

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.

Special consideration with respect to guidance for microbiological quality for short-term use

Studies on the microbiological quality of vegetable crops irrigated below the soil surface with domestic greywater originating from an informal settlement showed that although microbial levels in greywater were high, a number of simple precautions reduced risk of infection associated with greywater irrigation to within acceptable levels (see Case Studies in Technical Report). For this reason, the water quality guidance table (Table 7.4) allows for short-term use of greywater with microbial levels up to the mean concentrations detected in that study. However, exposure precautions ***must*** be implemented, in accordance with Table 7.1. In brief:

- Handlers of greywater, must wear gloves and boots, and wash face, hands, arms, feet and legs with water and soap after greywater use;
- Handlers of greywater-irrigated produce must wash thoroughly with water and soap after handling produce; and

- Greywater-irrigated produce must be washed, peeled and cooked prior to consumption.

Table 7.4: Water quality guidance for use of greywater for small-scale irrigation in South Africa.

Greywater constituent	**Target water quality range**	**Maximum water quality range (applicable only to well-drained, chemically stable soils)**	**Water quality suitable only for short-term use on site-specific basis.**[1]	**Water quality not recommended for irrigation use**
	Suitable for unrestricted use with minimal risk to human health, plants or soil	**Increasing risk to human health, plants or soil**	**Significant risk to human health, plants or soil; tolerable for short-term use only**	**Excessive risk to human health, plants or soil**
Physical constituents				
Electrical conductivity (mS/m)	< 40	40-200	200-540	> 540
Oil and grease (mg/ℓ)	< 2.5	2.5-10	10-20	> 20
pH	6.5-8.4	6-9	6-9	< 6 > 9
Suspended solids (mg/ℓ)	< 50	50-100	> 100	> 100
Chemical constituents				
Boron (mg/ℓ)	< 0.5	0.5-4.0	4.0-6.0	> 6.0
Chemical oxygen demand (COD, mg/ℓ)	< 400	400-5 000	> 5 000	> 5 000
Sodium adsorption ratio[2] (SAR)	< 2.0	2.0-5.0	5.0-15.0	> 15.0
Total inorganic nitrogen (mg/ℓ)	< 10	10-20	20-60	> 60
Total phosphorus (mg/ℓ)	<10	10-15	15-50	> 50
Microbiological constituent				
E. coli (colony-forming units, CFU/100 mℓ)	< 1	1-10^3 (1-1 000)	10^3 10^5 (1 000-100 000) *Note: Only with appropriate exposure restrictions – see text. Range can be extended to 10^7 (10 000 000) if irrigation is sub-surface.*	> 10^7 (> 10 000 000)

1. Treatment to maximum range (at minimum) is the preferred option. If this is not sustainable in the long term, then disposal to a sewer should be considered.

2. Sodium adsorption ratio:

$$\mathbf{SAR = [sodium]/\sqrt{([calcium]+[magnesium])/2}} \qquad \textbf{Equation 2}$$

All concentrations measured in mmol/ℓ, SAR is reported without units

7.2.3 Number of samples

It is difficult to balance the conflicting requirements of capturing the variability in greywater quality and of containing costs so that analysis remains within the reach of small-scale users and small municipalities. The guidance on sample numbers given here represents a first tentative attempt to strike this balance. It is based on practical considerations rather than sound statistical principles and should therefore be reviewed in the future, in the light of experience.

A single sample is insufficient to assess the quality of greywater since this varies widely. A minimum of three samples is suggested, to be taken over a period of two weeks. Two samples should be taken on weekdays, although not on the same day of the week. The third sample should be taken on a weekend.

In general, the arithmetic mean of the three readings should be used for comparison to the greywater quality guidance in Table 7.4. The exceptions are suspended solids (DWAF, 1996) and *E. coli* (Standard Methods, 2005), for which the geometric mean should be used.

Because the quality of greywater varies over time with changing uses of water in the household, sampling should be repeated periodically. Yearly sampling is proposed as the minimum. However, if analysis results for more than one variable for minimum analysis, or more than two variables for full analysis, fall within the maximum range rather than the target range, then the risk of exceeding this range is increased and sampling should be repeated at six monthly intervals. Furthermore, yearly (or six monthly) sampling assumes that the sources of greywater remain broadly the same over that period. If the sources of the greywater change significantly, then sampling and analysis should be repeated, irrespective of the time elapsed since the last sampling.

If treatment is applied in such a way that the treated greywater can be sampled, then both the untreated greywater and the treated greywater should be sampled on a yearly (or six monthly) basis.

7.3 Greywater Quality: Guide to Mitigation of Greywater Quality

Two approaches to treatment are presented in this section:

1. Integrated ameliorative 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.
2. 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.

7.3.1 Integrated mitigation practices

The mitigation practices described below aim to minimise potential adverse effects associated with some of the physico-chemical characteristics of greywater, in particular salts contributing to electrical conductivity and SAR, and the elements sodium and boron.

Irrigation method

The most suitable method for applying greywater to plants, from the perspective of microbial contaminants and salinity, is one which applies the water as close as possible to the root zone of the plant, preferably below the surface of the soil. This avoids contact of the leaves or fruit with micro-organisms which may cause health effects and with greywater constituents which can be absorbed through the leaves, such as sodium. Installation of expensive high technology drip irrigation equipment is not essential for root zone application of greywater. Planting towers in various forms, as described in Section 7.3.2 are an example of delivery of irrigation water directly to the roots of the plant. Another method which has been applied in practice in eThekwini Municipality is to puncture the base of a plastic bottle and to bury this to approximately two-thirds of its length near the base of single plants (for small bottles, *e.g*. 250 or 500mℓ) or at the centre of a group of plants (for large bottles, *e.g.* 2ℓ). Greywater is poured into the bottle and drains out of the bottom, directly to the plant roots (Figure 7.5).

A **B**

Figure 7.5: Irrigation of vegetable crop plants in root zone by way of plastic bottle buried alongside the plant (A). Water exits the bottle via holes punctured in the base (B).

Amelioration of soil
Increased leaf drop as a result of boron toxicity to trees can be counteracted by applying extra nitrogen to soil to promote vegetative growth (DWAF, 1996).

Increased SAR, as also elevated sodium, can be mitigated by the addition of soluble salts of calcium or magnesium to either the irrigation water or the soil. In practice, agricultural gypsum is most commonly used. Sulphate salts (as in gypsum) are preferable to chloride salts because sulphates are considered non-toxic. Gypsum can also be added to soil (DWAF, 1996).

Leaching
Surplus irrigation water can be applied to leach out accumulating boron in soil. Since boron concentrations in soil are strongly buffered by adsorption of boron to soil, this requires large volumes of water (about two to three times the volume of water required to achieve similar reduction on chloride concentrations) (DWAF, 1996).

Leaching is also one of the main mitigation practices which can be used to manage soil salinity. Applying irrigation water in excess of plant requirements leaches salts out of the root zone of the soil. The disadvantage of this practice is its contribution to salinisation of surface waters and groundwater (DWAF, 1996).

Since potted plants are not subject to any natural leaching, it is particularly important to flush potted plants with fresh water frequently, if greywater is used to irrigate these (DWAF, 1996).

Planting tolerant plant species
The plant toxicity effects of boron can be minimised by planting boron-tolerant crops, as listed in Appendix C.

The adverse effects of salinity can be minimised by planting salt-tolerant plants, as listed in Appendix C.

The plant toxicity effects of sodium can be minimised by planting sodium-tolerant plants, as listed for salinity, or by switching to plants with low foliar absorption of sodium (Appendix C).

Other mitigation practices
Accepting a reduced crop yield is a common mitigation practice where levels of, *e.g.* boron or salt, are not excessive. Alternately, annual plants can be planted at a higher density, thereby offsetting total yield reduction by accepting a reduced yield on a greater number of plants (DWAF, 1996).

Increasing frequency of irrigation with saline irrigation water, like most greywater, reduces the effect of salt concentration in the soil between applications because the resulting higher soil water content between applications reduces concentration of salts in the soil by evaporation of soil water. Therefore a higher irrigation frequency will have a lower impact on crop yield and quality than will a low irrigation frequency. Increasing the frequency and decreasing the duration of irrigation also minimises the time available for foliar absorption of sodium resulting from any contact between the irrigation water and leaves (DWAF, 1996).

Using an irrigation method which does not wet the leaves is important in managing sodium toxicity to leaves, and also for avoiding microbial contamination of plants and crops (DWAF, 1996).

Using irrigation with greywater only to supplement rainfall means that application of undesirable greywater constituents is minimised and rainwater can contribute to dilution and leaching in the soil (DWAF, 1996).

7.3.2 Greywater treatment systems

Many commercial greywater treatment systems have been described (see Technical Report). However, the processes described below have been confined to generic processes known to have been tested in pilot studies in South Africa. They aim to lower levels of total suspended solids, oil and grease, COD and health-related micro-organisms. Some removal of nutrients (nitrogen, phosphorus) may also occur, although this is of lesser concern where the treated greywater is used for irrigation.

Simple filtration is a widely implemented method of reducing the solids content of any wastewater, including greywater, as a primary screening treatment.

The mulch tower and resorption bed combination of biological primary and secondary treatment was piloted in the Hull Street Project, Kimberley (Ridderstolpe, 2007), and the Scenery Park Development, Buffalo Park Municipality (BCM) (Whittington-Jones, 2007). The two systems 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 re-use. 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, was tested by Naicker (Naicker, 2008; Naicker *et al.*, 2009).

The tower garden concept was adapted by Chris Stimie from implementations seen in Kenya (Crosby, 2005). Pilot implementations are in the Eastern Cape and in Limpopo. 'Agritubes', or growing tubes, are a similar idea, designed and tested by Nick Alcock (Khanyisa Projects) and implemented by eThekwini Municipality.

Simple filtration

Simple filtration, *e.g.* through fabric or geotextile, is a first step to improving the quality of greywater. Used on its own, it will not much improve the quality of greywater other than the suspended solids content and is therefore not recommended for use in isolation. However, it can be used effectively to prevent blockages of irrigation equipment and clogging of soil if greywater is to be used without other treatment (Table 7.1), or as a pre-screening method to minimise blockages in treatment processes which follow it.

Mulch tower

A mulch tower (a mulch filter implemented in an above-ground structure), is the minimum treatment required for use of kitchen greywater. It is a primary treatment process, aimed at removal of suspended solids and oil and grease, and some 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 will need replacing periodically, the interval between replacements depending on how heavily the mulch filter is loaded. Samples of treated greywater can be collected from the outflow pipe from the mulch tower to determine the extent to which this treatment process has improved the quality of greywater. An implementation of a mulch filter in Buffalo City Municipality is shown in Figure 7.6.

Two studies testing the performance of mulch towers have shown that this treatment process significantly improves greywater quality (Naicker, 2008; Zuma *et al.*, 2009).

Design of a mulch tower, with dimensions and description of packing, is shown in Appendix C.

A

B

Figure 7.6: Mulch tower situated at outlet of kitchen sink (A), and view of mulch tower from above (B), showing organic filtering material (mulch).

Mulch tower and resorption bed

The combination of mulch tower and resorption bed represents a combination of primary and secondary treatment. The mulch tower provides primary treatment, while secondary treatment is performed by a sub-surface 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 7.7). The resorption bed also consists of stone chips, and is lined and enclosed with geotextile. Biofilm development in the Infiltra serves as a site for removal of COD and biological oxygen demand (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 micro-organisms (Ridderstolpe, 2007). Water travelling through the resorption bed permeates through the geotextile lining 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. A combination of mulch filter and resorption bed, constructed at the University of KwaZulu-Natal (Durban), is shown in Figure 7.7. Design details are provided in Appendix C.

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). However, this may be 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).

Figure 7.7: Combination of mulch tower and sub-surface resorption bed, including embedded infiltration zone and surrounding gravel filter. Note access points for sampling.

Tower gardens and "Agritubes"

Variations on the concept of tower gardens for using 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. 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 (Crosby, 2005). Implementations of tower gardens are shown in Figure 7.8. Design and dimensions are provided in Appendix C.

In this case, the tower garden is simultaneously a means of treating greywater (as it moves over the stones which become coated in biofilm, and as it moves through the soil) and of delivering greywater to the roots of the plants. The integrated nature of this form of treatment however, means it cannot be sampled easily to determine the quality of greywater exiting the system.

A **B**

Figure 7.8: 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 presently being introduced in eThekwini Municipality (Alcock, pers. comm.; Gounden, pers. comm.). 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. This pipe can be cheaply and simply constructed from interlocking 2 ℓ cool drink bottles, inverted, with the base cut off and the lid left on. Since the core is narrower, the entire column is also narrower, being approximately 0.4 m in diameter. 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 loading of the Agritubes such that overflow does not occur. The soil used in pilot studies with growing tubes was composted sludge from a sewage treatment works. An example of a pilot implementation in eThekwini Municipality is shown in Figure 7.9. Design and dimensions are given in Appendix C.

As with tower gardens, Agritubes provide combined greywater treatment and plant root zone application, and are therefore not suited to monitoring of treated greywater. It should also be noted that both tower gardens and Agritubes should still be preceded by mulch towers for kitchen greywater.

Figure 7.9: Growing tube (Agritube), as tested by eThekwini Municipality for growing plants with greywater. (From Nick Alcock, Khanyisa Projects; used with permission).

7.4 Greywater Quantity: Guide to Irrigation Volumes

The following section provides general guidance in selecting the volumes of greywater which can be applied to a garden or in small-scale crop cultivation. It is assumed that greywater irrigation occurs within climatic regions and on soil types for which best practices with respect to suitable plants, cultivation and irrigation methods, *etc*. have already been established or will be established using existing procedures for this purpose. The purpose of the information given here is not to provide detailed technical specifications for 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. This is given in the context of the overall aims of the Guidance Report, *viz:*

- The volume of greywater which can be applied without unacceptable increase in risk to human health.
- The volume of greywater which can be applied without unacceptable increase in risk to plant growth and productivity.
- The volume of greywater which can be applied without unacceptable increase in risk to the environment, specifically to the ability of the soil to sustain plant growth.

Because the quantity of water applied impacts most directly on plant growth and the soil environment, this section concentrates particularly on the last two points.

For more detailed coverage on how water volumes for irrigation can be calculated, the reader is referred to the Technical Report.

7.4.1 *Estimating plant water use*

The maximum estimated water use (which is the same for greywater as for conventional irrigation water) for a given crop / plant type over a given area may be derived using the following equation:

$$\textbf{EWU} = \textbf{E}_0 \times \textbf{CF} \times \textbf{HA} \qquad \textbf{Equation 3}$$

EWU = estimated water use (measured in ℓ/day)
E_0 = reference evapotranspiration rates (location-specific and season-specific; a meteorologically derived measure. Measured in mm/day).
CF = crop factor, a measure of plant-specific water use (a unitless ratio)
HA = area to be irrigated (measured in m^2).

A description of the terms used in Equation 3 is given in Appendix D. The sources used in derivation of this equation are discussed in full in the Technical Report. The equation is essentially the same as that presented by Green (1985) for calculation of agricultural water use.

Estimated water use (EWU) represents ***only*** the amount of water required by the plant in light of climatic conditions such as solar radiation, rainfall, wind speed *etc*. Note that EWU does not include other factors which affect the water requirement of plants and thus represents the ***maximum*** amount of water which should be applied. Estimates of EWU are presented in Table 7.5 and Table 7.6 in Section 7.4.2. These tables may be used as a guide to identify the maximum amount of greywater which can be applied under a range of irrigation scenarios. Adjusting EWU for other factors which affect water use, *viz.* soil type, planting density (crop coverage), and recent rainfall, is considered in Section 7.4.3.

Reference evapotranspiration (E_0)

Reference evapotranspiration (E_0, measured in mm/day) is a measurement that combines the effect of temperature, humidity, solar radiation and wind on the water use (evapotranspiration) of a reference crop. It is therefore specific to a particular location and season. As a general rule of thumb, within a season, the drier and hotter the area, the higher the applicable E_0 value. The wetter and more temperate the area, the lower the E_0 value. Values of E_0 for a given location are typically higher in summer than in winter.

In the guidance presented here, historical values of E_0 were used for representative weather stations in different climatic regions of South Africa (Green, 1985). The climatic regions were identified on the basis of historical rainfall and temperature data (Blignaut *et al*., 2009).

Crop factors

Crop factors (CF) relate E_0 to evapotranspiration (water use) of a specific plant or crop type. Values of CF range between 0.0 and 1.0. A high CF represents a plant with high water use, while a low CF represents a plant with low water use.

7.4.2 *Quick look-up tables of estimated water use per climatic region by season*

Equation 3 was used to calculate the weekly estimated water use (EWU) of plants at representative locations based on Green (1985) and Blignaut *et al*. (2009). These tables (Table 7.5 for summer and Table 7.6 for winter) may be used to obtain quick estimates of estimated water use, *i.e.* the volumes of greywater which will be required by crops with high water use (CF 0.8), moderate water use (CF 0.5) or low water use (CF 0.3), in different climatic regions in South Africa. Both daily and weekly estimates are given. The tables can also be used to get an indication of the area that can be irrigated with the available greywater.

Table 7.5: 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 3 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

			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**
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
	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 7.6: 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 3 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

Climatic region, Province, Representative weather station	Winter E_0	Crop Factor (CF)	EWU in Litres Per Day, Winter; Applicable to irrigated area (HA) of: 5 m^2	10 m^2	20 m^2	EWU in Litres Per Week, Winter; Applicable to irrigated area (HA) of: 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

7.4.3 Other factors to consider when plants are irrigated with greywater

Adjusting water application for soil type

The estimates for water use depicted in Table 7.5 and Table 7.6 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 thus require that the water use by plants be replenished more frequently and in smaller quantities

In contrast to sandy soils, clayey 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.

Adjusting water application for planting density
The estimates for water use depicted in Table 7.5 and Table 7.6 assume 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 should be reduced accordingly, as shown in Table 7.7.

Table 7.7: Reduction in plant maximum water use (estimated water use, EWU) on the basis of the proportion of planted area covered by crop (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 4)
10	60	0.4
30	40	0.6
50	20	0.8
≥70	0	1.0

Adjusting water application 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. The weekly estimated water application (Table 7.5. and Table 7.6) 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 thus 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 per week is as follows:

$$\mathbf{EWU_{adjusted} = (EWU \times CC) - (mm\ rainfall\ in\ preceding\ 24\ hours \times HA)} \quad \textbf{Equation 4}$$

$EWU_{adjusted}$ is the estimated water use, adjusted for site-specific factors affecting water use.
EWU is estimated water use as per Equation 3 and Table 7.5 and Table 7.6.
CC is crop coverage factor from Table 7.7.
HA is area to be irrigated (measured in m^2), as in Equation 3.
mm rain is subject to the considerations in text in the paragraph above.
Greywater application rate and frequency are adjusted for soil type as described in text above.

7.4.4 Worked examples of calculation of quantity of water to be applied

Example scenarios:

1. Western Cape near Elgin weather station, winter (rainy season); medium water use crop, 10 m^2 planted area, grown on sandy soil, at 50% crop density, no recent rainfall.

2. Western Cape near Elgin weather station, winter (rainy season); medium water use crop, 10 m^2 planted area, grown on sandy soil, at 50% crop density, 5 mm rainfall in past 24 hours but 10 mm fell on preceding day so ground was already wet.

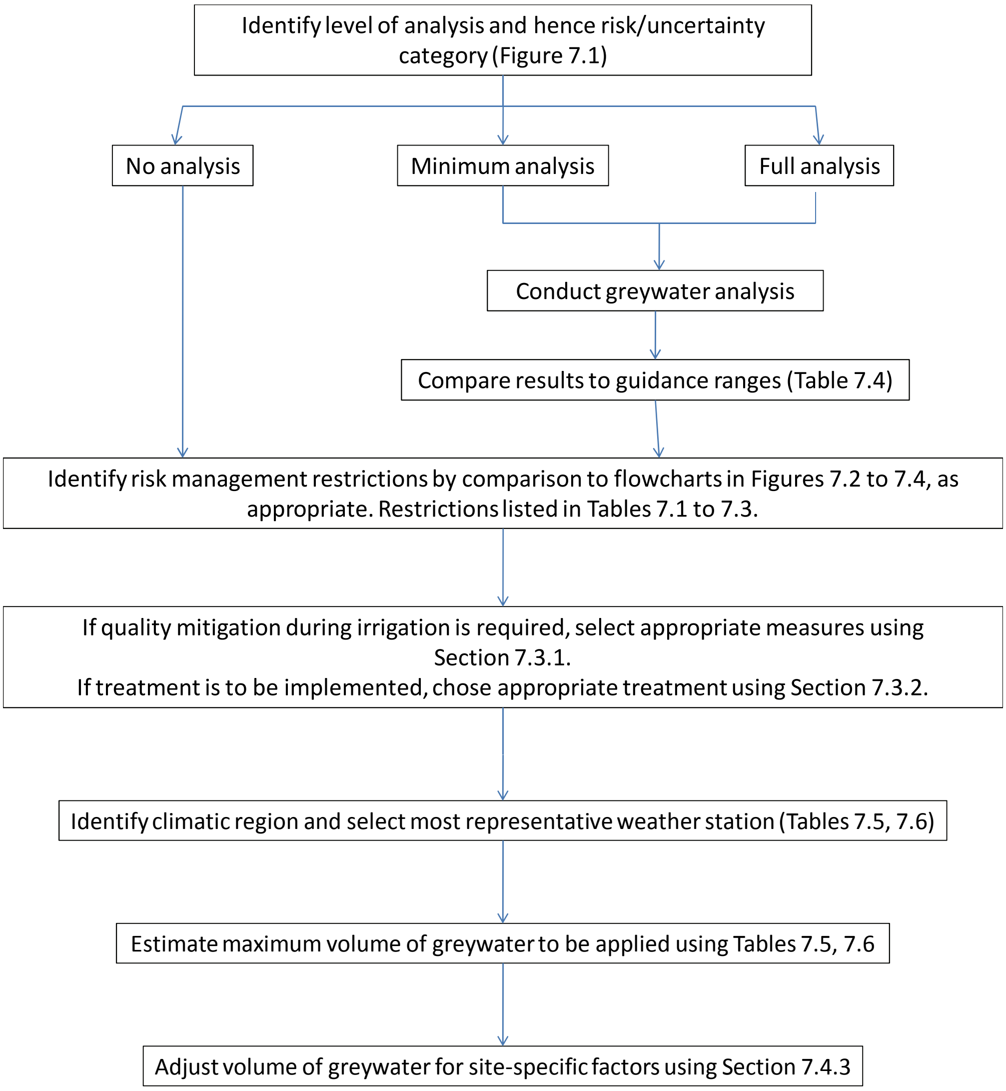
Example 1
Greywater volume to be applied is calculated as follows:

- From look-up table (Table 7.6) for Western Cape, Elgin weather station, medium water use (CF 0.5) and irrigated area of 10 m^2 :
  - Daily greywater application: 15 ℓ
  - Weekly greywater application: 105 ℓ
- 50 % crop coverage yields a crop coverage factor of 0.8 (Table 7.7)
  - Daily greywater application: 15 ℓ x 0.8 = 12 ℓ
  - Weekly greywater application: 105 ℓ x 0.8 = 86 ℓ
  - Sandy soil, therefore high watering frequency and lower quantities per application. Daily estimates more likely to be used.

Example 2
Greywater volume to be applied is calculated as for Example 1, with the following addition:

- 5 mm of rainfall in past 24 hours, but because ground was already moist from previous day's rainfall, the rainfall of the preceding day is also considered:
  Reduction in greywater application
  1 mm rainfall = 1 ℓ/m^2
  (5 + 10 ℓ/m^2) x 10 m^2 irrigated area = 150 ℓ
- This exceeds the estimated greywater application for both daily and weekly estimates, so additional greywater application should be avoided.

8 Summary of Guidance for Sustainable Use of Greywater in Small-Scale Agriculture and Gardens in South Africa



This approach should yield an integrated greywater irrigation implementation addressing greywater quality, risk management strategies, greywater treatment (if desired), and appropriate greywater application planning.

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Appendix 1 Additional information for Section 7.1, "Guide to Managing Risk and Uncertainty"

1 User Information Leaflet

Figure 1 presents an information leaflet intended for users of greywater, based on Table 7.1 in the Guidance Report, "Risk management restrictions for use of greywater for irrigation without analysis of greywater". The leaflet was developed by Khanyisa Projects in support of eThekwini Municipality's implementation of greywater irrigation projects in informal settlements (Agritubes, see Section 7.3.2 in Guidance Report and Appendix 3).

Greywater Irrigation for Agriculture

ETHEKWINI MUNICIPALITY

What is greywater?

Greywater is used water generated by households during cooking, washing and rinsing clothes, dishes and bathing.

Greywater does not contain urine or faeces (i.e. not from the toilet)

Why should we use greywater for irrigation?

- Greywater is a reliable free source of water
- We can save clean water supplies for other uses
- Greywater contains nutrients that help plants grow better

Why should we use greywater CAREFULLY?

Greywater can contain some contaminants from sources such as:

- Dirty nappies (laundry)
- Food waste such as oil and grease

These contaminants can pose a risk to your health and can stop your plants from growing well

How can you be greywater wise?

- Irrigate your garden regularly
- Do not store water for more than 24 hours
- Do not pour water **DIRECTLY** onto leaves of plants
- Pour water into central distribution pipe (agritube) coke bottle or furrows
- Wash your hands after gardening and after using greywater (using clean water)
- Wash vegetables thoroughly, peel or cook before eating
- Do not use greywater that has been in pools or running on the ground
- Only use greywater generated by your household.

X ✓

X ✓

X ✓

2

Figure 1: User information leaflet explaining precautions to be taken when using greywater for irrigation without treatment. (Developed by Khanyisa Projects for eThekwini Municipality, used with permission)

Appendix 2 Additional Information for Section 7.2, "Greywater Quality: Guide to Greywater Constituents"

1 Rationale Underlying Choice of Greywater Constituents for Inclusion in Guidance Report

The constituents included in the Guidance Report for quality of greywater to be used for small-scale irrigation reflect the aims and scope of the overall Document, *viz*.

- Protection of human health.
- Protection of irrigated plants.
- Protection of the environment, specifically the irrigated soil.

Thus the constituents included are related to human health, plant growth and yield, and soil quality.

As explained in the text of the Guidance Report, distinction is made between ***minimum analysis*** and ***full analysis***.

Minimum analysis

- Electrical Conductivity (EC)
- Sodium Adsorption Ratio (SAR)
- *E. coli*
- pH

Full analysis

Minimum analysis

- Electrical Conductivity (EC)
- Sodium Adsorption Ratio (SAR)
- *E. coli*
- pH

In addition

- Boron
- Chemical Oxygen Demand (COD)
- Oil and grease
- Suspended solids
- Total inorganic nitrogen
- Total phosphorus

The rationale for inclusion of each of these constituents is presented below.

1.1 Minimum Analysis

1.1.1 Electrical conductivity (EC) and sodium adsorption ratio (SAR)

Both of these constituents are included in the guidance for minimum analysis to indicate the extent to which dissolved ions, particularly sodium ions, are likely to adversely affect soil structure. Electrical conductivity (EC) indicates the extent to which greywater may increase soil salinity, while the SAR indicates the potential impact on soil sodicity. For both constituents, the ion with the greatest impact is sodium (Na^+). Sodium is present as a counter ion in detergent formulations therefore especially laundry greywater is expected to have a potentially high impact in terms of EC and SAR.

Electrical conductivity (indicator of total dissolved solids and of salinity)
Electrical conductivity measures the ability of water to conduct electrical current. This occurs as a result of movement of charged ions and therefore provides a measure of the total concentration of charged ions in the irrigation water. Since dissociated ions in solution originate from ionic salts, EC also provides an indication of the total salt concentration of the irrigation water. This means that EC indicates the potential of the irrigation water to cause salts to accumulate in the soil, *i.e.* to increase soil salinity. Soil salinity is a function of both the salt content of irrigation water and the amount of leaching of the soil that occurs. Th ions which contribute to soil salinity are sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}) and chloride (Cl^-). Salts can be removed from the soil profile by leaching, although this will ultimately cause an increase in the salt concentration of surface waters and groundwater. However, leaching is one way of controlling soil salinity, provided the soil is well drained (DWAF, 1996, SAWQG V4).

Crop yield and quality are affected by soil salinity when the salt concentration in the root zone accumulates to the extent that it reduces the physiological availability of water to plants. When the salt content reaches a concentration at which plants can no longer extract water from the soil, salinity-induced water stress develops. If this situation continues for a significant period of time, crop yield and quality will be reduced. The symptoms of salinity-induced water stress are comparable to those of drought, *viz.* stunted growth, wilting, dark bluish-green colour of leaves and sometimes thicker, waxier leaves (DWAF, 1996, SAWQG V4).

The salinity at the bottom of the root zone is a combination of the salinity of the irrigation water and the degree of leaching that takes place. The degree of leaching is described by the leaching fraction, which is the fraction of 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 (DWAF, 1996, SAWQG V4).

Sodium-containing salts are of particular concern with respect to the effect of irrigation water on plants and soil. Sodium occupies cation exchange sites (sites which bind positively charged ions) on soil particles, which can adversely affect the structure, water infiltration and hydraulic conductivity of soil. Sodium is also toxic to plants at high concentration, with uptake through both roots and leaves, although plants vary in their sensitivity. Sodium is therefore of particular concern among the salts which contribute to water and soil salinity (DWAF, 1996, SAWQG V4).

Salts are likely to increase in the soil as a result of loss of water from soil through evapotranspiration or through addition of greywater with a high content of dissolved salts. Thus EC and SAR are of particular importance in assessing the suitability of greywater for irrigation use in regions of the country where evapotranspiration is high.

Management practices which can be used to reduce the effects of soil salinity are mainly leaching to reduce the concentration of salts in the soil or planting of salt- and/or sodium-tolerant plants.

Sodium adsorption ratio (SAR, indicator of potential to impact soil sodicity)
The SAR of irrigation water indicates the potential of the water to induce sodic conditions in the irrigated soil. Soil sodicity refers to the percentage of the cation exchange capacity (total number of sites available for binding positively charged ions) of a soil which is occupied by sodium ions, and is therefore a more specific indicator of potential sodium-associated hazards than EC. It is calculated as a ratio of sodium ion concentration to calcium and magnesium ion concentrations, as per Equation B1 (DWAF, 1996, SAWQG V4):

$$\mathbf{SAR = [sodium]/\sqrt{([calcium]+[magnesium])/2}} \qquad \textbf{Equation 1}$$

All concentrations measured in mmol/ℓ,
SAR usually reported without units

The SAR gives an indication of the exchangeable sodium percentage (ESP) at which the irrigated soil will stabilise after prolonged irrigation. Since the soil profile is well buffered against changes in SAR (*i.e.* it takes a long time for SAR of soil throughout the soil profile to change in the direction of SAR of the irrigation water), it is usually the effect of irrigation water on ESP at and near the soil surface which is of interest. In increase in soil ESP as a result of irrigation with water of high SAR can have the following negative effects:

- The growth of sodium-sensitive plants may be adversely affected as a result of uptake of sodium by the roots.
- Sodium-induced hardsetting of soils may occur.
- The hydraulic conductivity of the soil profile may be reduced.
- Surface sealing of the soil may occur, reducing infiltration of water into the soil (DWAF, 1996, SAWQG V4).

Management options include growing sodium-tolerant plants, and adding calcium and magnesium ions by dissolving agricultural gypsum in the irrigation water (see Section 7.3 Greywater Quality: Guide to Mitigation of Greywater Quality).

1.1.2 Escherichia coli
Thermotolerant coliforms (also called faecal coliforms) and *E. coli* are considered to be faecal indicator organisms, *i.e.* organisms which indicate the potential presence of harmful micro-organisms originating from faecal matter. Thermotolerant coliforms is the preferred nomenclature for faecal coliforms since this group is characterised by its ability to grow on selective culture medium at elevated temperature. While it typically contains faecal organisms, predominantly *E. coli*, it can also include organisms which are not exclusively of faecal origin and is therefore a less specific indicator of faecal pollution than is *E. coli.* Faecal matter can enter greywater by a number of routes, notably washing clothes or nappies soiled with faeces. If the

individual from whom the faeces originate is ill with an infectious disease (*e.g.* diarrhoea), it is probable that the organisms causing the disease (pathogens) are present in the faeces. The pathogens may therefore be transmitted to anyone handling greywater which contains small amounts of the faeces, or through contact with or consumption of crops irrigated with such greywater. Transmission of diseases in this manner is more likely to occur when contact is made with contaminated greywater originating outside the household of origin, since within the household transmission is likely to occur more readily via other pathways (such as direct contact, food or drinking water) and since other household members are likely to acquire resistance to the micro-organisms prevalent in their immediate environment (DWAF, 1996, SAWQG V4). In this Guidance Report, *E. coli* was chosen as the sole microbiological constituent because it is more specific for faecal pollution and because it is less prone to regrowth in greywater than the less specific group of thermotolerant coliforms

Removal of *E. coli* from greywater can be achieved during biological treatment or by disinfection of greywater prior to use. Proper selection of irrigation practices, plants to be cultivated and barriers to exposure of greywater users and of those who come into contact with the irrigated produce can reduce or eliminate the need for treatment.

1.1.3 pH

The pH of water is given by the negative of the logarithm to the base ten of the hydrogen ion concentration as per Equation B2:

$$\mathbf{pH = -log_{10}[H^{+}]} \qquad \textbf{Equation 2}$$

It is a measure of the acidity or alkalinity of the water. Conditions which result in the production of hydrogen ions increase the acidity of the water and lower the pH. Conditions which favour the neutralisation of hydrogen ions increase the alkalinity and increase the pH. The ability of water to resist changes in pH is termed its buffering capacity (DWAF, 1996, SAWQG V4).

Greywater may have high pH because of the influence of detergents, especially laundry detergents. Laundry greywater has the highest pH, typically in the range 8 to 10 (Eriksson *et al*., 2002).

Within the context of irrigation, pH does not have negative consequences, except at the extremes. Since irrigation water is applied to soil, and since soil has a greater buffering capacity than water, pH of soil changes only very slowly over time. The soil pH affects the availability of micro-nutrients, possibly to levels which may be toxic to plants. Most micro-nutrients and heavy metals are unavailable for uptake at high pH and become more available as pH decreases. Soil pH also affects populations of micro-organisms in the soil, which in turn may affect nutrient availability and plant growth. Contact of water with either very high or very low pH with plant foliage may cause leaf burn which in turn may affect plant growth and/or yield. Extreme pH can also cause damage to irrigation equipment (DWAF, 1996, SAWQG V4).

Soil pH can be modified, .*e.g.* by the addition of lime to soil. However, it is more effective to manage irrigation practices so that the buffering capacity of soil is maintained.

1.2 Full Analysis

As for minimum analysis, plus the following parameters:

1.2.1 Boron

Boron is an essential plant nutrient at very low concentrations (in the range µg/ℓ in irrigation water), but rapidly becomes toxic as the concentration increases to mg/ℓ. While boron is not a major constituent in domestic chemicals, mainly detergents, likely to enter greywater, it is present as a trace contaminant in the manufacturing process. It is important in greywater because of its toxicity to plants at low concentrations. Plants take up boron through root uptake of soil solution. The concentration of boron in the soil solution is dependent on sorption of boron to soil and subsequent desorption as the concentration of boron in soil water is increased by plant water uptake. Adsorption of boron to soil particles is strongly pH-dependent, being greatest at pH 7 to 11. These interactions mean that boron concentrations in soil solution are buffered against short term changes in boron concentration in irrigation water, and that effects on plants are likely to become evident only after several seasons. Plant response to elevated boron concentration is usually visible first as yellowing, spotting or drying of older leaves at the tips and edges of the leaves. As boron accumulates, these symptoms progress towards the centre of the leaf between the veins, until eventually leaf drop occurs. A gum or exudate on the limbs or trunk, and twig die-back may occur without leaf symptoms. The yield response of plants to boron is similar to that in response to salinity – the yield remains unaffected until a threshold concentration is reached, where after yield decreases. However, this threshold has been established quantitatively for only a few plants (DWAF, 1996, SAWQG V4).

Boron cannot readily be removed from irrigation water, including greywater. Common management practices to mitigate boron toxicity include:

- applying excess irrigation water from other sources to leach boron and thereby prevent it accumulating in the soil
- accepting a reduced crop yield
- switching to crops which are more boron-tolerant
- applying excess nitrogen to stimulate vegetative growth in cases where boron toxicity has caused leaf drop to an extent sufficient to reduce the photosynthetic capacity of the plant (generally trees in this case).

1.2.2 Chemical oxygen demand (COD)

Chemical oxygen demand is defined as the oxygen equivalent of the organic matter content of a sample that is susceptible to oxidation by a strong chemical oxidant. The COD therefore reflects the oxidisable organic content of a sample, and hence also the extent to which it can be oxidised and used as a metabolic fuel, *e.g.* by micro-organisms (DWAF, 1996, SAWQG V3).

Most of the COD in greywater derives from detergents such as dishwashing and laundry detergents (Eriksson *et al.*, 2002). Particulate, suspended and dissolved food residues and organic dirt in laundry may also contribute to greywater COD.

Thus kitchen and laundry greywater are expected to have the highest COD. Particulate and dissolved organic material in greywater can support the growth of micro-organisms in the water itself during storage, in irrigation equipment and in soil. This can lead to the formation of biofilms which can attach to the surfaces of storage containers, the inner surfaces of irrigation equipment, soil particles and the support media of biological treatment systems. Excessive biofilm formation can cause clogging of equipment, soil and treatment systems. Rapid proliferation of micro-organisms can lead to depletion of oxygen in water or soil, potentially resulting in anaerobic conditions which can cause bad odours and restrict plant root growth. Oxidisable matter which is present in the form of oil and grease can also affect the water repellency (hydrophobicity) of soil.

Excessive COD in greywater can be removed through biological treatment.

1.2.3 Oil and grease

Oil and grease is typically present at concentrations of 50 to 100 mg/ℓ in untreated domestic wastewater, of which approximately two-thirds originates from greywater. Kitchen greywater is the greatest contributor to this fraction, but all greywater contains some oil and grease. Oil and grease is defined by its extractability in certain solvents, therefore it is a group of related materials rather than a single component. It is characterised by being non-polar, hence hydrophobic, and can therefore alter water movement through greywater-irrigated soils. The presence of hydrophobic material in the soil matrix and of organic coatings on soil particles affects the water repellency of the soil, which is the degree to which water is able to penetrate soil. Increased soil water repellency can lead to runoff, ponding and preferential flow through the soil that results in more rapid downward transport of water pollutants (Travis *et al.*, 2008).

When greywater was used for long-term garden irrigation, oil and grease was observed to accumulate to a maximum depth of 20cm in the soil profile. Greater accumulation was observed with kitchen greywater than with bath greywater. It was found that the impact on water repellency was more closely associated with the composition of the oil and grease than with absolute concentration. Water imbibition by soil was decreased (although not beyond a threshold maximum) (Travis *et al.*, 2008).

Oil and grease in greywater intended for irrigation use can be minimised by excluding kitchen greywater, and by a combination of physical and biological treatment such as found in a mulch filter.

1.2.4 Suspended solids

Suspended solids are defined as the solids retained on a glass fibre filter, after filtering a well-mixed sample and drying the filter at 103-105˚C. Settleable solids are that fraction of suspended solids which settles out of the sample within a defined period of time. Suspended solids in greywater originate from the uses to which water has been put in the household, and are not expected to originate from the source water unless this has been obtained from an unimproved water source. Greywater may be expected to contain both organic and inorganic suspended solids, although organic material is likely to dominate. Examples include food residues, hair, lint, sand and grit. Organic particulates may support bacterial growth and promote the development of biofilm in greywater storage containers, irrigation equipment and on soil. However, the predominant effects of suspended solids are expected to relate to physical blockages. Orifices in irrigation equipment may be partially or completely blocked by particulates in water and increased wear on irrigation system components can be expected. Soil surfaces, too, may be obstructed by the formation of a crust of suspended solids, which can decrease infiltration of water into the soil. Deposition of suspended solids on leaves can negatively influence their photosynthetic ability and deposition on crops may reduce crop quality (DWAF, 1996, SAWQG V4).

Suspended solids can be removed from greywater by a combination of physical sieving and biological action to break down organic material. Such conditions can be provided by a mulch filter.

1.2.5 Total nitrogen

Levels of nitrogen in greywater are typically lower than in domestic wastewater since urine, the major contributor of nitrogen, should be absent from greywater. Kitchen greywater has the highest nitrogen concentrations, with lower concentration in laundry and bathwater (Eriksson *et al*., 2002). Nitrogen in the environment is in a constant state of flux among the free inorganic forms of nitrogen (ammonia – NH_3; ammonium – NH_4^+; nitrite – NO_2^-; nitrate – NO_3^-), nitrogen bound in organic molecules, and nitrogen gas (N_2). Ammonia and ammonium constitute the reduced inorganic forms of nitrogen, while nitrite and nitrate constitute the oxidised inorganic forms of nitrogen. The flow of nitrogen through its various forms is termed the nitrogen cycle. Nitrogen is an essential macronutrient, being a critical component of proteins and nucleic acids (DWAF, 1996, SAWQG V4).

Ammonia and ammonium are interchangeable, the predominant form depending on temperature and pH. Ammonia is the form which is more toxic to aquatic life. Ammonium, as a cation, participates in cation exchange reactions in soil. Leaching of ammonium occurs only rarely. Ammonia/ammonium is the form in which nitrogen occurs most commonly in various wastewater fractions (DWAF, 1996, SAWQG V4).

Under normal environmental conditions, nitrite is rapidly converted to nitrate. Nitrate, as an anion, interacts only weakly with soil and therefore leaches readily. Nitrate is the form in which nitrogen occurs most commonly in environmental waters (DWAF, 1996, SAWQG V4).

The free inorganic forms of nitrogen are released from organically-bound nitrogen by microbial action in the soil; therefore this constituent refers to the total amount of nitrogen in greywater, both organic and inorganic.

The guidance presented here for total nitrogen recognises that nitrogen in greywater is, in the first instance, an opportunity to supplement the nutrient requirements of plants. Nitrogen is an essential component of proteins and nucleic acids. It is required throughout the lifespan of a plant, but especially at times of growth and development. The guidance ranges proposed here recognise that for poor farmers, fertiliser application may be economically infeasible and that greywater used for irrigation therefore is a *de facto* fertiliser.

However, it is also recognised that inorganic forms of nitrogen can be detrimental when present in excess. Crop yield of nitrogen-sensitive plants is reduced and over-stimulation of plant growth can occur, resulting in delayed crop maturity and in lodging (weak stems and resultant collapse of stems). Excess nitrogen can also leach from the soil and contaminate groundwater. Excess nitrogen in runoff water can stimulate the growth of nuisance plants, especially algae, in surface water bodies (eutrophication). Excess biological growth in greywater storage containers and irrigation equipment can also pose a problem (DWAF, 1996, SAWQG V4).

If necessary, excess nitrogen can be removed to some extent in aerobic biological treatment systems.

1.2.6 Total phosphorus

Phosphorus is an essential macronutrient. It is a structural component of nucleic acids and is central to the storage and use of energy by living cells. However, at excessive levels it can stimulate undesirable biological growth, particularly of aquatic nuisance plants (DWAF, 1996, SAWQG V7).

In the environment, phosphorus occurs as both organic and inorganic species, in both soluble and particulate forms. The forms of phosphorus in water are continually changing because of exchange between organically bound forms and oxidised inorganic forms. Orthophosphate is the only soluble form in which phosphorus is readily available to plants, soil biota and aquatic biota (DWAF, 1996, SAWQG V7). Phosphate in greywater originates predominantly from washing detergents, thus laundry greywater typically has the highest phosphorus levels. Phosphorus levels in greywater can be expected to decrease as phosphate-free detergents become increasingly common worldwide, including in South Africa (Eriksson *et al*., 2002).

Under oxidising conditions, phosphorus is extremely reactive. It readily combines with many cations (*e.g.* Al^{3+}; Fe^{2+}; Fe^{3+}; Ca^{2+}) to form insoluble complexes which precipitate out of solution. Phosphorus adsorbs to many soil components, such as inorganic colloids, humic substances and particulate material such as clays. Thus ionic forms of phosphorus in soil are often unavailable for uptake by plants. In addition, African soils are typically phosphorus-depleted. It is therefore unlikely that phosphorus in greywater will exceed the capacity of soil and plants. However, because phosphorus is the most significant factor in causing eutrophication in surface waters, it is important that irrigation use of greywater does not contribute to this problem (DWAF, 1996, SAWQG V7).

The guidance presented here for phosphorus recognises that phosphorus in greywater is, in the first instance, an opportunity to supplement the nutrient requirements of plants. The guidance ranges proposed here recognise that for poor farmers, fertiliser application may be economically infeasible and that greywater used for irrigation therefore is a *de facto* fertiliser. Limits are set on the conservative assumption that the soil is saturated with phosphorus and hence all phosphorus applied in greywater is potentially available for uptake. In most cases this is unrealistic. As noted above, phosphorus in soil is rapidly complexed and becomes unavailable. Repeated addition of phosphorus to soil may over time saturate soil phosphate reservoirs so that added phosphorus becomes more available for plant uptake.

If necessary, phosphorus can be removed from greywater to some extent by aerobic biological treatment.

2 Greywater Quality Guidance, Expanded Table

Section 7.2 of the Guidance Report presents a table of greywater constituents, Table 7.4, which lists suitability of various quality ranges for irrigation use. Table 1 provides additional information on these quality ranges, indicating the expected effects on human health, plants and soil in each range, for each constituent.

Table 1: Guidance for small-scale irrigation use of greywater by greywater quality and risk classes, showing expected effects for ranges indicated for each constituent (continued over the page)

Greywater constituent	**Target water quality range** **Suitable for unrestricted use with minimal risk to human health, plants or soil**	**Maximum range, (mostly applicable to well-drained, chemically stable soils)** **Increasing risk to human health, plants or soil**	**Short-term use on site-specific basis only. Treatment to maximum range (at minimum) is preferred option. If this is not sustainable in the long term, then disposal to sewer should be considered.** **Significant risk to human health, plants or soil; tolerable for short-term use only**	**Not recommended for irrigation use** **Excessive risk to human health, plants or soil**	**Source**
Electrical conductivity (mS/m)	< 40 Should be tolerated by even salt sensitive plants. Wetting of foliage should be avoided.	40-200 Salt toxicity expected in salt sensitive plants. Relative yield of 90% in moderately salt tolerant plants can be expected. A leaching fraction of 0.15 may be required. Wetting of foliage should be avoided.	200-540 Relative yield of 90% in moderately salt tolerant plants can be expected. A leaching fraction of up to 0.2 may be required. High frequency irrigation necessary. Wetting of foliage should be avoided.	> 540 Increasing restrictions on irrigation and soil management required. Increasing reduction in quality of plants/crops and decreasing yields.	SAWQG, Volume 4 (V4) Irrigation Use (DWAF, 1996); DWAF (2004)
Oil and grease (mg/ℓ)	< 2.5 Minimal accumulation of oil and grease in uppermost layer of soil only. Largely counteracted by breakdown in lipids.	2.5-10 Some accumulation of oil and grease in uppermost soil layer.	10-20 Increasing accumulation of oil and grease in soil. Can be tolerated in the short term because of breakdown of lipids in the soil over time.	> 20 Cannot be tolerated in the long term because of increasing hydrophobicity of the soil, leading to downward migration to groundwater or to runoff and ponding.	Indian General Standard (1983); DWAF (2004); Travis *et al.* (2008)
pH	6.5-8.4 No adverse effects expected.	6-9 Minimal to no adverse effects expected in soils as listed above.	6-9	< 6, > 9 Increasing problems with availability of several micro- and macro-nutrients in potentially toxic concentrations in the	SAWGQ, V4 Irrigation Use (DWAF, 1996); DWAF (2004)

Greywater constituent	**Target water quality range** **Suitable for unrestricted use with minimal risk to human health, plants or soil**	**Maximum range, (mostly applicable to well-drained, chemically stable soils)** **Increasing risk to human health, plants or soil**	**Short-term use on site-specific basis only. Treatment to maximum range (at minimum) is preferred option. If this is not sustainable in the long term, then disposal to sewer should be considered.** **Significant risk to human health, plants or soil; tolerable for short-term use only**	**Not recommended for irrigation use** **Excessive risk to human health, plants or soil**	**Source**
				long term. Soil becomes increasingly acidic or alkaline in the long term. Increasing problems with corrosion, encrustation or clogging of irrigation systems.	
Suspended solids (mg/ℓ)	< 50 No adverse effect expected.	50-100 Slight to moderate problems with clogging of drip irrigation equipment. Possibility of soil clogging, especially if suspended organic matter supports biological growth.	> 100 Increasing problems with clogging of irrigation equipment. Irrigation use of greywater of this quality in all but the short term is likely to lead to problems associated with biological growth in greywater and in greywater-irrigated soil.	> 100 Increasing clogging of irrigation equipment, biolfim formation on irrigated soil, reduction in available oxygen and clogging of soil. Greywater of this quality should not be used for long term irrigation.	SAWGQ, V4 Irrigation Use (DWAF, 1996)
Chemical constituents					
Boron (mg/ℓ)	< 0.5 Should be tolerated by all plants.	0.5-4.0 Should be tolerated by moderately tolerant plants, although sensitive and moderately sensitive plants are likely to show symptoms	4.0-6.0 Moderately tolerant plants begin to show symptoms of foliar injury and/or yield decrease. Adverse effects unlikely for tolerant plants.	> 6.0 Tolerant and very tolerant plants show increasing symptoms of foliar injury and/or yield decrease.	SAWQG, V4 Irrigation Use (DWAF, 1996)

Greywater constituent	**Target water quality range** **Suitable for unrestricted use with minimal risk to human health, plants or soil**	**Maximum range, (mostly applicable to well-drained, chemically stable soils)** **Increasing risk to human health, plants or soil**	**Short-term use on site-specific basis only. Treatment to maximum range (at minimum) is preferred option. If this is not sustainable in the long term, then disposal to sewer should be considered.** **Significant risk to human health, plants or soil; tolerable for short-term use only**	**Not recommended for irrigation use** **Excessive risk to human health, plants or soil**	**Source**
		of foliar injury and/or yield decreases.			
Chemical oxygen demand (COD, mg/ℓ)	< 400 No adverse effects expected.	400-5 000 Supports biological growth on soils and in irrigation equipment.	> 5 000 Irrigation use of greywater of this quality in all but the short term is likely to lead to problems associated with biological growth in greywater and in greywater-irrigated soil.	> 5 000 Increasing biological growth in standing greywater and on irrigated soil. Growth of biofilm on irrigated soils leads to reduction in free oxygen, possible anaerobic conditions and soil clogging. Greywater of this quality should not be used for long term irrigation.	DWAF (2004)
Sodium adsorption ratio (SAR), see Equation B1	< 2.0 Should be tolerated by even the most sodium sensitive plants. Avoid wetting of foliage to prevent absorption of sodium through the leaves.	2.0-5.0 The most sodium sensitive plants may absorb toxic concentrations of sodium through the roots. Avoid wetting of foliage to prevent absorption of sodium through the leaves.	5.0-15.0 Sodium-sensitive plants absorb toxic concentrations of sodium through the roots. Adverse effects unlikely for moderately sensitive and tolerant plants. Avoid wetting of foliage to prevent absorption of sodium through the leaves. Adverse effects on soil structure likely for all but short-term application.	> 15.0 Increasing toxic effects as a result of root uptake of sodium, even in tolerant plants. Increasingly adverse effects on soil structure.	SAWGQ, V4 Irrigation Use (DWAF, 1996); DWAF (2004)
Total inorganic nitrogen (mg/ℓ)	< 10	10-20	20-60	> 60	Guideline for

Greywater constituent	**Target water quality range** **Suitable for unrestricted use with minimal risk to human health, plants or soil**	**Maximum range, (mostly applicable to well-drained, chemically stable soils)** **Increasing risk to human health, plants or soil**	**Short-term use on site-specific basis only. Treatment to maximum range (at minimum) is preferred option. If this is not sustainable in the long term, then disposal to sewer should be considered.** **Significant risk to human health, plants or soil; tolerable for short-term use only**	**Not recommended for irrigation use** **Excessive risk to human health, plants or soil**	**Source**
	Low risk of over-application of nitrogen to sensitive plants, and of run-off to surface water or leaching to groundwater. Some risk of enhanced biological growth of micro-organisms in water, in irrigation equipment and on soil above 2.5 mg/ℓ.	Suitable for most plants, but requires that application rate be reduced to within nitrogen requirement of particular plant.(i.e. supplement plant's water requirements with a nutrient poor source) Acceptable risk of run-off to surface water or leaching to groundwater. Increasing risk of enhanced biological growth of micro-organisms in water, in irrigation equipment and on soil.	Using greywater to supply complete plant water requirement will lead to over-fertilisation of most plants. Application rate needs to be reduced to within nitrogen requirement of plant if used in anything but short term. Increasing risk of run-off to surface water or leaching to groundwater. Enhanced biological growth of micro-organisms in water, in irrigation equipment and on soil is likely to present a problem.	Not suitable for regular irrigation use. Can be used as low grade soluble fertiliser, but plant water requirement needs to be obtained from alternative nutrient-poor water source. Unacceptable risk of run-off to surface water, leaching to groundwater and over-stimulation of biological growth in water, irrigation equipment and soil.	nitrogen based on an assumed average application for home gardening of approximately 200 kg N/ha/year, applied in a total of 1 000 mm water/ha/year. Additional input from SAWQG, V4 Irrigation Use (DWAF, 1996).
Total phosphorus (mg/ℓ)	<10 Low risk of over-application of phosphorus to sensitive plants, and of run-off to surface water or leaching to groundwater.	10-15 Suitable for most plants, but requires that application rate be reduced to within phosphorous requirement of particular plant. (i.e. supplement plant's water requirements with a nutrient poor source). Acceptable risk of run-off to surface water or leaching to groundwater. Some risk of enhanced biological growth	15-50 Using greywater to supply complete plant water requirement will lead to over-fertilisation of most plants. Application rate needs to be reduced to within phosphorous requirement of plant if used in anything but short term. Increasing risk of run-off to surface water or leaching to groundwater. Enhanced	> 50 Not suitable for regular irrigation use. Can be used as low grade soluble fertiliser, but plant water requirement needs to be obtained from alternative nutrient-poor water source. Unacceptable risk of run-off to surface water, leaching to groundwater	Guideline for phosphorus based on assumed average application for home gardening of approximately 150 kg P/ha/year, applied in a total of 1 000 mm water/ha/year. Additional input from Standen and

Greywater constituent	Target water quality range Suitable for unrestricted use with minimal risk to human health, plants or soil	Maximum range, (mostly applicable to well-drained, chemically stable soils) Increasing risk to human health, plants or soil	Short-term use on site-specific basis only. Treatment to maximum range (at minimum) is preferred option. If this is not sustainable in the long term, then disposal to sewer should be considered. Significant risk to human health, plants or soil; tolerable for short-term use only	Not recommended for irrigation use Excessive risk to human health, plants or soil	Source
		of micro-organisms in water, in irrigation equipment and on soil.	biological growth of micro-organisms in water, in irrigation equipment and on soil is likely.	and over-stimulation of biological growth in water, irrigation equipment and soil.	McGuckian (2000).
Microbiological constituent					
E. coli (counts/100mℓ)	< 1 No adverse effects expected, even with extensive direct contact with greywater.	$1\text{-}10^3$ (1-1 000) Low possibility of transmission of disease via direct contact with greywater, by consumption of greywater-irrigated vegetables eaten raw or by consumption of milk of cows grazing on greywater-irrigated pastures. Irrigation methods which apply greywater as close to the roots as possible should be used.	$10^3\text{-}10^5$ (1 000-100 000) $10^3\text{-}10^7$ (1 000-10 000 000) if irrigation is sub-surface. These levels have been shown to cause no additional health risk relative to conventionally-irrigated produce. However, in the case of illness in the contributing households or community of origin, transmission of disease can occur. Should only be used on crops which do not come in direct contact with greywater, and with irrigation systems that apply greywater as close to the roots as possible. At levels above 5×10^4, clogging of drip irrigation	$> 10^7$ (> 10 000 000) Increasing risk of disease transmission by direct contact with greywater or consumption of crops irrigated with greywater.	SAWGQ, V4 Irrigation Use (DWAF, 1996); DWAF (2004); Jackson (in preparation); Technical Report, Case Studies

Greywater constituent	**Target water quality range** **Suitable for unrestricted use with minimal risk to human health, plants or soil**	**Maximum range, (mostly applicable to well-drained, chemically stable soils)** **Increasing risk to human health, plants or soil**	**Short-term use on site-specific basis only. Treatment to maximum range (at minimum) is preferred option. If this is not sustainable in the long term, then disposal to sewer should be considered.** **Significant risk to human health, plants or soil; tolerable for short-term use only**	**Not recommended for irrigation use** **Excessive risk to human health, plants or soil**	**Source**
			systems can occur.		

Appendix 3 Additional Information for Section 7.2, “Greywater Quality: Guide to Mitigation of Greywater Quality”

1 Mitigation of Greywater Quality by Planting Tolerant Plant Species

The following tables (Table 2 to Table 11) provide guidance on sensitivity of selected plants and crops to boron and to salinity/sodium.

Table 2: Crops grouped by boron tolerance, according to the threshold boron concentration in the soil solution (from DWAF, 1996, SAWQG V4). Crops listed in approximate order of increasing tolerance.

Very sensitive <0.5mg/ℓ	**Sensitive 0.5 to 1.0 mg/ℓ**	**Moderately sensitive 1.0 to 2.0 mg/ℓ**	**Moderately tolerant 2.0 to 4.0 mg/ℓ**	**Tolerant 4.0 to 6.0 mg/ℓ**	**Very tolerant 6.0 to 15.0 mg/ℓ**
Lemon* Blackberry*	Lemon* Avocado* Grapefruit* Orange* Apricot* Peach* Cherry* Plum* Persimmon* Fig, kadota* Grape* Walnut* Pecan* Onion Garlic Sweet potato Wheat Sunflower Bean, mung* Sesame* Lupine* Strawberry* Artichoke, Jerusalem* Bean, kidney* Bean, snap Bean, lima* Peanut	Broccoli Pepper, red Pea* Carrot Radish Potato Cucumber Lettuce*	Cabbage* Turnip Bluegrass, Kentucky* Barley Cowpea Oats Maize Artichoke* Tobacco* Mustard* Clover, sweet* Squash Muskmelon* Cauliflower	Lucerne* Vetch, purple* Parsley* Beet, red Sugar beet Tomato	Sorghum Cotton Celery* Asparagus*

* Tolerance based on reductions in vegetative growth rather than marketable product.

Table 3: Rootstocks of citrus and stone fruit ranked in order of increasing boron accumulation and transport to scions (from DWAF, 1996, SAWQG V4)

Citrus	**Stone fruit**
Alemow Gajanimma Chinese box orange Sour orange Calamondin Sweet orange Yuzu Rough lemon Grapefruit Rangpur lime Troyer citrange Savage citrange Cleopatra mandarin Rusk citrange Sunki mandarin Sweet lemon Trifoliate orange Citrumelo 4475 Ponkan mandarin Sampson tangelo Cuban shaddock Sweet lime	Almond Myrobalan plum Apricot Marianna plum Shalil peach

Table 4: Ornamental plants grouped into boron tolerance classes according to threshold boron concentration in soil solution (from DWAF, 1996, SAWQG V4). Plants listed in order of increasing tolerance, based on appearance and growth reduction. Boron concentrations exceeding the threshold may cause leaf burn and loss of leaves**.**

Very sensitive **< 0.5 mg/ℓ**	**Sensitive** **0.5 to 1.0 mg/ℓ**	**Moderately sensitive** **1.0 to 2.0 mg/ℓ**	**Moderately tolerant** **2.0 to 4.0 mg/ℓ**	**Tolerant** **4.0 to 8.0 mg/ℓ**
Oregon grape Photinia Xylosma Thorny elaeagnus Laurustinus Wax-leaf privet Pineapple guava Spindle tree Japanese pittosporum Chinese holly Juniper Yellow sage American elm	Zinnia Pansy Violet Larkspur Glossy abelia Rosemary Oriental arborvitae Geranium	Gladiolus Marigold Poinsettia China aster Gardenia Southern yew Brush cherry Blue dracaena Ceniza	Bottlebrush California poppy Japanese boxwood Oleander Sweet pea Carnation	Indian hawthorn Natal plum Oxalis

Table 5: Relative salt tolerance of various commercial crops at germination, expressed in terms of electrical conductivity (EC) at 50% emergence reduction (after Ayers and Westcott, 1985; as quoted in DWAF, 1996, SAWQG V4)

Crop	Fifty percent emergence reduction, given in EC (mS/m) of saturated soil extract
Barley	1 600-2 400
Cotton	1 550
Sugar beet	500-1 250
Sorghum	1 300
Safflower	1 230
Wheat	1 400-1 600
Beet, red	1 380
Lucerne	820-1 340
Tomato	760
Rice	1 800
Cabbage	1 300
Muskmelon	1 040
Maize	2 100-2 400
Lettuce	1 140
Onion	560-750
Bean	800

Table 6: Fruit and nut crops classified according to salt tolerance classes (after Ayers and Westcott, 1985, and Maas, 1990; quoted in DWAF, 1996, SAWQG V4)

Sensitive	Moderately sensitive	Moderately tolerant	Tolerant
Almond	Castor bean	Fig	Date palm
Apple	Grape	Jujube	Guayule
Apricot		Olive	Jojoba
Avocado		Papaya	
Blackberry		Pineapple	
Boysenberry		Pomegranate	
Cherimoya			
Cherry, sweet			
Cherry, sand			
Currant			
Gooseberry			
Grapefruit			
Lemon			
Lime			
Loquat			
Mango			
Orange			
Passion fruit			
Peach			
Pear			
Persimmon			
Plum/prune			
Pomelo			
Raspberry			
Rose apple			
Sapote, white			
Strawberry			
Tangerine			

Table 7: Vegetable crops classified according to salt tolerance classes (after Ayers and Westcott, 1985, and Maas, 1990; quoted in DWAF, 1996, SAWQG V4)

Sensitive	Moderately sensitive	Moderately tolerant	Tolerant
Bean Carrot Okra Onion Parsnip Pea	Broccoli Brussels sprouts Cabbage Cauliflower Celery Maize, sweet Cucumber Eggplant Kale Kohlrabi Lettuce Muskmelon Pepper Potato Pumpkin Radish Spinach Squash, scallop Sweet potato Tomato Turnip Watermelon	Artichoke Beet, red Squash, zucchini	Asparagus

Table 8: Fibre, seed and sugar crops classified according to salt tolerance classes (after Ayers and Westcott, 1985, and Maas, 1990; quoted in DWAF, 1996, SAWQG V4)

Sensitive	Moderately sensitive	Moderately tolerant	Tolerant
Bean Guayule Rice, paddy Sesame	Broad bean Castor bean Maize Flax Millet, foxtail Groundnut/peanut Sugarcane Sunflower	Cowpea Kenaf Oats Safflower Sorghum Soybean Wheat	Barley Cotton Guar Jojoba Rye Sugarbeet Triticale Wheat, Durum

Table 9: Grass and forage crops classified according to salt tolerance classes (after Ayers and Westcott, 1985, and Maas, 1990; quoted in DWAF, 1996, SAWQG V4)

Sensitive	**Moderately sensitive**	**Moderately tolerant**	**Tolerant**
None	Alfalfa (lucerne) Bentgrass Bluestem, Angleton Brome, smooth Buffelgrass Burnet Clover, alsike Clover, Berseem Clover, ladino Clover, red Clover, strawberry Clover, white Dutch Cowpea (forage) Dallis grass Foxtail, meadow Grama, blue Lovegrass Lucerne (alfalfa) Maize (forage) Milkvetch, Cicer Oatgrass, tall Oats (forage) Orchard grass Rye (forage) Sesbania Siratro Sphaerophysa Timothy Trefoil, big Vetch, common	Barley (forage) Brome, mountain Canary grass, reed Clover, Hubam Clover, sweet Fescue, meadow Fescue, tall Harding grass Panic grass, blue Rape Rescue grass Rhodes grass Ryegrass, Italian Ryegrass, perennial Sudan grass Trefoil, narrowleaf birdsfoot Trefoil, broadleaf birdsfoot Wheat (forage) Wheat, Durum (forage) Wheatgrass, standard crested Wheatgrass, intermediate Wheatgrass, slender Wheatgrass, western Wildrye, beardless Wildrye, Canadian	Alkali grass, Nuttall Alkali sacation Bermuda grass Kallar grass Saltgrass, desert Wheatgrass, fairway crested Wheatgrass, tall Wildrye, Altai Wildrye, Russian

Table 10: Ornamental shrubs, trees and ground covers, classified into salt tolerance classes (after Maas, 1990; quoted in DWAF, 1996, SAWQG V4)

Very sensitive	Sensitive	Moderately sensitive	Moderately tolerant	Tolerant	Very tolerant
Star jasmine Pyrenees cotoneaster Oregon grape Photinia	Pineapple guava Chinese holly, cv. Burford Rose, cv. Grenoble Glossy abelia Southern yew Tulip tree Algerian ivy Japanese pittisporum Heavenly bamboo Chinese hibiscus Laurustinus, cv. robustum Strawberry tree, cv. Compact Crape myrtle	Glossy privet Yellow sage Orchid tree Southern magnolia Japanese boxwood Xylosma Japanese black pine Indian hawthorn Dodonaea, cv. atropuruea Oriental arborvitae Thorny elaeagnus Spreading juniper Pyracantha, cv. graberi Cherry plum	Weeping bottlebrush Oleander European fan palm Blue dracaena Spindle tree, cv. Grandiflora Rosemary Aleppo pine Sweet gum	Brush cherry Ceniza Natal plum Evergreen pear Bougainvillea Italian stone pine	White iceplant Rosea iceplant Purple iceplant Croceum iceplant

Table 11: Relative susceptibility of crops to foliar injury from saline sprinkling waters, expressed as sodium concentration at which foliar injury occurs (from DWAF, 1996, SAWQG V4). Data are general guidelines for daytime sprinkling under conditions that are not too hot or too dry.

Sensitive < 115 mg Na/ℓ	Moderately sensitive 115-230 mg Na/ℓ	Moderately tolerant 230-460 mg Na/ℓ	Tolerant > 460 mg Na/ℓ
Almond Apricot Citrus Plum	Grape Pepper Potato Tomato	Barley Maize Cucumber Lucerne Safflower Sesame Sorghum	Cauliflower Cotton Sugar beet Sunflower

2 Design Details for Greywater Treatment Systems

2.1 Mulch Tower

Design of a mulch tower, with dimensions and description of packing, is shown below (Figure 2 and Figure 3). The design of the mulch filter as shown here is dimensioned to treat a flow of 200 ℓ per day.

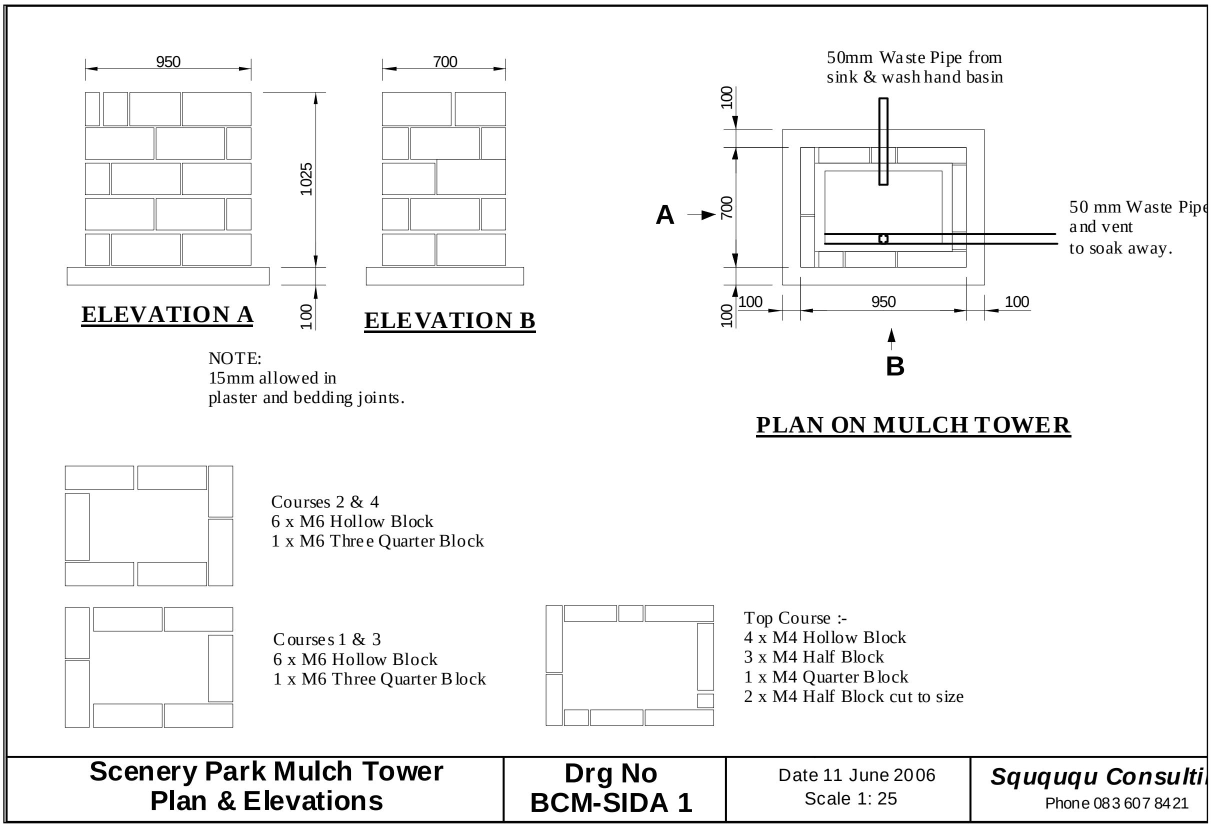


Figure 2: Design of mulch tower, plans for external construction. (From Whittington-Jones, 2007, used with permission)

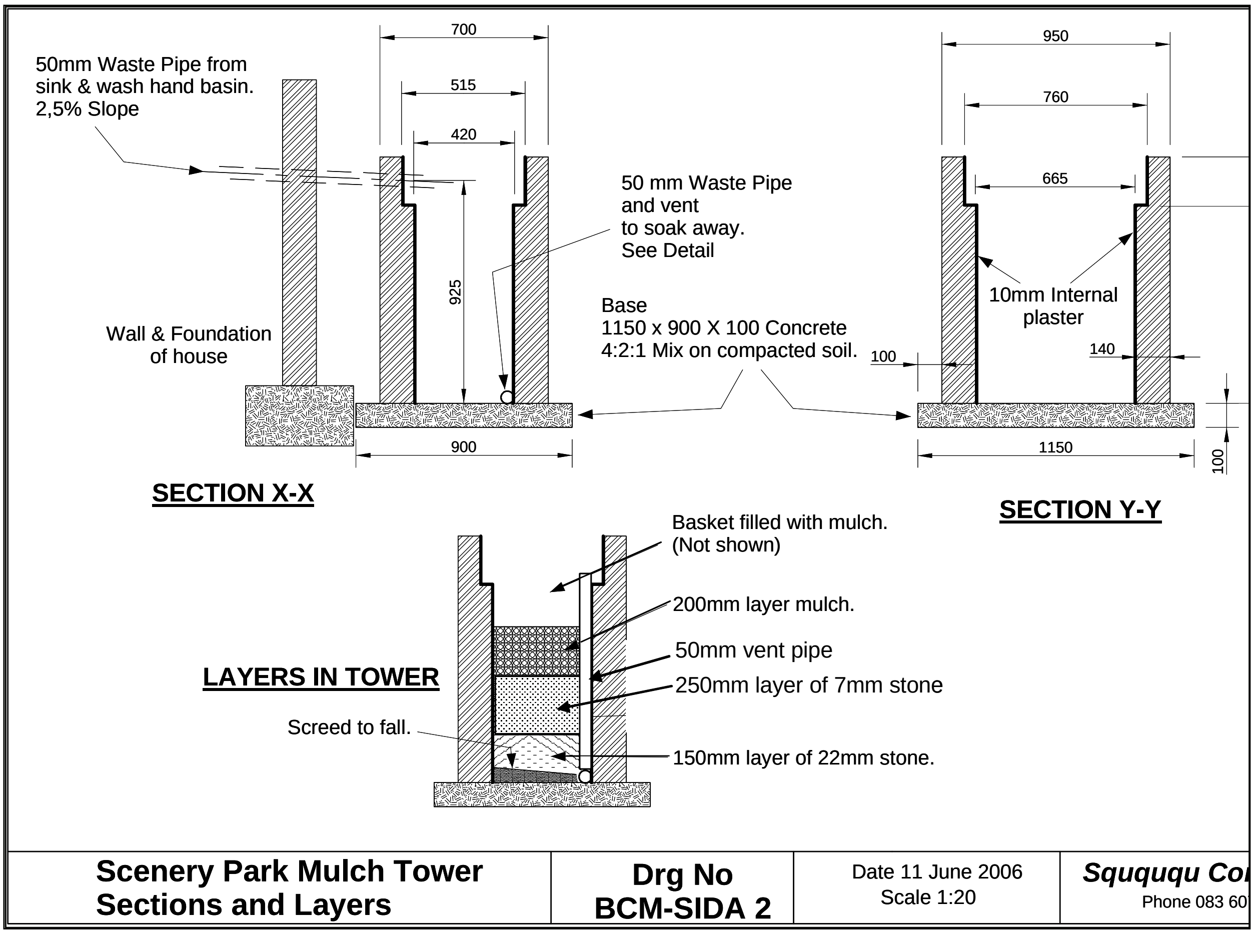


Figure 3: Design of mulch tower, plans for internal construction and layers. (From Whittington-Jones, 2007, used with permission)

2.2 Mulch Tower and Resorption Bed

In the combination of mulch tower and resorption bed, the outflow from the mulch tower forms the inflow to the resorption bed.

Figure 4 shows a cross section through the resorption bed with embedded filtration zone (“Infiltra”). Figure 5 shows a longitudinal section through the resorption bed, indicating the position of sampling pipes.

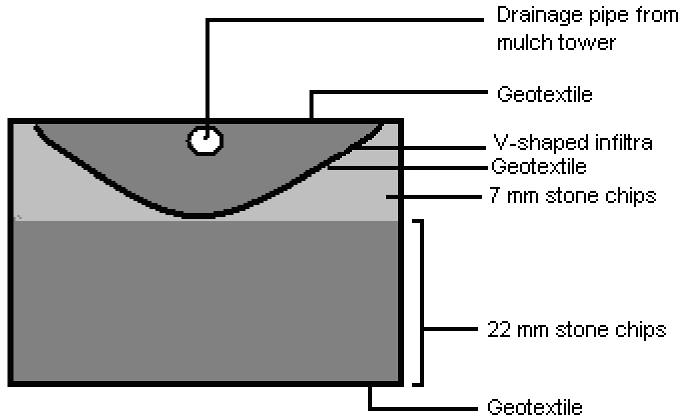


Figure 4: Schematic cross-section of resorption bed with embedded infiltration zone ("Infiltra") (From Naicker, 2008; based on Whittington-Jones, 2007; used with permission)

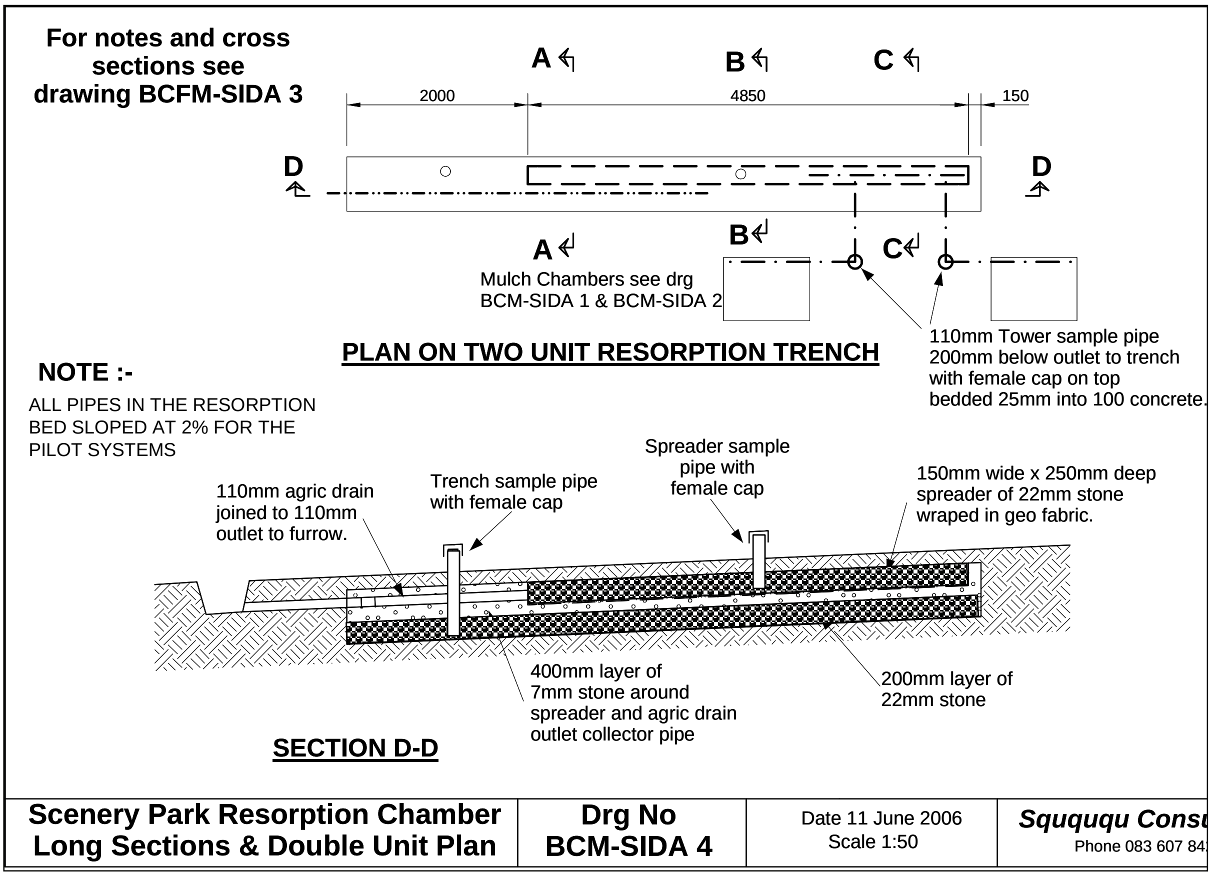


Figure 5: Schematic longitudinal section of resorption bed with embedded infiltration zone ("Infiltra"). (From Whittington-Jones, 2007; used with permission)

2.3 Tower Gardens and “Agritubes”

Specifics of the constructions and dimensions of tower gardens found to yield the best results are shown in Figure 6 and Figure 7. A column of approximately 0.9 m in diameter is constructed of shade cloth, supported by wooden poles and attached to the poles by nylon line or fishing line. The soil mixture comprises six parts soil, four parts manure and two parts ash, this mixture providing the best conditions in terms of soil fertility. Stones should be flat, or a mixture of dimensions such as found in building rubble. Holes should be arranged diagonally around the circumference of the column. Leafy plants such as spinach grow best in the holes, while the upper surface of the column can be used to plant standing plants such as tomatoes. The wooden poles can be extended to provide trellising for plants which require support. Two buckets of clean water should be poured onto the stones once a week to prevent build-up of soaps or grease on the stones (Crosby, 2005).

In this case, the tower garden is simultaneously a means of treating greywater (as it moves over the stones which become coated in biofilm and as it moves through the soil) and of delivering greywater to the roots of the plants. The integrated nature of this form of treatment means it cannot be sampled to determine the quality of greywater exiting the system.

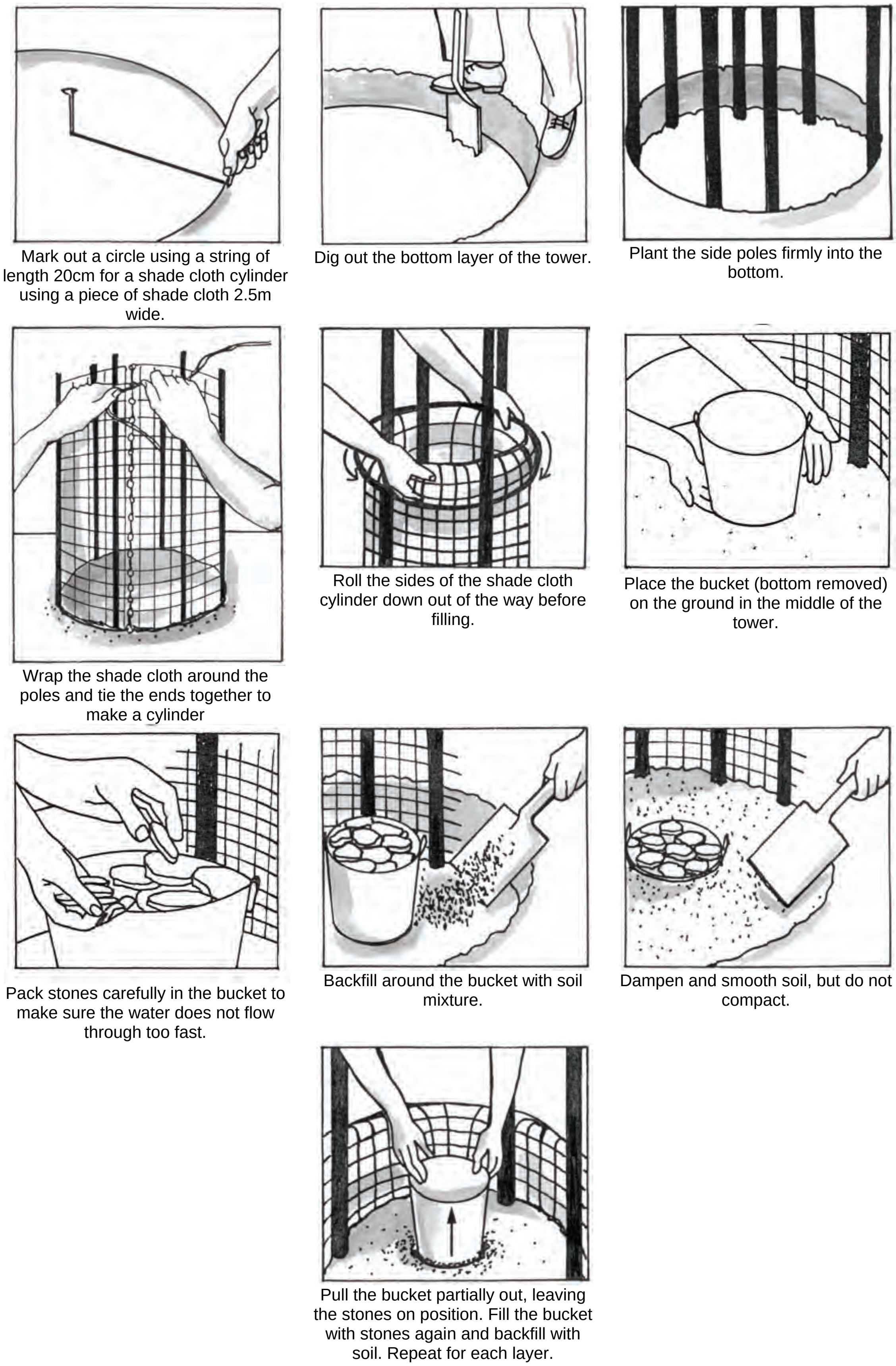


Figure 6: Schematic representation of construction of a tower garden with a central stone core. (From Crosby 1995; used with permission)

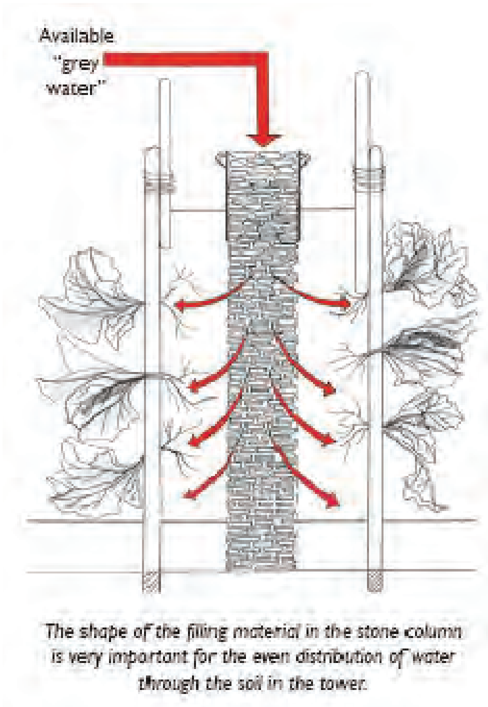


Figure 7: Schematic representation of a completed tower garden, showing functioning of central stone core in distributing greywater. (From Crosby, 1995; used with permission)

Growing tubes, or "Agritubes", are a similar concept to tower gardens. The dimensions of the Agritube are shown in Figure 8, and its use is explained in the user information leaflet shown Figure 9.

As with tower gardens, Agritubes provide combined greywater treatment and plant root zone application, and are therefore not suited to monitoring of treated greywater.

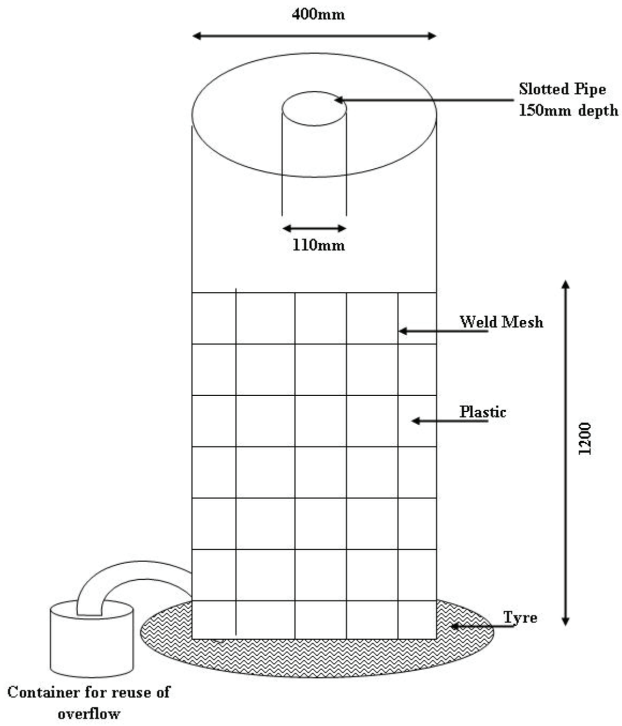
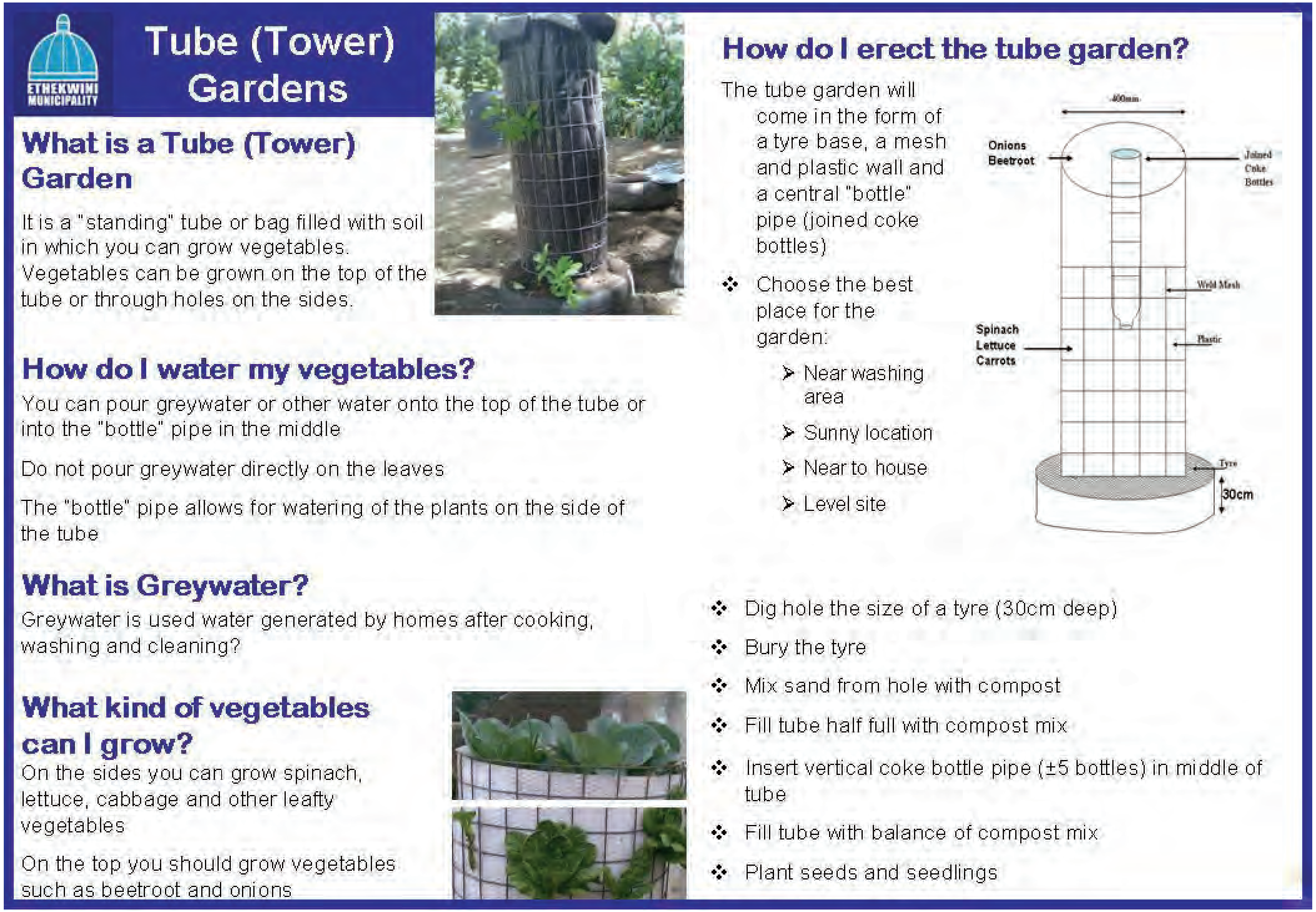


Figure 8: Dimensions of an ‘Agritube’ or tube garden. (From Nick Alcock of Khanyisa Projects, used with permission)



Tube (Tower) Gardens

ETHEKWINI MUNICIPALITY

What is a Tube (Tower) Garden

It is a "standing" tube or bag filled with soil in which you can grow vegetables. Vegetables can be grown on the top of the tube or through holes on the sides.

How do I water my vegetables?

You can pour greywater or other water onto the top of the tube or into the "bottle" pipe in the middle

Do not pour greywater directly on the leaves

The "bottle" pipe allows for watering of the plants on the side of the tube

What is Greywater?

Greywater is used water generated by homes after cooking, washing and cleaning?

What kind of vegetables can I grow?

On the sides you can grow spinach, lettuce, cabbage and other leafty vegetables

On the top you should grow vegetables such as beetroot and onions

How do I erect the tube garden?

The tube garden will come in the form of a tyre base, a mesh and plastic wall and a central "bottle" pipe (joined coke bottles)

- Choose the best place for the garden:
  - Near washing area
  - Sunny location
  - Near to house
  - Level site

- Dig hole the size of a tyre (30cm deep)
- Bury the tyre
- Mix sand from hole with compost
- Fill tube half full with compost mix
- Insert vertical coke bottle pipe (±5 bottles) in middle of tube
- Fill tube with balance of compost mix
- Plant seeds and seedlings

Figure 9: User information leaflet explaining the use of growing tubes (Agritubes). (Developed by Khanyisa Projects for eThekwini Municipality, used with permission)

Appendix 4 Additional Information for Section 7.3, "Greywater Quantity: Guide to Irrigation Volumes"

1 Estimating Plant Water Use

The maximum estimated water use (which is the same for greywater as for conventional irrigation water) for a given crop/plant type over a given area may be derived using Equation D1:

$$\mathbf{EWU = E_0 \times CF \times HA} \qquad \textbf{Equation 3}$$

EWU = estimated water use (measured in ℓ/day)
E_0 = reference evapotranspiration rates (location specific and season specific; a metereologically-derived measure. Measured in mm/day).
CF = crop factor, a measure of plant-specific water use (a unitless ratio)
HA = area to be irrigated (measured in m^2).

The sources used in derivation of this equation are presented in full in the Technical Report.

EWU represents ***only*** the amount of water required by the plant in light of climatic conditions such as solar radiation, rainfall, windspeed, *etc*. Note that EWU does not include other factors which affect the water requirement of plants and thus represents the ***maximum*** amount of water which should be applied. Estimates of EWU for various climatic regions in South Africa, in summer and in winter, are presented in the text of the Guidance Report and may be used as a guide to identifying the maximum amount of greywater which can be applied under a range of irrigation scenarios. Adjusting this value for other factors which affect irrigation water volume is also discussed in the text of the Guidance Report.

1.1 Reference Evapotranspiration (E_0)

Reference evapotranspiration (E_0) is a measurement that combines the effect of temperature, humidity, solar radiation and wind on the water use (evapotranspiration) of a reference crop. It is therefore specific to a particular location and to season. The measure of E_0 used in the calculation of estimated water use of plants varies among countries and irrigation applications, therefore caution must be used when applying E_0 values derived from literature. In South Africa, E_0 was historically ***measured*** by pan evaporation, or evaporation of water from a container of specified size and shape, and is independent of plant/crop type (Green, 1985). Currently increasing use is made of a value ***calculated*** from meteorological parameters (such as minimum and maximum temperature, wind speed, etc.) using the so-called Penman-Montieth equation, which has become the international standard for calculating a reference evapotranspiration.

To simplify the selection of values for E_0 to be used in providing estimates of EWU South Africa was subdivided into climatic regions. For this purpose the classification presented recently by Blignaut *et al.* (2009) was adopted (Table 12 and Table 13). Weather stations within each region were selected from among those listed by Green (1985). Location of the selected weather stations is shown on the map in Figure 10.

Table 12: 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 13: 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

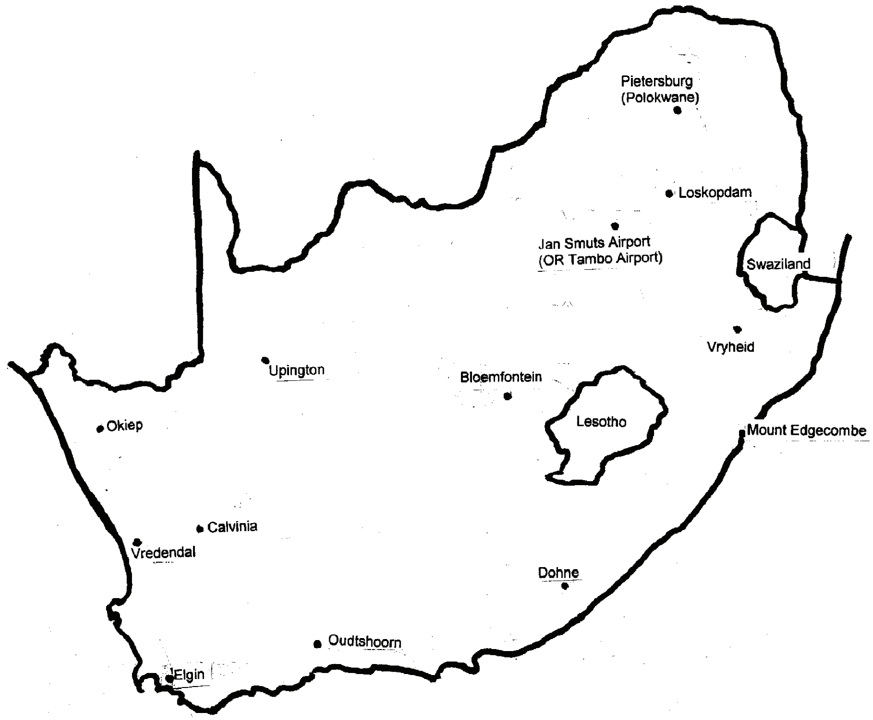


Figure 10: Map of South Africa, showing weather stations for which data was used in deriving evapotranspiration data (adapted from Green, 1985).

In order to illustrate the regional and temporal effect of climate, examples of mean seasonal values of E_0 at selected weather stations are given in Table 14. The reader's attention is drawn to the difference in E_0 values among climatic regions, and between summer and winter at the same location. As a general rule of thumb, for each region and season, the drier and hotter the area, the higher the applicable E_0 value. The wetter and more temperate the area, the lower the E_0 value.

Table 14: Classification of climatic regions of South Africa based on data in Table 13, and pan evaporation (E_0) values for summer and winter, for representative weather stations in those regions (from 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

1.2 Crop Factors

Crop factors relate E_0 to water use of a specific pant or crop type. It represents the ratio of actual evapotranspiration of the plant/crop type (ET) to reference evapotranspiration at that site (E_0), as per Equation D2 (Green, 1985).

$$\mathbf{CF = ET / E_0} \qquad \textbf{Equation 4}$$

CF = crop factor
ET = actual evapotranspiration of a given plant or crop type
E_0 = reference evapotranspiration (pan evaporation in South Africa).

A high crop factor represents a plant with high water use, while a low crop factor represents a plant with low water use.

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